AN ASSESSMENT OF STOL TECHNOLOGY

J. H. DE LEEUW - Project Manager
L. D. REID - Technical Coordinator

A STUDY PREPARED FOR THE

CANADIAN TRANSPORT COMMISSION

RESEARCH DIVISION

November, 1970.

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ABSTRACT

A study of STOL (short takeoff and landing) technology is presented in an attempt to identify impedances to the introduction of a Canadian STOL transport system. Five route types are considered (Intercity, Municipal Feeder, Downtown to Airport, Regional, and Northern) and five major aspects of STOL are investigated (Vehicle Design and Performance, Operational Aspects, Navigation/Guidance/Air Traffic Control, Non-Passenger Public Acceptance, and STOLports). As an aid in determining the viability of a Canadian system, economic models are developed for all but the Regional application. These models are applied to typical Canadian routes and the results presented in tabular and graphical form.

An extensive bibliography covering all aspects of the STOL field has been compiled in support of this study and is included herein. The material is organized under subject headings and is fully annotated as to depth of coverage and relevance.

Based on an analysis of the available information it is concluded that no major technological impedances exist that will prevent the introduction of a first generation STOL transport system based upon STOLports at grade level and turboprop vehicles with light wing loadings. However, the acceptance of such a system by the non-passenger public is not certain.

At the present time it appears that Canadian industry will participate in the introduction of any first generation STOL system. If this involvement is to continue on into the second generation system, with its many technical, economic, and institutional impedances, Canadians must undertake a comprehensive research and development program. These impedances facing the second generation are identified and used in the development of a recommended approach to their solution within the Canadian context. It is emphasized that this effort should be designed to complement work performed elsewhere in an attempt to utilize our national resources in the most cost-effective manner.
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In recent years the development of STOL (Short Takeoff and Landing) aircraft has progressed to the stage where its application to fill present and future gaps in Canada's overall transportation system is perhaps feasible. This document reports on a study carried out for the Canadian Transport Commission to provide them with an accurate assessment of STOL technology within a specifically Canadian framework. Particular attention has been devoted to identifying those areas of the technology where further development is required to ensure the suitability of STOL transportation to Canadian needs.

The terms of reference called for the completion of the project within a four month period, thus determining to some extent the depth of coverage and the study techniques employed. The final report to the CTC was completed on July 31, 1970. The present publication is based on this report and also contains the bibliography compiled in support of the study. The information incorporated herein is basically that contained in the original final report augmented by the results of a STOLport study for the CTC carried out by the Construction Engineering and Architectural Branch of the Canadian Air Transportation Administration completed on September 17, 1970.

In considering the Canadian application of STOL transportation the following route types were envisaged.

1. Intercity Transport - This is a system operating between major population centres having STOLports situated so as to minimize passenger access/egress times.

2. Municipal Feeder Transport - This system would link smaller population centres to the central business district of neighbouring major cities and to CTOL (Conventional Takeoff and Landing) airports.

3. Downtown to Airport Transport - This system would link major CTOL airports to the central business district of neighbouring major population centres.

4. Regional Transport - This system would link the smaller population centres, as an alternative to the present railroad or highway facilities, operating from small easily accessible municipal airfields.

5. Northern Transport - This system would link northern activity centres to each other and to trunk routes from the south. It would accommodate the unique northern environmental problems and perhaps place a greater emphasis on the movement of freight.

The study was further subdivided into five main areas, with a different group of individuals responsible for each section. The personnel involved are listed below under the five main area titles where applicable.

Dr. J. H. deLeeuw (Project Manager)  
Mrs. H. Eisen (Secretary)

(1) Vehicle Design and Performance
Dr. L. D. Reid (Technical Coordinator)  
Prof. B. Etkin (Consultant)  
Mr. A. R. Gray

(2) Operational Aspects
Mr. R. J. Taborek  
Mr. D. Yue

(3) Navigation, Guidance and Air Traffic Control
Mr. T. Ussher  
Dr. H. W. Smith (Consultant)  
Mr. L. Steigerwald

(4) Non-Passenger Public Acceptance
Dr. L. Filotas  
Dr. H. S. Ribner (Consultant)

(5) STOLports
Mr. P. T. Hodgins

Work in all areas was performed simultaneously and interaction among the study personnel was encouraged in order to achieve a coordinated effort. This cooperation was formally encouraged through seven group meetings during the course of the four month program. These were attended by the CTC Project Officers.

The first phase of the study involved several steps, designed to assure a suitable coverage of the various fields of interest. The CTC requested and was forwarded a program plan at the beginning of the project. This document outlined the proposed timing for the various phases, and the anticipated division of effort among the study personnel. The next step involved the preparation of a complete listing of all technological areas relevant to STOL aviation. Subsequently each area was rated by the appropriate specialists as to its relative importance within the context of the route types considered. A composite rating was achieved by combining the individual responses and this was forwarded to the CTC.

The basic purposes served by this effect were to generate a cooperative spirit among the personnel and to produce guidelines to be used in selecting the most relevant STOL areas to investigate.
Based in part on the results of the above, a Bibliography of STOL Technology was produced to serve as an aid in assessing the present state of STOL aviation. The details of the literature search are described in the general introduction to the bibliography.

In conjunction with the literature survey, study personnel visited and interviewed STOL experts both in government and in industry in order to obtain as complete a picture of the field as possible. Where possible the CTC Project Officer was present at these meetings. A brief summary of these is enclosed giving Location of Visit, Person Interviewed or Conference Attended, and Purpose of Visit:

Vehicle Design and Performance

1. Ottawa: Canadian Aeronautics and Space Institute Annual General Meeting. Attended a discussion session on "The Near Term Evolution of STOL".
2. Toronto: Mr. J. Uffen, Director of Research and Technical Design, de Havilland Aircraft of Canada. Discussed the design and performance of STOL transports.
3. Toronto: Industry-wide group developing a "STOL Trends" document. Discussed technological impedances to STOL.
5. Toronto: De Havilland Aircraft of Canada. A demonstration of STOL operations from a simulated STOLport flown in a Twin Otter.

Operational Economics

2. Montreal: Mr. H. de Jordy, V.P. Operations - Quebecair. Discussed regional air services.
3. Ottawa: Mr. J. Courtney, Economist - CTC. Discussed northern traffic flows.

Navigation, Guidance and Air Traffic Control

2. Ottawa: Mr. D. R. Button, Aviation Systems Planning, Department of Transport. Discussed STOL navigation for Canada.


5. New York: Mr. W. D. Kies, Chief of Planning Staff FAA Eastern Region: Mr. R. K. Ransone, Development Engineer V/STOL Technology, American Airlines; Capt. C. R. Tennstedt, Manager of Flight Standards, Eastern Airlines. Discussed the results and recommendations of the STOL demonstration programs and the FAA approach to STOL integration in the American transportation system.

Non-Passenger Public Acceptance

1. Washington: Dr. J. D. Powers, Director of FAA Office of Noise Abatement; Mr. Olson FAA Coordinator STOL Noise Task Force. Discussed the latest American views on controlling the anticipated noise and pollution problems of STOL aircraft.

STOLports

1. Winnipeg: Canadian Transportation Research Forum, Sixth Annual Meeting. Attended Conference.

Following the completion of the bibliography an interim verbal presentation was made to the CTC outlining the results of this first phase of the study.

The second phase of the study involved the development of simple models for a parametric study of the five STOL route types outlined above. These operational models and the results of the parametric studies are contained in Section 1.

The third and final phase of the study analyzed the previous work to determine the impedances to the introduction of STOL in Canada and recommended future research and development programs to overcome them. This work is contained in Sections 2 and 3.
SUMMARY

This summary is intended to acquaint the reader with the material contained in the report and has been compiled by extracting the highlights from each section (in most cases verbatim).

SECTION 1

A number of operational models were developed to assist in the assessment of the 5 route types.

The first model was used to describe the intercity and municipal feeder routes. The differences between these two types of route were minor from the modelling point of view. This model predicts the traffic that would be attracted to a STOL transport system from existing transportation modes: auto, bus, rail and CTOL. This prediction is based on a comparison of the total trip cost and time by each of the modes. The total trip is composed of terminal access (the trip from the passenger's point of origin to the terminal), the intercity trip and the egress portion (from the terminal at the other end to the point of destination). In order to generate Canadian data the model was applied to 17 city pairs in Ontario and Quebec. Here the emphasis was on typical results rather than a detailed description of any single route.

The heart of the model is the 'Value of Time' concept. It is postulated that travellers value their time at some rate related to their hourly income. The penetration of a new STOL mode of transportation into any existing travel market is then based on the incremental cost of saving an hour of time by utilizing a STOL system. Travel surveys indicate that a different value of time curve applies for each existing mode due to the effects of the present fare structure and the income level of travellers.

As an example of the application of this concept consider the passengers in the downtown area of one city who normally travel to a certain zone in another city by CTOL. If a newly introduced STOL system could shorten the total trip time by one hour for these people with an increase in total trip cost of $5 then all those who value their time at greater than $5/hour, according to the model, would switch to STOL.

The primary output from the model is the above mentioned penetration. In addition, for cases where a city is served by more than one STOLport, the fraction of the traffic using each one is predicted. Average total trip time and cost for all the competing modes can be generated by summing up the individual contributions from each city zone. One of the most interesting results is obtained when the change in modal penetration by STOL is determined by repeating the computer calculations with different initial assumptions about the STOL system. This has been used in the present study to indicate the sensitivity of the STOL system to cruising speed, fare, the number of STOLports and the passenger's value of time.

The results of this model study indicate that a STOL aircraft cruising at 300 mph., serving 2 STOLports in each of Toronto and Montreal with an acceptable frequency of service and CTOL fares would attract sufficient traffic to operate a viable intercity and municipal feeder service now.

It appears that the best method of attracting ground travellers on short stages is to increase the number of STOLports in Toronto and Montreal, while for longer stages a switch to jet cruising speeds is more effective. CTOL penetration primarily responds to an increase in cruising speed, and is markedly reduced on short stages by an increase in STOL fares. It was found that CTOL penetration was quite insensitive to the assumed level of the passenger's value of time.

The downtown to airport transport model was based on the intercity model. The value of time concept was used to determine the penetration of STOL into an average ground access mode. This technique was applied to the proposed new international airports at Toronto and Montreal. These were chosen because the distance from downtown to airport in these cases corresponded to successful routes operated in the United States for which fare data was available. The new Toronto airport was assumed to be located at Bolton 32 miles northwest of the city. The new Montreal airport is of course located at Ste. Scholastique about 33 miles from downtown Montreal.

Frequency of service is an extremely important factor in this application. In order to get some idea of a reasonable frequency the schedules of the American operators were studied. It was found that during the peak hours the service requires at least one flight every half hour while in the offpeak period a flight every hour is sufficient.

In the Toronto based airport access study 14 STOLports were located in a Toronto centred region of 50 miles radius. The analysis indicated that only 5 of these generated sufficient traffic to warrant their existence and together these captured approximately 5% of the access market, with 4% of this from within Toronto.
A similar analysis for the Montreal-Ste. Scholastique route yielded 16.4% penetration by STOL based on 6 STOLports.

At the present time typical penetrations by American operators using STOL aircraft or helicopters are about 3% and thus the Montreal results are suspect. However, passenger data for the region around Montreal was not available and this could explain part of this discrepancy.

The effect of frequency of service on penetration was checked by determining the influence of average waiting time for STOL passengers. It was found that if the waiting time was reduced from 15 minutes to zero, STOL traffic increased fourfold. If the waiting time become more than half an hour, very few travellers were attracted to this service.

Time did not permit the development of a formal model for the regional transport application. An alternate approach was adopted: company officials of two Canadian regional carriers who have provided services of this nature were interviewed. The main points which emerged are as follows: When attempting to link a group of small towns together the problems encountered result from the low traffic density generated. In an attempt to minimize the investment in such a service the operator can either purchase older aircraft or schedule existing aircraft during slack periods on his higher density routes.

An attempt can be made to increase the traffic density by establishing a field midway between several communities to act as a regional airport.

The indirect operating costs should be held down by providing a level of customer services related to what is essential to attract passengers.

These factors should form the basis of any model developed to describe this type of route.

Based on a review of northern operations, a simple model was developed to describe the relative preference for STOL and CTOL operations in the Canadian North. For a given state of technology STOL aircraft will be more expensive to operate than CTOL aircraft in an uncongested environment; however, the cost of building airfields is less for STOL than for CTOL. These expenses are the two main elements used by the proposed model which minimizes the sum of aircraft and airfield costs in selecting the preferred vehicle for a particular operation. It is shown that the choice of the most economical system depends on the ratio of STOL aircraft operating costs to CTOL, the ratio of STOL airfield costs to CTOL, the amount of cargo and passengers flown into and out of the airfield, and the distance of the site served from the nearest main distribution centre.

It should be noted that this is a tentative model aimed at developing the logic of the methodology. Specific applications and further development require the collection of additional data not available within the time allocated to this study.

Based on a typical STOL/CTOL operating cost ratio (from 0-20% as range increases) and estimated airfield costs, the system which minimizes total costs in the Canadian North was determined for a range of annual tonnages and trip distances. It was found that for short stages and low tonnages the STOL system was superior.

It was found that the regions of preference for STOL and CTOL systems were not sensitive to the ratio of CTOL to STOL airfield cost over the range of values considered. This was largely due to the fact that STOL airfield costs tend to be a relatively small portion of the total STOL costs at tonnages and ranges where STOL and CTOL system costs are equal.

SECTION 2

The impedances to the introduction of a Canadian STOL transportation system have been identified and analyzed. In general it appears that except for the question of public acceptance of STOL aircraft noise there is no major impedance to the introduction of a first generation STOL system.

Consider Vehicle Design and Performance. As mentioned above there are no major technical impedances to the introduction of a first generation vehicle. However, the limitations of this class of vehicle, while they might not prevent production, could reduce the aircraft’s market potential. In particular, the light wing loading can result in poor gust response affecting both the pilot’s ability to control the vehicle and the passenger’s riding comfort. Turboprop powerplants in conjunction with these light wing loadings result in low cruising speeds by today’s standards. While this would be relatively insignificant in the downtown to airport application, and of marginal significance in the municipal feeder and regional service, it remains as a minor impedance to intercity and northern route applications. Finally, the image of propeller aircraft, as somewhat outdated vehicles when compared to jets, may result in a diminished passenger appeal.

It must be emphasized, however, that the importance of these characteristics is not fully understood and that their impact on the market potential of STOL will depend to a great extent on the actual aircraft design and the method of operation. Also,
the implications of noise factors, riding qualities, airspeed and their trade-off against the convenience of short access/egress times are uncertain.

In considering the technical development of second generation STOL aircraft with higher cruising speeds, higher wing loadings, turbofan propulsion and increased payloads, several areas of difficulty appear:

**Aerodynamics/High Lift Devices**

Short field performance can be achieved through the use of light wing loadings or powered lift. Both these techniques allow the aircraft to land at low forward speeds resulting in short landing distances. Powered lift systems rely on powerplant effects to achieve the necessary high lift coefficients. The development of these powered lift systems will require the solving of a range of technical problems. The results of their application will be improved riding qualities and higher cruise speeds, both important in assuring the continued success of a STOL system.

**Propulsion Systems**

The basic problem is to produce a quiet propulsion system with the required thrust characteristics which is at the same time economically viable. Research undertaken by Hamilton Standard on propellers indicates that a marked decrease in propeller noise should be realized in the time period 1975-1980. This is based on the use of low tip speeds, light-weight materials and variable camber blades. The outlook for a quiet turbofan engine based on high bypass ratios depends upon which manufacturer you believe. At the present time no noise break-through is evident.

**Handling Qualities/Crew Factors**

Generally speaking the low approach speeds used by STOL aircraft produce poor lateral handling qualities. This results in the need to pay careful attention to the lateral control system characteristics. The complex interactions involved in the assessment of STOL handling qualities are not well understood and considerable work must be carried out on each new design to ensure pilot acceptance.

**Certification**

Powered lift STOL aircraft cannot be certified under the current regulations which are based on power-off aircraft characteristics such as the power-off stalling speed. Before powered lift STOL aircraft can be put into service a new set of regulations will have to be formulated.

**Thrust Asymmetry**

The problems of handling the results of thrust asymmetry following the failure of an engine increase with increasing thrust level. In the case of powered lift STOL aircraft, this thrust asymmetry can produce both a yawing and a rolling moment. When this failure occurs at low speed the generation of sufficient control power to overcome these effects is a problem because the effectiveness of aerodynamic control decreases with airspeed. On vehicles with high thrust levels various techniques have been suggested: cross-shafting or cross-ducting to spread the power of the remaining engines over the wing, or boundary layer control on the rudder to allow the generation of larger yawing moments to compensate for the asymmetric thrust.

**Landing**

The control technique found to be most effective for STOL aircraft using glide slope angles of the order of 7 1/2° is to fly at constant angle of attack and to maintain the glide path through thrust modulation. This poses a problem in the case of turbofan propulsion since thrust response to throttle changes is too sluggish.

The impedances under Operational Aspects are discussed in conjunction with the 5 route types.

**Intercity and Municipal Feeder Transport**

Metropolitan STOLports do not presently exist in Canada. Naturally operators are reluctant to commit themselves to the purchase of STOL aircraft until they are shown concrete evidence of the availability of STOLports in major traffic generating areas.

The fare that a passenger pays is based on the direct operating costs of the vehicle and the indirect costs of the airline providing the service. The major element of costs on short stages is that due to the indirect cost structure of the airline. As a result, consideration should be given to the development of carriers specializing in short haul operations in order to achieve the best opportunity for minimum fares consistent with a profitable service.

**Downtown to Airport Transport**

Again the problem is the lack of STOLports in the downtown area and the lack of STOL runways at the CTOL airports. These operations based at major airports must provide convenient access for the traveller while at the same time be capable of IFR operations on a non-interfering basis with CTOL traffic. These problems are not considered to be of high priority by airport operators and planners because of the
uncertainty surrounding full scale implementation of STOL services, because proper guidelines for the phasing in of STOLports are lacking and because of uncertainty concerning the level of traffic expected.

Regional Transport

The development of services to smaller communities involves improving the attractiveness and economics of small aircraft and reducing indirect operating costs. Community participation appears to be a good way to minimize indirect operating costs. The formation of Pem Air is an example of this. The community centred on Pembroke constructed the runway and terminal and it appears that Pem Air executives contribute freely of their own time. Thus indirect costs are held far below those that could be achieved by a conventional airline serving the route.

Northern Transport

Many of the operational problems here are similar to those found for Regional Transport because they arise as the result of low density traffic. In an attempt to minimize costs, operators often purchase used CTOL equipment. At the present time little used STOL equipment with suitable payload capacity is available.

A related problem is that the choice of available CTOL aircraft models exceeds that of STOL. Frequent requests are received by manufacturers for larger STOL aircraft, with greater payload, range, speed and volumetric capacity. Until such aircraft are available operators will have no choice but to use CTOL aircraft.

Most of the impedances identified in the area of Navigation, Guidance and Air Traffic Control are not expected to be present at the time of initial introduction of the STOL system. Rather they will develop as traffic density grows and the demand for all-weather operation increases.

Communications

The present equipment is quite adequate. An economic impedance could develop when the required facilities have to be provided at new STOLport sites.

In the severe weather conditions in the north there will be additional maintenance problems. However it is anticipated that these can be handled with proper planning.

Navigation

The full potential of STOL can be achieved through the use of area navigation equipment. This system allows the pilot to navigate his aircraft without following the present airway patterns. One manufacturer's equipment provides a chart presentation of the area over which the aircraft is flying and a trace on this map showing the track the aircraft has flown. This technique has the potential to relieve the crowded airways, especially near terminal areas, and thus help the air traffic controller. The technique is much more flexible than the present airway system.

At the present time VOR/DME, doppler or hyperbolic inputs may be used. For operation in terminal areas additional ground stations are required to achieve the desired accuracy. The impedances are mainly economic.

Approach and Landing Aids

The greatest technical problems exist in the area of approach and landing aids. The present ILS system is not suitable for operations out of small downtown STOLports because of the requirement for large areas of flat ground in front of the antenna.

No microwave landing aid suited for use on STOL operations is presently ready for airline use.

Air Traffic Control

As mentioned previously, the introduction of area navigation has the potential to relieve the controller's work load in the terminal area. The use of this technique would simplify arrival and departure control and reduce the amount of communication required between the pilot and the air traffic controller.

Control procedure will have to be developed for handling a mixture of CTOL and STOL aircraft in an efficient manner. This should result in the independent operation of CTOL and STOL if congestion is to be alleviated through the introduction of STOL.

With the advent of STOL service there will be a need for tower and approach control staff at many of the fields serving the smaller population centres. It is possible to omit the latter in some cases, but tower operators are a necessity on controlled airfields.

Presently air traffic control in the far north is virtually non-existent. New sectors and controllers will have to be provided at some sites.

Cockpit Instrumentation

As lower landing limits and improved equipment allow the pilot to make approaches under extremely poor visibility conditions, displays must be developed which present the situation as it would be seen from the cockpit under VFR conditions. This of course does not represent an obstacle
to the introduction of STOL, but it does present a challenge to be met as we approach the all-weather landing situation.

Collision Avoidance Systems

Some form of collision avoidance warning in the cockpit will be mandatory with the introduction of area navigation systems. The shifting of the navigation task from the ATC system into the cockpit means that the pilot will be required to monitor the presence of aircraft in his vicinity by other than visual means. This equipment is presently in the experimental stages. The difficulty is to produce a system that is completely reliable yet not priced out of the market.

In developing a STOL system consideration must be given to Non-Passenger Public Acceptance. In considering the benefits from such a service one must weigh the price to be paid in the form of noise, pollution and the risk of injury from crashes.

Subjective Response to Noise

The subjective response of an individual to the single occurrence of a noise is very complex and variable. Prediction of the reaction of an individual to a given noise remains well beyond the state-of-the-art. On the other hand collective human response to a number of aircraft flybys is reasonably predictable. However the acceptable noise levels for downtown and suburban STOL operations are not presently known.

STOL Noise vs. CTOL Noise

In transferring the experience with reactions to CTOL noise to STOL operations, one essential difference must be recognized. Very compelling arguments can be advanced to show that a healthy conventional air transportation industry is essential to the economic and social welfare of the nation. On the other hand a commercial STOL system does not yet exist. Thus arguments counselling tolerance to a limited amount of conventional aircraft noise cannot immediately be extended to STOL.

The noise produced by a STOL aircraft is influenced by several factors. The fairly high installed powers tend to produce high noise levels while the associated fast rate of climb and manoeuvrability tend to give the pilot the means to avoid noise sensitive areas.

Acceptable STOL Noise Levels

There is no guarantee that the present noise level target of 95 PNdB at 500 feet will be acceptable in all STOL operations. It is possible that in downtown areas with moderate to high continuous background noise levels the noise of a STOLport may not be objectionable. However in other areas the noise problem is very real. To get some perspective of the magnitudes involved a diesel freight train travelling at 50 mph produces 95 PNdB of noise at 500 feet.

Control of Noise

Noise can be controlled at the source, along the transmission path and at the receiver. As mentioned previously propeller research is underway to reduce this noise at the source. Work on turbofan engines has met with some success through the use of acoustic liners in the nacelles (with substantial penalties in range, weight and direct operating costs). This in combination with high bypass ratios will reduce the noise levels of future engines.

Transmission path measures include moving the receiver further away from the source and noise insulation of structures. NASA sponsored studies have shown that in areas exposed to less than 100 PNdB interior noise levels can be reduced by up to 10 dB through structural modifications; in all areas exposed to greater than 100 PNdB a bearable interior environment can only be achieved through major reconstruction.

As far as the human receiver is concerned little can be done beyond tax relief to account for property devaluation.

Noise Certification of STOL Aircraft

One method by which the noise of STOL aircraft can be controlled is through denial of an airworthiness certificate to any vehicle not complying with specified noise requirements. Such noise certification requirements are currently mandatory for transport aircraft in the United States. The problem is one of selecting the proper requirements and measurement technique.

Air Pollution

Pollution from aircraft exhaust emissions is still a secondary factor in determining public reaction to CTOL operations. What reaction there is seems to be directed against the conspicuously visible exhaust smoke mainly on esthetic grounds. However consideration should be given to the possibility of local exhaust concentrations in populated areas.

Other Impedances

These include the effects of the fear of crashes in the STOLport neighbourhood and the present tendency of people to actively resist what they feel are undesirable developments.

When considering STOLports it is found
that most of the technical knowledge re-
quired has been already developed for
CTOL airports. However some problems do
exist that are peculiar to STOL operations.

The Land Cost Factor

The desire to build STOLports near the
traffic generating areas means that the
required land could be quite expensive
and the available area limited. Thus
it is obvious that investments in compact
construction of STOLports may pay off
handsomely.

Development Timescale

It has not uncommonly been found that a
major airport project takes as much as
ten years. While this might not be the
case for STOLports, it must be pointed
out that a single STOLport, much less a
network of STOLports, will not be made
ready overnight in any event.

STOLport Sites

One problem is to ensure the availability
of downtown STOLport sites. Current re-
development in our major cities is not
taking into account the possibility of
STOLports and as a result several ideal
sites could be lost. It is suggested
that candidate cities for downtown STOL-
ports be alerted to the possibilities
as soon as possible.

Ground Congestion

It would be a mistake to centralize STOL-
port operations as has been done in the
past with CTOL operations. Downtown traf-
ic arteries feeding the STOLport might
be unable to bear the traffic burden. The
solution is to operate several STOLports
spread throughout the metropolitan area
close to the traffic generation areas.

STOLport Capacity

Based on the concept of decentralization
it is felt that a typical STOLport might
have an annual capacity of one million
passengers. A study of a modular STOLport
of this capacity has been completed by the
Canadian Air Transportation Administration
for the CTC.

Navigation Aids

As mentioned previously navigation aids
will have to be developed to fit within
the confines of the downtown STOLport.
This could involve the use of antennae
mounted on high buildings in the downtown
area.

Working Committees

CTOL airport planning experience has shown
that the only practical means of achieving
a systematic design is to constitute

interdisciplinary working committees. A
shortage of available man-hours is an im-
portant potential impediment to such an
effort.

Airline Space Requirements

An important unknown in STOLport planning
is what facilities the various operators
will demand, and will pay for. Should
extensive and expensive facilities be re-
quired by these groups, spiralling land
requirements, facility costs and possibly
public dissatisfaction can be foreseen.
Our current lack of knowledge in this area
must at present be seen as a constraint on
progress toward STOLport developments.

Official Guidelines

Guidelines and criteria affecting the air-
craft operating areas on, and airspace at
STOLports have not yet been firmly fixed
anywhere in the world, although the FAA in
the United States is approaching this goal
with respect to metropolitan STOLports.
Attention has been turned to developing
similar official guidance applicable within
Canada.

SECTION 3

The following research recommendations
were based on the work of the previous
phases of the study. From this analysis
it was concluded that most of the impe-
dances hampering the introduction of a
Canadian STOL transportation network are
economic and institutional.

It is quite clear that American industrial
and government laboratories will continue
to vigorously pursue STOL research and
development to meet the challenge of the
remaining technological problems. The
present study did not uncover any area
that appeared to require large scale re-
search and development due to individually
Canadian conditions. Some Canadian re-
search will, however, be essential in order
to monitor the American work and to main-
tain the level of technical expertise
needed to exploit American developments.
If Canadian industry wishes a share of the
STOL market beyond the first generation
system it must keep abreast.

In view of these considerations, it was
the opinion of the project staff and con-
sultants that a moderate level of Canadian
research effort in all STOL areas is neces-
sary to assure a healthy Canadian STOL
aviation industry.

The following recommendations presuppose
the necessity for high calibre STOL re-
search in Canada. At the same time it is
recognized that our national resources
must be utilized in a cost-effective man-
ner. Accordingly advantage must be taken
of existing capabilities and special
competence within Canadian institutions to avoid needless duplication of foreign research.

Collection and Distribution of Data

In a number of areas, impedances to STOL aviation are aggravated by a lack of Canadian data and the poor distribution of existing data. Work should be carried out in the areas of passenger statistics, airline operational information and public reaction to aircraft.

STOL System Operational Study

This program would involve the simulated operations of a complete STOL system. Fully instrumented STOL aircraft and STOLports would be used to obtain the maximum amount of data from each flight. The data generated would include vehicle related information, STOLport and navigation aids evaluation and the assessment of non-passenger public reaction.

Regulations

Sets of regulations must be developed to govern the use of powered lift devices, to restrict the noise produced by STOL aircraft and to govern the use of new navigation and landing aids. Results helpful in the framing of these regulations could be drawn from the STOL system operational study.

Advanced STOL Concept Selection

At the present time a large number of advanced STOL concepts show attractive possibilities. Numerous paper studies have been carried out to determine their relative merits and over the years a variety of wind tunnel tests and actual flight tests have been performed. Continuation on this broad front appears unduly expensive. It would make sense to gather together all the available information and rank the concepts in an overall effort to establish the most promising. Attention could then be focussed on developing one or two concepts.

Communications

Canada should simply monitor American work in this field.

Navigation Systems

Work should be carried out in the field of area navigation and northern navigation. As a first step the suitability of the various candidate systems should be determined in the Canadian environment.

Handling Qualities

To date a considerable amount of Canadian effort has gone into the study of V/STOL handling qualities, but this area of research has not yet produced a set of guidelines which are sufficiently complete to allow the design of an advanced concept STOL aircraft with any degree of certainty. It appears that the most productive application of this research would be to study the handling qualities of the vehicle concepts selected as most promising.

STOLport Development

Simple packaged STOLport concepts complete with various degrees of IFR capability should be analyzed and the results made available to interested communities. The emphasis should be on reliability and low cost. It is recommended that community noise studies be made an integral part of these STOLport specifications.

Studies of specific sites should be initiated with particular attention paid to land costs. Consideration should be given to what decisions may have to be made at a very early date, if the lead time required for STOLport development is not to produce a good deal of trouble in future.

STOLport Turbulence

It is very desirable to determine the nature of the STOLport environment with regard to turbulence, wind shear and crosswinds. This information in turn would serve as a realistic input to the handling qualities work by providing information about the disturbances through which the aircraft must fly. Such research could involve both theoretical and wind tunnel studies, with support from actual site data.

Propulsion Systems

Canadian industry has expressed the desire to carry out work in developing quiet propellers.

In the field of turbofan engines it is recommended that the bulk of this work be left to the manufacturers. The Canadian program should be a small effort aimed at monitoring advances in the field while at the same time contributing to the understanding of the basic phenomena.
Further Systems Analysis

It is recommended that the crucial step in model studies of deciding what factors to include in the system model be carefully re-examined. For example, very useful results might be obtained from a study into methods by which non-passenger public reaction could be injected into economic models. At best this type of research would lead to a way of estimating the cost/benefit relationships of various proposals: at the very least it would serve to pinpoint some of the relevant issues.

The intercity model presented earlier was based on the 'Value of Time' concept. The development of a more sophisticated technique using additional passenger preferences would be particularly useful in the analysis of the less dense, short municipal feeder routes where competition is very important.

Consideration could also be given to studying factors influencing the production base of a second generation Canadian STOL aircraft. For the applications studied it would appear that one or two distinct STOL aircraft types might profitably be developed. One vehicle would have about 11 to 25 seats, the other 30 to 60. It is expected that a system optimizing travel benefits and at the same time providing a substantial production base for a second generation vehicle could be defined.
This section describes a mathematical model designed to calculate the traffic attracted to a STOL system following its introduction under a given set of conditions on a number of intercity and municipal feeder routes. The two types of routes are considered together because the differences between them are minimal.

This general analysis seeks to establish the overall level of traffic in the STOL system under given conditions, and to pinpoint those conditions most powerful in assisting or impeding the development of the system. Changes in aircraft speed, fare level, and the number of STOLports in the major cities are among the parameters isolated for study.

Note

This analysis is not intended to be a detailed study of any particular city pair, where an improved simulation could generally be obtained by incorporating more detail into the analysis. The emphasis here is on a more general viewpoint. In keeping with this the input data have been smoothed to focus attention on trends. In certain instances where individual route data vary significantly from the smoothed trend curves, adjustments can be made by re-running the simulation incorporating the detailed information particular to that city pair.

Figure 1 illustrates the Canadian city pairs that were selected for study because of the availability of data on air, rail, bus and auto traffic among them. There are 8 routes that might be called intercity routes because they are presently served by trunk airlines and 9 routes focussed on Toronto that might be classified as municipal feeder routes.

The basic approach of this analysis is to determine the total number of travellers between any two cities, and to pinpoint the particular zone in the major city to or from which the individual wishes to travel. STOL makes it possible to locate terminals conveniently in the major traffic generating areas, saving time and cost in access and egress to a quick modern mode of transportation.

Consider Figure 2. A typical zone near the centre of a major city A, is shown. Travellers from this zone wishing to travel to another city B must first get to the terminal serving their selected mode, incurring an access time and cost related to their distance from the terminal in addition to the normal time and cost of traveling on the intercity vehicle. Similar considerations apply to egress times and costs at the destination. The total time and cost for the trip includes then the access, egress, and intercity portions. The model assumes that the traveller is attracted to the mode with the lowest total cost and lowest total travel time. The choice between a faster and more expensive trip, and a slower but cheaper one, is made on the basis of a Value of Time Concept. Travellers are assumed to value their time in a manner related to their income. If the cost incurred in saving an hour of travel time by selecting the faster mode is less than the value that the passenger places on an hour of his time, he will select the faster mode. With this technique the number of passengers attracted to the STOL service from auto, rail, bus and conventional air can be determined. Generally air travel will be faster on short stages by STOL than by CTOL (conventional takeoff and landing aircraft) because STOL time savings in access and egress outweigh CTOL aircraft time savings in the cruise portion of the journey.

Distribution of Passengers O & D's

One of the chief advantages of STOL is the time saved by the traveller in using an air terminal in the major traffic generating area of a city. To quantify the time saved by passengers using a downtown STOLport instead of an airport located outside the city, it is necessary to know the origin and destination (O & D) patterns of the passengers, that is the particular place in a city at which they begin and end their trip. For the 17 city pairs considered, data on the local origin and destination of air travellers was available only for Toronto and Montreal. It is in these two cities that the distances to be travelled to the airport are greatest, and the access time benefits of STOL would be most pronounced. These cities were divided into zones to permit a detailed estimation of the traffic. For the other smaller cities, all passengers were assumed to be concentrated in one zone surrounding the central business district. This assumption while satisfactory for the smaller towns investigated, becomes less valid as the size of the city increases. However it was beyond the scope of this study to gather O & D data for intermediate cities, with the result that the assumption of traffic concentrated in the downtown area was incorporated into the model. For Toronto and Montreal data existed covering the O & D distribution of air passengers inside the metropolitan area as a result of airport surveys. ("A Comprehensive Survey of Passengers
Flying From Toronto International Airport, May - June 1968", M. G. McLeod, UTIAS Tech. Note No. 141, Aug. 1969 and "Traffic Survey for Montreal International Airport", Dept. of Transport, 1968). The data were expressed as percentages of local passengers using the airport. Figures 3 and 4 indicate the distribution of these passengers among the city zones. The expected concentrations of traffic in the central business district are evident.

The regions surrounding Metropolitan Toronto and Montreal, were divided into larger zones. The division was quite arbitrary, especially at Montreal where the results of the Dorval Airport survey did not disclose the origin of the passengers outside Montreal proper (30% of local passengers originated outside Montreal). It was assumed that they were distributed evenly among three zones, with traffic generation centring around Sherbrooke, Trois Rivieres, and Sorel. For the 6 zones outside Toronto, the distribution was based on the University of Toronto, Institute for Aerospace Studies passenger survey. The details of these zones are contained in Figures 5 and 6.

The distribution of auto passengers in Toronto was extracted from the O & D surveys carried out by the Ontario Department of Highways (DHO) over the past few years. However no such information was available for Montreal. Past work ("The Demand For Intercity Passenger Transportation by VTOL Aircraft", N. J. Asher, E. Wetzler, S. M. Horowitz and W. B. Schneider, Institute for Defense Analyses report R-144, Aug. 1968) has indicated that the air passenger distribution for a city can often be expressed as a function of the radial distance from the central business district. To test the validity of this theory, the present case, cumulative O & D percentages for air passenger distribution curves are shown in Figure 7. The two curves are quite comparable. The same plotting procedure was repeated for auto passengers in Toronto (see Figure 8). The data indicate that a higher proportion of auto travellers have O & D's near the city centre, than do air travellers. To normalize the distributions the radii were expressed as a percent of the total city radius. The auto curve rises to 100% since the analysis considers only the auto traffic generated within the metropolitan area. Based on this similarity between the air traffic patterns in the two cities the percent radial distribution of auto passengers in Montreal was assumed the same as in Toronto. This same distribution curve was applied to Montreal, to determine the auto traffic for each zone in that city. Rail and bus passengers were assumed to have the same distribution as auto passengers.

Base Year Data For Intercity Travel

The starting point for this analysis is a set of data giving the intercity traffic for a number of city pairs for a base year. This information is extrapolated to predict future traffic levels. The number of passengers that might be diverted to a future STOL service is then generated by the model.

This data consisted of the intercity travel survey of the Quebec-Windsor corridor carried out by the CTC during the summer of 1969 and the set of intercity traffic data for travel to and from Toronto recently collected and compiled by UTIAS. This data is presented in Table 1. The 1969 data was not complete for all the city pairs. While air data was readily available (from Airline Passenger Origin and Destination Statistics compiled by the Air Transport Committee) the 1969 report was not yet released at the time of preparing this report. The air data used was obtained by projecting annual average growth rates. The Canadian National Railway provided rail data and suggested that the yearly traffic was constant. Thus the rail data supplied for 1968 was taken to be representative of the year 1969. Bus data was the most difficult to obtain; bus companies usually do not compile statistics for intercity bus passenger traffic. Hence bus traffic had to be estimated from schedules contained in the Official Canadian Bus Guide. Load factors were assigned to the buses based on express, one-stop or multi-stop local service. These load factors were suggested by the Gray Coach Line. The load factor is 100% on a non-stop express, and 50% for a one-stop express. For a multi-stop local service the load factor is determined by dividing 100% by the number of intermediate stops.

Auto data was obtained from the DHO. This information was gathered over a number of years in a series of roadside interviews at various stations. The survey not only gives the O & D of the passenger but also other relevant information such as the trip purpose. By choosing stations carefully, it is possible to determine the auto traffic between two cities.

Since the surveys were carried out over several years, it was necessary to apply growth rates at various sections of the highways to project the volume of auto passengers to the year 1969.

Access Time

Access to airports and STOLports was considered for two types of travel inside the city, and for highway travel outside the city. In the case of travel inside a city, the Institute for Defense Analyses (IDA) has conducted studies of the time and cost involved in getting to an airport from various parts of a city (IDA report
R-144, Aug. 1968). These form the basis of the access data used in this study. From this writer's travelling experience in Canada it was observed that one of the IDA curves corresponded to rush hour traffic conditions, while another represented the travel time in the off-peak traffic period. Hence the IDA curves were modified into a single curve taking into account the percentage of passengers traveling under the on and off-peak traffic conditions. (According to a UTIAS Toronto International Airport Survey (UTIAS Tech. Note. No. 141) 25% of the passengers travelled to the airport during the rush hour.) This curve was also used for STOLport access.

For those zones where passengers reach the airport exclusively via highways a different access time was derived. Since these passengers do not have to face city traffic congestion, and because of higher speed limits, it was assumed that they averaged 50 mph in travelling to the airport. These access time curves are presented in Figure 9. A minimum access time of 10 minutes was imposed, even for nearby airports, resulting from time to get underway and parked. This is reflected in the Y intercept of 10 minutes in the figure.

The access time curve for bus and rail terminals was taken from the de Havilland Northeast Corridor V/STOL Investigation Report. Access time for intercity auto travellers was taken to be zero as their cars were assumed to be located at their trip origin.

Access Costs

The access costs derived by the IDA ("Proposal for a Study to Determine Passenger Traffic in the Northeast Corridor", Institute for Defense Analyses, Dec. 1968) were modified in a fashion similar to the access times and used for airport and STOLport access from zones within a city. The costs for those passengers driving to the airport via highways were based on intercity highway data (as described in the following section on intercity block fares). These curves are shown in Figure 10. The differences between the two cases result from the consideration that airport access by travellers from within the city makes more frequent use of taxis and limousines with a higher cost per mile, whereas access by travellers from more distant regions outside the city usually emphasises the personal car, with a lower cost per mile, but with higher fixed costs for parking.

The access cost curve for bus and rail terminals was taken from the de Havilland Northeast Corridor V/STOL Investigation Report.

Access costs for intercity auto travellers were taken to be zero as their cars were assumed to be located at their trip origin.

Intercity Block Times

The block times for the various modes of transport were determined from several sources. Smoothed curves based on the available data were drawn. These acted as block time input data to the model.

Auto:

Automobile travel times were calculated on the basis of an average highway speed of 50 mph. For the 17 routes considered, the highway mileages were obtained from a road map. The travel times could thus be calculated once the distances and speed were known. For routes longer than 150 miles, a rest stop of 20 minutes was included. The total trip time was the sum of the driving time and the stopping time. These were then plotted as a function of the straight line intercity distances as in Figure 11.

Bus and Rail:

Bus and rail block times were taken from schedules corresponding to the year 1969. In cases where there were two types of service, such as an express and a local service, the block time for the faster service was chosen. The smoothed curves of block times vs. straight line distance between city pairs are presented in Figure 11.

CTOL:

The block times for the CTOL aircraft were obtained from the Official Airline Guide flying times. When two different aircraft operated over the same route, the flying time for the faster vehicle was used. The plot in Figure 11 shows the smoothed curves of block time vs. straight line distance between city pairs.

STOL:

Two types of STOL aircraft were considered in this study. They were fictitious aircraft designated as STOL 1 cruising at 300 mph and STOL 2 cruising at 500 mph. STOL 1 represents the first generation turboprop STOL whereas STOL 2 is typical of the second generation turbofan STOL. The block times were taken from the de Havilland Northeast Corridor V/STOL Investigation Report. They are shown as functions of straight line distance in Figure 11.

By calculating results for these two aircraft speeds it was possible to estimate the effect of different STOL flight speeds on demand for the service.
Intercity Block Fares

Conventional airline fares and bus fares for the various city pairs were extracted from the Official Airline Guide and the Official Canadian Bus Guide for the year 1969. The rail fares were taken from the Canadian National Railway schedules.

Cost estimates for auto transportation vary considerably. They depend on whether the individual driver considers only the cost of gasoline and parking or also other factors such as depreciation. A value of 5¢ per mile, a reasonably low evaluation of automobile operating cost, was adopted. This operating cost was then divided by the "passenger occupancy rate per auto" factor supplied by the Ontario Department of Highways O & D Surveys. This rate varied from 1.3 to 2.5 depending on the route. In general the occupancy rate increased on longer stage lengths. An expenditure of $1.00 for refreshments was added to the trip cost when driving times exceeded 3 hours.

Computations were performed for two levels of STOL fares, the first with STOL fares equal to CTOL fares, and the second with STOL fares 10 percent higher than CTOL fares. With these calculations an elasticity of demand with fare could be estimated in order to determine the effect of fare changes on STOL traffic.

The costs for the various modes are presented in Figure 12 as a function of straight line distance. These curves were used as block fare input data to the model.

Derivation of the 'Value of Time' Curves

The Value of Time Method is widely used to determine the penetration of a new transportation mode into the traffic of an existing mode. This approach was successfully employed by a number of participants in the recent Northeast Corridor Investigation, and it is based on the hypothesis that travellers value their time in a manner related to their income. There is no question as to the validity of such an assumption, however, the problem is to determine how a passenger relates his value of time to his hourly income. It was demonstrated from American passenger surveys that business passengers value their time at approximately one and a half times their hourly income while those on pleasure trips value theirs at approximately one half their hourly income. It seems reasonable to apply the same ratios to Canadian travellers.

The CTC 1969 summer O & D survey along the Quebec-Windsor corridor provided the data for the distribution of passengers by income for the three common carriers (air, bus and rail). This was further broken down into business and pleasure trips.

Based on these inputs the value of time curves in Figure 13 were constructed for Canadian air, bus and rail passengers. These take into account the actual distribution of travel between business and pleasure. The air travellers have the greatest value of time. That is, they are willing to pay more in order to save time.

Calibrating the value of time curve for the auto passengers presented some difficulty since the O & D interviews conducted by the DHO did not investigate the passenger's income. This problem was circumvented by adopting the provincial income distribution of Ontario residents for the year 1967 to form the auto passenger's value of time curve. This was based on the belief that travel by auto was so universal that the income distribution of those who drive would be more or less equivalent to that of the whole province. A 50/50 split between business and pleasure trips by auto was used for all income levels, a value derived from DHO traffic data. It should be noted that because of the special nature of auto travel for pleasure it was assumed that no STOL penetration would be made into this auto market and as a result the curves shown apply only to auto travel for business.

Since these curves form one of the key inputs to the model a second set was drawn up under the assumption that business travellers valued their time equal to their hourly income and pleasure travellers equal to one third of their hourly income. Calculations to determine the sensitivity of the model to these parameters could then be performed. (See Figure 14.)

To illustrate the application of these techniques consider the curves shown in Figure 13. They show the percentage of travellers by mode that value their time at a rate greater than that shown on the abscissa. For example, if travellers who normally used CTOL found that the trip by STOL was an hour shorter but cost 5 dollars more, then that portion of the CTOL travellers valuing their time at more than $5 per hour, 74 percent from the CTOL curve of Figure 13, would elect to use STOL. This assumes of course that all other factors inherent in the choice such as frequency, congestion, safety etc. are equal.

Terminal Locations

The locations of the terminals for all transportation modes are required by the model as input data.

Bus and rail terminals are normally situated adjacent to the central business district. For the sake of simplicity in the present study all bus and rail

14
terminals are assumed to be located at the city centres.

CTOL airports were located at their present sites if they existed. However, in the cases of Kitchener, Barrie and Belleville, where suitable airports were not available, new ones were assumed to exist nearby (see Table 2 for the details) to represent possible CTOL competition.

STOLport sites must be located near the large traffic generating regions in order to offer the convenience of easy access to passengers. Three STOLport sites were established for Toronto and Montreal (these are included in Figures 27 and 33) while a single site was selected for each of the other cities. In Toronto and Montreal one of the sites was taken to be the existing airport. In Quebec City, Ottawa and Hamilton possible sites were selected near the assumed major traffic sources. For all other cities the STOLport was located at the CTOL airport because they were reasonably close to the downtown area. (See Table 2.)
### TABLE 1
ANNUAL INTERCITY AND MUNICIPAL FEEDER TRAFFIC VOLUMES FOR 1969
(Thousands)

<table>
<thead>
<tr>
<th>Town</th>
<th>AUTO</th>
<th>BUS</th>
<th>RAIL</th>
<th>CTL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toronto - Barrie</td>
<td>1209</td>
<td>50</td>
<td>11</td>
<td>-</td>
</tr>
<tr>
<td>Belleville</td>
<td>268</td>
<td>160</td>
<td>50</td>
<td>11</td>
</tr>
<tr>
<td>Hamilton</td>
<td>3765</td>
<td>406</td>
<td>38</td>
<td>-</td>
</tr>
<tr>
<td>Kingston</td>
<td>372</td>
<td>234</td>
<td>66</td>
<td>-</td>
</tr>
<tr>
<td>Kitchener</td>
<td>1590</td>
<td>141</td>
<td>41</td>
<td>-</td>
</tr>
<tr>
<td>London</td>
<td>1025</td>
<td>163</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>Niagara Peninsula</td>
<td>1920</td>
<td>213</td>
<td>33</td>
<td>-</td>
</tr>
<tr>
<td>North Bay</td>
<td>221</td>
<td>53</td>
<td>23</td>
<td>-</td>
</tr>
<tr>
<td>Oshawa</td>
<td>3730</td>
<td>50</td>
<td>6</td>
<td>-</td>
</tr>
<tr>
<td>Ottawa</td>
<td>397</td>
<td>87</td>
<td>79</td>
<td>21</td>
</tr>
<tr>
<td>Peterborough</td>
<td>798</td>
<td>87</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sarnia</td>
<td>169</td>
<td>18</td>
<td>78</td>
<td>-</td>
</tr>
<tr>
<td>Sudbury</td>
<td>259</td>
<td>64</td>
<td>17</td>
<td>35</td>
</tr>
<tr>
<td>Windsor</td>
<td>283</td>
<td>100</td>
<td>158</td>
<td>117</td>
</tr>
<tr>
<td>Montreal - Ottawa</td>
<td>975</td>
<td>254</td>
<td>402</td>
<td>117</td>
</tr>
<tr>
<td>Quebec City</td>
<td>672</td>
<td>186</td>
<td>348</td>
<td>87</td>
</tr>
<tr>
<td>Toronto</td>
<td>589</td>
<td>58</td>
<td>419</td>
<td>687</td>
</tr>
</tbody>
</table>

*No service at present*

### TABLE 2
LOCATION OF AIRPORTS AND STOLPORTS

<table>
<thead>
<tr>
<th>Town</th>
<th>Airport</th>
<th>Stolport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrie</td>
<td>3 mi. east of CBD on the shore of Lake Simcoe</td>
<td>Same as airport</td>
</tr>
<tr>
<td>Belleville</td>
<td>2 mi. south of CBD on the shore of Lake Ontario</td>
<td>Same as airport</td>
</tr>
<tr>
<td>Hamilton</td>
<td>Existing airport</td>
<td>Junction of HWY 403 and HWY 6</td>
</tr>
<tr>
<td>Kingston</td>
<td>Existing airport</td>
<td>Same as airport</td>
</tr>
<tr>
<td>Kitchener</td>
<td>4 mi. east of CBD</td>
<td>Same as airport</td>
</tr>
<tr>
<td>London</td>
<td>Existing airport</td>
<td>Same as airport</td>
</tr>
<tr>
<td>Montreal</td>
<td>Existing Dorval airport</td>
<td>(1) Expo parking lot</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) Dorval airport</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3) Junction of Pie IX Blvd. and Blvd. Metropolitan</td>
</tr>
<tr>
<td>Niagara Peninsula</td>
<td>St. Catharines airport</td>
<td>Same as airport</td>
</tr>
<tr>
<td>North Bay</td>
<td>Existing airport</td>
<td>Same as airport</td>
</tr>
<tr>
<td>Oshawa</td>
<td>Existing airport</td>
<td>Same as airport</td>
</tr>
<tr>
<td>Ottawa</td>
<td>Existing airport</td>
<td>2 mi. northwest of CBD on the south bank of the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ottawa River</td>
</tr>
<tr>
<td>Peterborough</td>
<td>Existing airport</td>
<td>Same as airport</td>
</tr>
<tr>
<td>Quebec City</td>
<td>Existing airport</td>
<td>3 mi. from CBD south of Parc des Champs de Bataille</td>
</tr>
<tr>
<td>Sarnia</td>
<td>Existing airport</td>
<td>Same as airport</td>
</tr>
<tr>
<td>Sudbury</td>
<td>Existing airport</td>
<td>Same as airport</td>
</tr>
<tr>
<td>Toronto</td>
<td>Existing Malton airport</td>
<td>(1) 1 mi. south of the junction of the Don Valley Parkway and the Fred Gardiner Expressway on the shore of Lake Ontario</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) Malton airport</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3) Junction of the Don Valley Parkway and HWY 401</td>
</tr>
<tr>
<td>Windsor</td>
<td>Existing airport</td>
<td>Same as airport</td>
</tr>
</tbody>
</table>
ASSUMPTIONS: BUSINESS PASSENGERS AT 1/2 TIMES THEIR HOURLY INCOME
PLEASURE PASSENGERS AT 1/3 THEIR HOURLY INCOME

VALUE OF TIME $/HR.

DISTRIBUTION OF TRAVELLERS BY VALUE OF TIME

FIGURE 13

ASSUMPTIONS: BUSINESS PASSENGERS AT THEIR HOURLY INCOME
PLEASURE PASSENGERS AT 1/3 THEIR HOURLY INCOME

VALUE OF TIME $/HR.

DISTRIBUTION OF TRAVELLERS BY VALUE OF TIME

FIGURE 14
MODEL APPLICATION

Six market cases were studied through the application of the model. They were characterized by an assumed value of time, STOL cruising speed, STOL fare, and the number of STOLports in Toronto and Montreal (as indicated in Table 3). The sensitivity of the model to changes in input parameters was then estimated by utilizing Case 1 as the reference.

STOL Penetration Into Existing Modes

The STOL penetration into the traffic of the existing modes is determined by applying the value of time concept to all possible origin/destination zone pairs. The total trip time and cost for STOL and the competing mode are compared to determine the percentage of travellers in those zones who would elect to use the STOL service. All of these penetrations for a given mode and city pair are summed in a manner producing the modal penetrations for that particular route.

Table 4 to 7 list the percent penetration for four cases studied. Figures 15 to 18 plot these values for a 300 mph STOL aircraft with CTOL fares and two STOLports each in Toronto and Montreal. It can be seen that penetration into business travel by auto is zero for trips shorter than 30 miles long and increases more or less linearly with distance for longer trips. Percent penetration into rail is higher, reaching 30 percent at 150 miles. Penetration into bus travel is about half that into rail. Penetration into CTOL varies from 68 to 72 percent on short stages and decreases to about 60 percent at 200 miles. Note that the tables show a CTOL and rail penetration for city pairs for which there is no existing CTOL and rail service. These values are to be interpreted as the penetration that would be made if CTOL and rail service existed. The very high penetrations of STOL into CTOL on the Montreal to Ottawa and Montreal to Quebec routes (reaching 100 percent for some cases) was partly due to the location of STOLports near the traffic generating areas in Ottawa and Quebec (where all the traffic was assumed to be generated in the central business district). On the relatively short stage lengths of these routes this gave STOL the overwhelming advantage (on longer routes such as Toronto to Ottawa the higher cruise speed of CTOL could reduce this effect).

Passengers Using the STOL System

A calculation of the number of travellers who would elect to use the STOL system was carried out using the annual trips made between city pairs for each mode and the penetration by STOL.

Tables 8 to 12 give these values for the year 1969 for five of the cases. It was assumed that once established, STOL travel on a route would grow at the rate of 12 percent per year. Based on this, 1980 traffic would be 3.45 times the 1969 values.

Average Total Trip Time and Cost

Considering in turn travellers using each mode, trip times and costs were averaged over all O & D zones. Average total trip times after the introduction of STOL are tabulated for each city pair and mode in Tables 13 and 14 and illustrated graphically in Figure 19: average total trip costs are similarly tabulated in Tables 15 and 16 and illustrated in Figure 20. Trips with end points close to a modal terminal would (for that mode) be faster and cost less than the values shown. Trips with end points remote from the terminal would be slower and more expensive. On very short stages the auto provides the fastest trip and as the distance increases STOL travellers have the advantage until eventually CTOL dominates for the case of 300 mph STOL.

Division of Traffic Among STOLports

Tables 17 and 18 indicate the division of traffic among the STOLports in Toronto and Montreal as calculated on the basis of the shortest straight line distance from the STOLport to the traveller's ultimate origin or destination in the city. With two STOLports in Toronto, approximately 75 percent of the traffic would use the Lakeshore site and 25 percent the Malton STOLport. An additional STOLport in Toronto at the Don Valley site would attract approximately 35 percent, relieving the Lakeshore STOLport which would then attract about 45 percent.

With two STOLports in Montreal, approximately 60 percent of the STOL traffic flowed through the Expo STOLport; 40 percent used the port at Dorval. With a third STOLport on the north part of the island the traffic was split approximately 30 percent to Expo, 30 percent to Dorval, and 40 percent to the new Nord site.

Thus for both Toronto and Montreal, it is possible to relieve traffic at the initial STOLport (in order to prevent the buildup of congestion and noise at that site) by constructing an additional STOLport in yet another traffic generating area. The site chosen, near Highway 401 and the Don Valley Parkway in Toronto and in the northern part of Montreal Island, successfully accomplished this, and increased the
accessibility of STOL to the traveller.

Elasticity of Demand

The basic STOL penetrations were calculated for a 300 mph STOL aircraft with equal STOL and CTOL fares, and with two STOLports in each of Toronto and Montreal. Other cases are also presented to allow study of the effects of certain parameters. Changes in STOL aircraft speed, STOL fare, the number of STOLports in Toronto and Montreal, and in the passengers' value of time were considered.

Change in Demand With Cruise Speed:

Figure 21 shows the percentage change in STOL traffic that would be captured from each mode if the cruise speed of the STOL aircraft were increased from 300 to 500 mph. Penetration into the ground modes would increase in most cases by from 10 to 20 percent. There would be little effect on CTOL traffic for distances shorter than about 100 miles, for longer trips percentage increase in penetration rises sharply, to about 35 percent for the Toronto-Montreal route.

Change in Demand With Fare:

Figure 22 shows the percentage change in STOL penetration into each mode if the STOL fare were 10 percent higher than CTOL. Penetration into business auto and rail would drop by between 13 to 25 percent, and penetration into bus would drop by about 25 percent for most routes. The penetration of the CTOL mode decreases very rapidly with increasing distance, dropping to 50 percent of the reference value for stage lengths of about 200 miles. The 328 mile Toronto-Montreal stage is somewhat of an exception to the trend, dropping only 35 percent, presumably because of the time and cost savings associated with two STOLports in each city.

Change in Demand With the Number of STOLports in Toronto and Montreal:

Figure 23 shows the percentage increase in the STOL penetration into each mode that would result from having a third STOLport in both Toronto and Montreal. The scatter of the points makes it difficult to draw trend lines, but it can be seen that penetration into ground modes on stages below 100 miles is markedly increased but that as the stage length increases above 100 miles the increase tends to drop below 10 percent.

Change in Demand With Value of Time Parameters:

The sensitivity of the model to the assumed value of time was checked by calculating the penetrations by STOL for the two sets of value of time given in Figures 13 and 14. (The 'initial' set of value of time was taken to be the one based on business travellers valuing their time at one and a half times their hourly income and pleasure travellers at one half times their hourly income.) An examination of Figure 24 indicates that there is a drop in penetration of auto, bus, and rail for all distances when passengers value their time at a lower rate. This is to be expected since fewer people would then be willing to pay premium STOL trip costs. No such trend in the penetration of CTOL exists. In fact the data indicates a slight increase in penetration on some routes. In general the change in CTOL penetration is negligible. Since there is a much smaller difference between STOL and CTOL travel costs and times than between STOL and the other modes there will exist pairs of city zones for which STOL is slower and cheaper than CTOL and other pairs for CTOL is slower and cheaper than STOL. (Note that the traffic split between two modes for a pair of zones in which one mode is cheaper and faster does not depend on the value of time because the superior mode always captures all the traffic.) If it is assumed that people place less value on their time there will be a shift towards the cheaper of the two modes in all pairs of zones (i.e. to STOL in some and to CTOL in others) resulting in little change in overall percent penetration.

Conclusions

The results of the modelling indicate that a STOL aircraft cruising at 300 mph, serving two STOLports in Toronto and Montreal with an acceptable frequency of service and CTOL fares would attract sufficient traffic to operate a viable intercity and municipal feeder service now. The size of vehicle required to generate an acceptable frequency and the implications for the development of second generation vehicles will be mentioned in Section 3.

Studies of the change in demand that would occur if certain basic parameters of the STOL system were to be changed indicate that the most powerful method of attracting ground travellers on short stages is to increase the number of STOLports in Toronto and Montreal, while for longer stages a switch to jet cruising speeds is more effective.

CTOL penetration primarily responds to an increase in cruise speed, and is markedly reduced on short stages by an increase in fares.

Increasing the number of STOLports in a city not only increases traffic, but is a mechanism whereby the traffic around any one site may possibly be kept from exceeding acceptable limits. For Toronto and Montreal, the new site introduced significantly relieved the existing STOLports!
share of traffic.

While there is general agreement that a Value of Time concept exists, there is some question as to its magnitude. It is shown that wide variations in the rate at which travellers value their time do not have a significant effect on the conclusions derived in this study and that penetration into CTOL is especially insensitive to this concept, giving increased confidence in the results of this model.
### TABLE 3

<table>
<thead>
<tr>
<th>CASE</th>
<th>VALUE OF TIME CURVE*</th>
<th>STOL CRUISING SPEED</th>
<th>FARE</th>
<th>NUMBER OF STOLPORTS IN TORONTO AND MONTREAL</th>
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</thead>
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<td>1</td>
<td>A</td>
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<td>CTOL</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
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<td>6</td>
<td>B</td>
<td>300</td>
<td>CTOL</td>
<td>2</td>
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</table>

* Value of time curves "A" assume the business passengers value their time at 1.5 times their hourly income and pleasure passengers at half their hourly income. Curves "B" assume these constants are changed to 1 and 1/2 times respectively.

### TABLE 4

<table>
<thead>
<tr>
<th>DISTANCE</th>
<th>BUSINESS</th>
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<td>3.7</td>
<td>0.9</td>
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<td>9.5</td>
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*No such service at present. Figures represent penetration if this mode were available.
### TABLE 5

**PERCENT PENETRATION BY CTOL**

(Value of time A, 300 mph, CTOL fares + 10%, 2 STOLports in Toronto and Montreal)

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<th>DISTANCE</th>
<th>BUSINESS AUTO</th>
<th>RAIL</th>
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<th>CTOL</th>
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<td>Belleville</td>
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<td>0.5</td>
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<td>2.5</td>
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<td>65.7*</td>
</tr>
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<td>0.9</td>
<td>65.7*</td>
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<tr>
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<td>12.1</td>
<td>26.7</td>
<td>14.8</td>
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<td>Oshawa</td>
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<td>0.1</td>
<td>3.5</td>
<td>0.4</td>
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*No such service at present. Figures represent penetration if this mode were available.

### TABLE 6

**PERCENT PENETRATION BY STOL**

(Value of time A, 500 mph, CTOL fares, 2 STOLports in Toronto and Montreal)

<table>
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<th>BUSINESS AUTO</th>
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*No such service at present. Figures represent penetration if this mode were available.
### TABLE 7

PERCENT PENETRATION BY STOL

(Thousands, Value of time $A$, 300 mph, CTOL fare, 3 STOL ports in Toronto and Montreal)

<table>
<thead>
<tr>
<th>DISTANCE MILES</th>
<th>BUSINESS AUTO</th>
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<th>BUS</th>
<th>CTOL</th>
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<td>London</td>
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<td>10.0</td>
<td>3.3</td>
</tr>
<tr>
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<td>70-ground</td>
<td>2.9</td>
<td>6.4</td>
<td>1.3</td>
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<tr>
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<td>34.4</td>
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<td>4.9</td>
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<td>6.4*</td>
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*No such service at present. Figures represent penetration if this mode were available.

### TABLE 8

1969 STOL PASSENGERS ATTRACTED FROM OTHER MODE (Thousands, Value of time $A$, 300 mph, CTOL fare, 2 STOL ports in Toronto and Montreal)

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<th>DISTANCE MILES</th>
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**1969 STOL PASSENGERS ATTRACTED FROM OTHER MODES**

(Thousands, 2 STOLports in Toronto and Montreal)

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### TABLE 10

**1969 STOL PASSENGERS ATTRACTED FROM OTHER MODES**

(Thousands, 2 STOLports in Toronto and Montreal)

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<th>BUS</th>
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### Table 13

**AVERAGE TOTAL TRIP TIME (hours)**

(Value of time $A$, 300 mph, CTOL fares, 2 STOLports in Toronto and Montreal)

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</table>

| Montreal - Ottawa | 103 | 2.5 | 3.3 | 3.4 | 2.3 | 1.3 |
| Quebec City | 148 | 3.6 | 4.4 | 4.7 | 2.3 | 1.5 |
| Toronto | 328 | 7.4 | 9.8 | 7.7 | 3.1 | 2.5 |

### Table 14

**AVERAGE TOTAL TRIP TIME BY STOL (hours)**

(Value of time $A$, CTOL fares)

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| Montreal - Ottawa | 130 | 1.3 | 1.1 |
| Quebec City | 148 | 1.5 | 1.3 | 1.4 |
| Toronto | 341 | 2.5 | 2.0 | 2.4 |
### TABLE 15

**AVERAGE TOTAL TRIP COST**

*(Value of time A, 300 mph, CTOL fares, 2 STOLports in Toronto and Montreal)*

<table>
<thead>
<tr>
<th>DISTANCE</th>
<th>BUSINESS</th>
<th>AUTO</th>
<th>RAIL</th>
<th>BUS</th>
<th>CTOL</th>
<th>STOL</th>
</tr>
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<tbody>
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### TABLE 16

**AVERAGE TOTAL TRIP COST**

*(Value of time A, 300 mph)*

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<th>DISTANCE</th>
<th>TOTAL TRIP COST</th>
<th>BUSINESS</th>
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<th>BUS</th>
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TABLE 17
DIVISION OF TRAFFIC BETWEEN STOLPORTS IN TORONTO AND MONTREAL
(Value of time A, 300 mph, CTOL fares, 2 STOLports in Toronto and Montreal)

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TABLE 18
DIVISION OF TRAFFIC AMONG STOLPORTS IN TORONTO AND MONTREAL
(Value of time A, 300 mph, CTOL fares, 3 STOLports in Toronto and Montreal)

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</thead>
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<tr>
<td>Toronto</td>
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Figure 19: Average Total Trip Time
Figure 20: Average Total Trip Cost
Figure 21: Percent Increase in Stol Penetration of Existing Modes 500 MPH instead of 300 MPH
Figure 22: Percent Change in Stol Penetration of Existing Modes Due to 10% Increase in Stol Fares
VALUE OF TIME - CURVE A
300 MPH
CTOL FARES

PERCENT INCREASE IN STOL PENETRATION OF EXISTING MODES
THREE STOLPORTS IN TORONTO AND MONTREAL INSTEAD OF TWO

FIGURE 23

PERCENT CHANGE IN STOL PENETRATION OF EXISTING MODES
WITH NEW VALUE OF TIME CURVE
FIGURE 24
DOWNTOWN TO AIRPORT TRANSPORT MODEL

This model describes the Canadian airport access problem when STOL vehicles are employed. In the United States both helicopters and STOL aircraft have achieved some success in carrying passengers to and from airports as shown in Figure 25. If CTOL airports continue to be built further and further from cities, as is now happening in Canada, STOL air service will become increasingly attractive because of reduced airport access times. This section develops a preliminary model to predict the number of passengers using such a STOL service.

Two cases are reviewed—the new airports at Toronto and Montreal. These airports were chosen because they will be the largest and busiest in Canada and will therefore be prime candidates for STOL service. In addition the location of the new Montreal airport, and most likely that of the new Toronto airport, will make them inaccessible to passengers. Abundant survey information is available from Montreal International and Toronto International Airport studies. These survey data provide some essential information describing the characteristics of air travellers originating and terminating in the two areas.

The airline passenger can choose from several modes of transportation when he wishes to travel to the airport: usually the faster service is more expensive. Given the fares and travel times for STOL along with the average for ground access, the cost per hour saved by the STOL passenger can be determined. It is reasonable to assume that the traveller will take the faster mode if the cost per hour saved is less than or equal to his valuation of that time. Thus, the model is based on the Value of Time Method—the same technique used in the intercity route analysis. The reference set of value of time curves is adopted from the previous section. While the site of the new Montreal Airport is known to be Ste. Scholastique, that of the new Toronto International Airport is unknown, however there are indications that it will be located to the northwest of the city. For the purposes of the present study it was postulated to be located at Bolton which is about 32 road miles from downtown Toronto. While the STOL vehicle to be flown over these routes was not specified it was assumed capable of cruising at 300 mph.

Toronto-Bolton STOL Access

Table 19 indicates the passenger traffic that Montreal International Airport and Toronto International Airport handled in 1968 and 1969. Compared to CTOLports in the United States the traffic is not heavy (See Figure 26). However, it is about the same as in Houston where STOL vehicles operated by Houston Metro provide access. From an unpublished Master Plan Study, it is estimated that by 1980 the New Toronto International Airport will handle around 14.3 million passengers annually (assuming that there will be no intercity STOL service by that time).

A consequence of STOL operations is conceivably a reduction in air passengers using the International Airports.

A recent Toronto International Airport Passenger Survey (UTIAS Tech. Note No. 141, Aug. 1969) disclosed that close to 25% of enplaned and deplaned passengers were transferring to or from other airplanes. That is, only 75% would actually make use of the airport access facilities.

The Toronto airport serves many other cities and towns. This region encompasses an area of radius 50 miles centred at Toronto, including Barrie to the north, Kitchener to the west, Peterborough to the east and the Niagara Peninsula to the south. The survey data indicates that 30% of air passengers come from outside the metropolitan Toronto area. Thus in order to offer STOL service to these passengers, additional STOLports would have to be located in outlying areas. It was assumed that the Toronto region would be served by a network of STOLports, as is currently the case with Los Angeles. The locations of these STOLports are shown in Figure 27.

The origins and destination (O & D) of passengers using the present Toronto airport are readily available from the UTIAS passenger survey. To give a better picture of this distribution, Toronto is divided into twenty zones in Figure 28 (indicating the percentage of travellers generated by each zone). Twelve more zones are provided for the region surrounding Toronto. (See Figure 29.)

The ground access time and cost to the STOLports and CTOLport were computed as in the STOL intercity study. The STOL aircraft block times were based on a 300 mph cruising speed. The STOL fare was developed from a review of the rates charged by STOL and helicopter carriers serving airports in the U.S. (See Figure 30). In calculating the total access time when using STOL, an arbitrary 15 minutes is added to account for the average waiting time of the passengers at the STOLport. The actual value would probably be a function of the frequency of service. The percentage of passengers that might be diverted to STOL service is derived by the Value of Time Method. A comparison of access time and cost along with the percent penetration is tabulated in Table 20. It is observed that STOL traffic is generated in nine out of twenty zones inside Toronto.

Of the 14 STOLports originally included in
the analysis only five of them generate sufficient traffic to justify their use. These are the Lakeshore and Don Valley sites, and the ones located at St. Catharines, Oshawa and Kitchener. The latter three combine to yield a total of 1.02 percent penetration while the two STOLports inside Toronto produce 4.18 percent. In total, 5.2 percent of the local air passengers would use STOL. (See Table 21.) To assure a convenient service, the system must offer frequent flights. The schedules of the Houston Metro and New York Airways indicate that a desirable frequency of service requires a flight every half hour during the peak hours and every hour in the off-peak periods. (These times were used in the present study.)

Assuming that the service runs from 7 a.m. to 11 p.m. with peak periods between 7 and 9 a.m. and 3 and 7 p.m., twenty-three flights per day will be required from each site. Using this flight frequency and a load factor of 0.5, it is possible to arrive at a suitable vehicle size for a particular STOLport.

The frequency of service exerts an important influence upon the selection of STOL as an airport access service. The advantage of STOL in terms of time savings is nullified if the traveller must wait very long for a flight. The STOL share of the access market was calculated for a range of waiting times. An elasticity curve is presented in Figure 31 to demonstrate the change in traffic with waiting time. A 15 minute waiting time is typical during the peak period. From Figure 31 the desirability of high frequency of service is obvious since high frequency results in short waiting times. If there were no waiting time for STOL service, traffic would increase by a factor of 4. If the waiting time becomes more than half an hour, very few travellers will use this service.

It is possible to obtain an indication of the realism with which the model describes the penetration by comparison with figures actually achieved by U.S. carriers (Figures 25 and 26). It is possible to determine the percent penetration these carriers have achieved as a percent of the total airport traffic. Figure 32 shows that this reached between 2 and 22 percent for the STOL carriers (and for the helicopter carrier as well prior to the Los Angeles Airways accidents). To convert this number to a percent of the local passengers in order to apply the present analysis consider the 1969 data for Toronto (Table 19) as typical. The ratio of total passengers (arriving plus departing) to enplaned and deplaned passengers is 5.74 or 1.09 and the ratio of enplaned and deplaned passengers to local passengers is 100 or 1.33 (UTIAS TN-141). Thus the factor to be applied in Figure 32 to give the ratio of total passengers to local passengers is roughly 1.45. Thus the value of 2 to 2.2 percent of the total passengers becomes 2.9 to 3.6 percent of the local passengers. This is in reasonable agreement with the range of values determined by the model, bearing in mind the sensitivity of the result to a parameter which is difficult to quantify, "the waiting time".

### Montreal-St. Scholastique STOL Access

When the new Montreal Airport is built at Ste. Scholastique, travellers from downtown Montreal will be faced with a 33 mile drive to the airport instead of the current 12 mile drive (see Figure 33). Thus the prospect of flying from a downtown STOLport, or from the Montreal Nord STOLport (proposed in the earlier section on intercity and municipal feeder transport) becomes increasingly attractive.

The O & D's of passengers for the present Montreal airport are shown in Figure 34 as percentages for each of the 26 city zones. Table 22 contains a set of data comparing access time and cost by STOL with the average ground mode. In addition to the three STOLports listed above, others (see Figure 33) were also located in Sorel, Trois Rivieres, Sherbrooke and Drummondville based on the considerable traffic generated in these areas. The model predicts that for an average 15 minute waiting time 16.4 percent of the local passengers would select STOL access. (See Table 23.) This result is three times as high as that for Toronto. It can be seen from a comparison of Table 20 for Toronto with Table 22 for Montreal, that the cost of time saved tends to be substantially less in the downtown Montreal areas, resulting in greater penetrations. This follows from the shorter distances Montreal passengers would have to travel to reach a STOLport. Part of the effect however may be due to deficiencies in the data. While O & D data for Montreal proper are available some 30 percent of the air traffic was unaccounted for and was assumed to come from outside Montreal proper. Based on maps of the population around Montreal it was decided to allocate this traffic to regions of higher population density (six groups of about 5 percent). These zones are shown in Figure 35. STOLports at Drummondville, Trois Rivieres and Sherbrooke are very effective in penetrating this traffic. Further investigation should of course be conducted to improve the accuracy of locating the "missing" 30 percent of the traffic. (See Section 3.)

Table 23 indicates the percentage of travellers passing through each STOLport. The majority, 6.38 percent of the local air traffic, would use Expo, 3.93 percent would use Nord, and only 24 percent would use Dorval. Drummondville, Trois Rivieres and Sherbrooke together would generate
5.85 percent. Sorel did not attract any traffic.

It should be noted that these calculations ignore three factors:

(1) the penetration by an intercity STOL service into projected airport traffic

(2) the possibility of substantial CTOL traffic allocated to Dorval

(3) the existence of a high speed rail link to Ste. Scholastique.
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<th>COST ($)</th>
<th>PENETRATION</th>
<th>STOL AS % OF TOTAL TRAFFIC</th>
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<td>($)</td>
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<tr>
<td>14</td>
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<td>5.45</td>
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<td>0.73</td>
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</tr>
<tr>
<td>20</td>
<td>4.44</td>
<td>0.69</td>
<td>3.30</td>
<td>0.73</td>
<td>9.30</td>
</tr>
</tbody>
</table>

**NOTES:** Average ground access time and cost are based on data from, "The Demand For Intercity Passenger Transportation by VTOL Aircraft", N.J. Asher, E. Wetzer, S.M. Horowitz and W.B. Schneider. IDA report R-144, Aug. 1968.

Source: Dominion Bureau of Statistics
### TABLE 22

**MONTREAL–GTE, SCHOLASTIQUE STOL ACCESS**

<table>
<thead>
<tr>
<th>ZONE</th>
<th>% OF TOTAL</th>
<th>GROUND ACCESS</th>
<th>STOL ACCESS</th>
<th>% STOL AS % OF TOTAL TRAFFIC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>TIME</td>
<td>COST ($)</td>
<td>TIME</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(HR)</td>
<td>($)</td>
<td>(HR)</td>
</tr>
<tr>
<td>1</td>
<td>1.14</td>
<td>0.72</td>
<td>10.55</td>
<td>37</td>
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<td>2</td>
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<td>0.70</td>
<td>10.45</td>
<td>41</td>
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<tr>
<td>3</td>
<td>1.07</td>
<td>0.74</td>
<td>10.65</td>
<td>23</td>
</tr>
<tr>
<td>4</td>
<td>1.09</td>
<td>0.74</td>
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<td>29</td>
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<td>10.80</td>
<td>28</td>
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<tr>
<td>6</td>
<td>1.12</td>
<td>0.75</td>
<td>10.70</td>
<td>30</td>
</tr>
<tr>
<td>7</td>
<td>1.03</td>
<td>0.81</td>
<td>10.95</td>
<td>2</td>
</tr>
<tr>
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<td>0.98</td>
<td>0.78</td>
<td>10.25</td>
<td>1</td>
</tr>
<tr>
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<td>1.03</td>
<td>0.76</td>
<td>10.40</td>
<td>13</td>
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<td>0.69</td>
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<td>0.75</td>
<td>10.40</td>
<td>33</td>
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<tr>
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<td>1.07</td>
<td>0.84</td>
<td>11.10</td>
<td>3</td>
</tr>
<tr>
<td>13</td>
<td>0.95</td>
<td>0.72</td>
<td>10.00</td>
<td>6</td>
</tr>
<tr>
<td>14</td>
<td>0.88</td>
<td>0.76</td>
<td>10.20</td>
<td>0</td>
</tr>
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<td>0.95</td>
<td>0.71</td>
<td>10.20</td>
<td>6</td>
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<tr>
<td>16</td>
<td>1.03</td>
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<td>10.25</td>
<td>20</td>
</tr>
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<tr>
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<td>0.76</td>
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<td>10.70</td>
<td>0</td>
</tr>
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<td>10.85</td>
<td>0</td>
</tr>
<tr>
<td>25</td>
<td>0.96</td>
<td>0.84</td>
<td>10.85</td>
<td>0</td>
</tr>
<tr>
<td>26</td>
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<td>0.82</td>
<td>11.05</td>
<td>10</td>
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<tr>
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<td>0.82</td>
<td>11.05</td>
<td>41</td>
</tr>
<tr>
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<td>10.40</td>
<td>0</td>
</tr>
<tr>
<td>102</td>
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<td>0</td>
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<tr>
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<td>12.20</td>
<td>0</td>
</tr>
<tr>
<td>104</td>
<td>0.72</td>
<td>0.83</td>
<td>14.00</td>
<td>37</td>
</tr>
<tr>
<td>105</td>
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<td>0.80</td>
<td>14.40</td>
<td>28</td>
</tr>
<tr>
<td>106</td>
<td>2.10</td>
<td>0.85</td>
<td>15.90</td>
<td>50</td>
</tr>
</tbody>
</table>

**NOTE:** Average ground access time and cost are based on data from IDA report N-144.

### TABLE 21

**STOL ACCESS TO A NEW TORONTO AIRPORT LOCATED AT BOLTON**

<table>
<thead>
<tr>
<th>STOLPORT</th>
<th>% OF LOCAL AIR PASSENGERS CARRIED BY STOL THROUGH THE STOLPORT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lakeshore</td>
<td>2.46</td>
</tr>
<tr>
<td>Don Valley</td>
<td>1.72</td>
</tr>
<tr>
<td>St. Catharines</td>
<td>.76</td>
</tr>
<tr>
<td>Oshawa</td>
<td>.05</td>
</tr>
<tr>
<td>Kitchener</td>
<td>.02</td>
</tr>
<tr>
<td>TOTAL</td>
<td>5.21</td>
</tr>
</tbody>
</table>
### TABLE 23

STOL ACCESS TO A MONTREAL AIRPORT LOCATED AT STE. SCHOLASTIQUE

<table>
<thead>
<tr>
<th>STOLPORT</th>
<th>% OF LOCAL AIR PASSENGERS CARRIED BY STOL THROUGH THE STOLPORT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expo</td>
<td>6.38</td>
</tr>
<tr>
<td>Dorval</td>
<td>0.24</td>
</tr>
<tr>
<td>Nord</td>
<td>3.93</td>
</tr>
<tr>
<td>Drummondville</td>
<td>1.42</td>
</tr>
<tr>
<td>Trois Rivières</td>
<td>1.89</td>
</tr>
<tr>
<td>Sherbrooke</td>
<td>2.54</td>
</tr>
<tr>
<td>TOTAL</td>
<td>16.40</td>
</tr>
</tbody>
</table>
ZONES OUTSIDE MONTREAL AIRPORT ACCESS CALCULATION

FIGURE 33

CTOL AIRPORTS AND PROPOSED STOLPORTS FOR MONTREAL REGION

FIGURE 33

PERCENT DISTRIBUTION OF CTOL PASSENGERS

FIGURE 34
It was not found possible in the time available to construct a meaningful model of a regional transport operation linking smaller population centres. An alternate approach was adopted: company officers of two Canadian regional carriers who have provided services of this nature were interviewed. The comments below are interpretations and assessments of the remarks of these officers.

In linking small communities the basic problem is that they do not generate sufficient traffic to permit a successful air service. This is due both to their small size and to their generally low level of economic activity. Indeed "small population centres" can be defined in the present context as centres that do not receive airline service. This situation is not peculiar to STOL; every airline faces it on low density routes. Consider the representative service shown in Figure 36. Three small towns (located between two larger communities) are to be linked. Normally an aircraft would leave one major city, stop at A, B and C in turn, and finally end up at another major city. For this type of service the traffic linking A, B and C would be small compared to the traffic from A, B, or C to either of the major cities. Furthermore the time taken in stopping at A, B and C reduces the speed and convenience of air travel and makes it less competitive with ground modes.

A standard technique for improving such a service to the mutual benefit of the airline and a majority of passengers is to develop a regional airport at one point, say B, most convenient to the greatest number of travellers. In this way station costs and stopping costs are reduced, the competitive position of air is improved, and the majority of travellers experience faster trips because of fewer stops. With this technique the system is transformed into the municipal feeder type of operation previously discussed.

An additional consideration bears on a carrier when selecting the points to serve: return on investment. In serving small communities revenues tend to be out of proportion to the investment required due to the small number of passengers. Thus a carrier would seek to minimize his investment in keeping with the low revenue and high risk involved. There are two ways in which this can be achieved, by using older aircraft, or by scheduling existing aircraft during slack periods. Airlines, with the aid of these devices, are able to serve smaller communities than would normally be considered for air service.

The foregoing discussion indicates that the problem is one of degree. The method of achieving service between smaller communities is understood: develop an airline able to operate at lower traffic densities than those presently in existence -- as for example have the commuter airlines in the United States. This type of operation is just now beginning to develop in Canada. The basic objective is to reduce both indirect and direct operating costs, relating investment to the revenues attainable. This generally implies the application of a used aircraft to initiate the service with a minimum of risk followed by a move to a newer but small vehicle once sufficient traffic has been established. Like the larger airlines, the regional operator has to balance the air travel advantages of speed, frequency of service and convenience against the cost of achieving them, but in the context of lower traffic densities. In the case of indirect costs, the level of customer services must be related to what is essential to attract passengers. In this manner viable air services can be extended to smaller population centres.
A TYPICAL SERVICE FOR SMALL TOWNS

FIGURE 36
The following simple model, based on a review of northern operations, describes the relative preference for STOL and CTOL operations in the Canadian North. For a given state of technology STOL aircraft will be more expensive to operate than CTOL aircraft in an uncongested environment; however, the cost of building airfields is less for STOL than for CTOL. These expenses are the two main elements used by the proposed model which minimizes the sum of aircraft and airfield costs in selecting the preferred vehicle for a particular operation. It is shown that the choice of the most economical system depends on the ratio of STOL aircraft operating costs to CTOL, the ratio of STOL airfield costs to CTOL, the amount of cargo and passengers flown into and out of the airfield, and the distance of the site served from the nearest main distribution centre.

It should be noted that this is a tentative model aimed at developing the logic and methodology. Specific applications and further development require the collection of additional data not available within the time allocated to this study.

Background Information

Air operations in the north focus on a number of main distribution points such as Frobisher, Churchill, Resolute, Yellowknife, Inuvik and Whitehorse. Access to these distribution centres from southern Canada is at present provided by CP Air, Nordair, Transair and Pacific Western Airlines. Figure 37 (from "Air Transport in the Developing North", J. Courtney, Canadian Transport Commission) illustrates this situation. This particular pattern of northern access has evolved in response to political and economic incentives in a manner described by K. Peiffer of Nordair, ("Air Transportation to and within the Arctic", K. Peiffer, Canadian Transportation Research Forum Annual Meeting, Winnipeg, Manitoba, May 1970). Passengers and cargo must also be carried from these major distribution points to their ultimate destinations. (Figure 37 illustrates several existing routes of this type as well) and it is this aspect of northern operations that has the greatest potential for STOL operations. The scope of air activities and their present growth may be judged from the traffic data in Table 24 (obtained from a preliminary draft of a study of northern traffic carried out by the Canadian Transport Commission). It can be seen that air activities are generated by a range of scheduled and charter services, oil and mining operations, and governmental activities. From the last nine months of 1968 to the first nine months of 1969 overall traffic has increased by 55 percent for freight, and 7 percent for passengers. Most of this growth occurred on scheduled operations and oil company and territorial government activities. At the moment these operations utilize the existing network of airfields in the north. Figure 38 indicates that these airfields are generally of significant length: only 6 of the 58 listed being 2000 feet or less. The present model attempts to describe whether, as a result of the demand for new service to a point, it would be more economical to provide this service with STOL aircraft and STOLports or with CTOL aircraft and conventional airfields.

Model Development

Consider the sketch of Figure 39, showing a site requiring air service. This site is to be linked to an existing distribution centre a distance d away. The annual requirement in terms of equivalent cargo tonnage and passengers (1 passenger = 200 lbs.) is known or can be estimated. The site does not have an existing airfield so that one must be constructed. The model must determine whether CTOL or STOL aircraft could provide the specified service at the minimum cost when both the cost of the aircraft and the cost of the airfield are included. The model may be formulated as -

\[
\text{Cost of Service to a Site} = \text{Aircraft Costs} + \text{Airfield Costs}
\]

In writing an equation of this nature it must be remembered that often aircraft costs are borne by the operator, whereas airfield costs are borne by the government. Therefore from the point of view of an operator the optimum solution is to select a vehicle which minimizes aircraft costs and to have the airport authorities construct an airfield to suit it: a traditional approach in the industry. Requiring the total cost to be minimized implies a more coordinated effort in aviation development policy and planning. These cost elements will be discussed in more detail prior to incorporating them into the model.

Aircraft Costs

A major element in the model is the cost of the aircraft needed to carry the specified annual tonnage the required distance. In general, the construction of a submodel describing aircraft costs is a standard procedure and will not be developed in this study. Rather, typical values of the results of such a submodel will be assumed to illustrate their use. Figure 40, for instance, shows operating costs for a typical turboprop CTOL aircraft ("The First 650,000 Flying Hours", A. J. Troughton and P. Bradshaw. Hawker-Siddeley Technical Review, Vol. 5, No. 3, 1970). It should be noted that while the costs reported for this vehicle in Canadian service tend to be somewhat higher than those...
shown in Figure 40, our primary concern at this stage is with the difference between STOL and CTOL operating costs. This cost difference depends on the particular operator since it involves pilot contracts, his present fleet mix and whether vehicles of that particular type already exist in the fleet or are in use at a nearby location. In addition, the availability and cost of financing varies from vehicle to vehicle. Thus detailed development of the model should consider these and other parameters in greater depth.

To illustrate the application of the model without evolving detailed aircraft design and cost comparisons, it was decided to assume an arbitrary direct operating cost (DOC) increase for STOL aircraft over CTOL. Figure 41 illustrates a typical estimate for the cost increase of STOL over CTOL. On very short stages, up to 100 miles, small savings in taxi and manoeuvring time by STOL tend to equalize costs, but as the stage length increases STOL DOC's rise above those for CTOL. A DOC increase of 10 percent at 250 miles is typical. Eastern Airlines' assessment of jet STOL aircraft indicates an 18 percent increase in DOC's on a 500 mile stage ("V/STOL's for the Airlines", S. M. Levin, Space/Aeronautics, May 1970).

The typical turboprop CTOL costs of Figure 40 and the assumed STOL to CTOL cost ratio of Figure 41 permit the calculation of the relative cost of moving a ton payload a given distance (cargo costs are based on the assumption that it costs as much to move 200 lbs. of cargo as it does to move one passenger). The results of this calculation, shown in Figure 42, are based on a 0.6 load factor.

**Airfield Costs**

Airfield costs used in developing the model must be assumed due to a scarcity of data. Although the values used were checked against whatever data were available, insufficient detailed cost information was available to draw firm conclusions from the model calculations.

It is known that the construction of a number of 3000 foot airstrips in the north cost approximately $600,000 to $1,000,000 each. The exact elements making up this cost, and the variation of cost with field length cannot presently be generalized.

Studies of STOL and CTOL aircraft in the military environment do, however, provide an indication of the relative cost of STOL and CTOL strips. Figure 43 ("The Influence of Airfield Costs on Supply System Economics", the de Havilland Aircraft of Canada Ltd., DHC 66-7, April 1966) shows the rates at which military construction units can build STOL and CTOL airstrips in various types of terrain, ranging from a terrain index of 1 where construction is easy, to a terrain index of 5 where construction is very difficult. These differences arise largely from surface strength requirements resulting from the higher wheel loadings and tire pressures of CTOL aircraft. The construction ratios which can vary from 4:1 in easy terrain to 20:1 in difficult terrain, become cost ratios when the relative areas of the two types of strips are considered. Assuming a STOL strip to be 2000 feet by 100 feet, and a CTOL strip to be 4000 feet by 100 feet, the cost ratios range from 8:1 to 40:1 as a function of terrain.

Additional data are available from Norwegian experience with both STOL and CTOL strips. It is reported that a standard Norwegian STOLport fully equipped with a terminal etc. cost 7 to 8 million Kroner (approximately 1 million dollars). A comparable CTOL airport costs about 45 million Kroner (approximately 6 million dollars) a ratio of 6 to 1.

For the purposes of this analysis it was therefore decided to assume that a 3000 foot CTOL strip costs one million dollars, and that the construction cost for a CTOL strip was either 3 or 6 times that for a STOL strip. With these assumptions the relative airfield costs of Table 25 were derived.

In order to make airfield costs compatible with aircraft costs it was necessary to write off the cost of the airfield over the annual tonnage carried through it. It was assumed that the airfield depreciates over a 25 year period, and that annual operating costs are 10 percent of the annual capital cost.

**Application of the Model**

Combining the aircraft and airfield cost data results in the system costs shown in Tables 26, 27, and 28. From these it is possible to determine whether a CTOL or a STOL system would give a lower total cost for carrying a specified tonnage over a particular distance. Several observations may be made on the basis of the data in the tables.

1. For low tonnages and short distances airfield costs are far higher than aircraft costs and hence the most economical solution is to select the vehicle which minimizes airfield costs: STOL.

2. For high tonnages and long stages aircraft costs are far higher than airfield costs and hence the most economical solution is to select the vehicle minimizing aircraft costs: CTOL.
3. For intermediate values of tonnage and distance combinations of tonnage and distance where STOL and CTOL system costs are equal exist. These values may be used to define areas of preference for STOL and CTOL in terms of tonnage and distance. Figure 44 for example plots the total cost of carrying 1000 tons annually against trip distance for the case where CTOL airfields cost three times as much as STOL airfields: for trips of less than 700 miles a STOL system is cheaper, whereas for trips greater than 700 miles a CTOL system is cheaper. Repeating the plot for various tonnages permits identification of the areas of preference shown in Figure 45.

4. Figure 45 indicates that the regions of preference for STOL and CTOL vehicles are not sensitive to the ratio CTOL to STOL airfield cost over the range of values considered. This is largely due to the fact that STOL airfield costs tend to be a relatively small portion of the total STOL costs at tonnages and ranges where STOL and CTOL system costs are equal.

5. For very low tonnages and distances costs for either STOL or CTOL systems would be prohibitive. This model could also be developed to define areas of preference for floatplanes and helicopters for these combinations of tonnage and distance.

The preceding comments are only valid, of course, to the extent that the assumed model input values are representative. It is felt, however, that they do indicate that the model does describe some of the prime parameters affecting the cost of air operations in the north, and that development of this model would lead to a clearer definition of the preferred areas for STOL and CTOL vehicles.

Some data are available to indicate the range of values of tonnage and distance likely to occur in northern operations. The distribution of route lengths plotted in Figure 46 for example is taken from K. Peiffer's paper on Arctic air transportation. The trip distances shown are for the more heavily travelled northern routes. The greatest number of these are less than 700 miles in length, again placing emphasis on short stage lengths.

To offset this emphasis on short stage lengths, it is important to remember that the weather and terrain are hostile in the north, navigation aids are few, and there tend to be few alternate airfields. The cost of transporting and storing fuel makes it desirable to fly several route segments on a single refuelling. Thus while there are many short stages, a long range capability is very advantageous for northern operations.

Selected values of tonnages carried to northern sites were obtained from J. Courtney of the CTC to illustrate the magnitudes of interest. Table 29 lists typical tonnages carried in the summer of 1969. It is believed that these constitute approximately two thirds of the annual tonnage and that for cargo operations back hauls constitute about an additional 10 percent, whereas passenger flows are about equal in both directions. Table 29 indicates that generally low tonnages are carried; in the range of tens, hundreds, and thousands of tons.
### TABLE 24

**TOTAL TONNAGE CARRIED ON NORTHERN OPERATIONS**

<table>
<thead>
<tr>
<th>FREIGHT</th>
<th>PASSENGERS</th>
<th>FREIGHT</th>
<th>PASSENGERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>(tons)</td>
<td>(thousands)</td>
<td>(tons)</td>
<td>(thousands)</td>
</tr>
<tr>
<td>Scheduled</td>
<td>9,380</td>
<td>250.</td>
<td>13,400</td>
</tr>
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<td>General Charter</td>
<td>750</td>
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<td>520</td>
</tr>
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<td>Private Companies</td>
<td>2,450</td>
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<tr>
<td>Oil Companies</td>
<td>4,840</td>
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</tr>
<tr>
<td>Mining Companies</td>
<td>4,470</td>
<td>10.2</td>
<td>3,540</td>
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<td>Div Line Resupply</td>
<td>6,990</td>
<td>13.1</td>
<td>7,560</td>
</tr>
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<td>Telecommunications</td>
<td>15</td>
<td>1.4</td>
<td>50</td>
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<td>Tourism</td>
<td>420</td>
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<td>585</td>
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<td>Federal Govt.</td>
<td>2,610</td>
<td>16.7</td>
<td>1,780</td>
</tr>
<tr>
<td>Territorial and Provincial Govt.</td>
<td>95</td>
<td>2.7</td>
<td>756</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>31,580</strong></td>
<td><strong>337.6</strong></td>
<td><strong>40,021</strong></td>
</tr>
</tbody>
</table>

RATIO 1969/1968 (nine months) | 1.55 | 1.07 |

---

### TABLE 25

**AIRFIELD COSTS**

(Base on a reference cost of $1,000,000 for a 3,000' CTOL airfield)

<table>
<thead>
<tr>
<th>TYPE</th>
<th>CTOL</th>
<th>STOL</th>
<th>STOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>4,000'</td>
<td>2,000'</td>
<td>2,000'</td>
</tr>
<tr>
<td>Ratio of CTOL/STOL costs</td>
<td>6:1</td>
<td>3:1</td>
<td></td>
</tr>
<tr>
<td>Capital cost</td>
<td>$1,333,000</td>
<td>$222,000</td>
<td>$444,000</td>
</tr>
<tr>
<td>Capital cost per year over 25 years</td>
<td>$53,300</td>
<td>$8,900</td>
<td>$17,800</td>
</tr>
<tr>
<td>Operating cost of 10% of annual capital cost</td>
<td>$5,300</td>
<td>$900</td>
<td>$1,800</td>
</tr>
<tr>
<td>Total cost per year</td>
<td>$58,600</td>
<td>$9,800</td>
<td>$19,600</td>
</tr>
<tr>
<td>Total cost per annual tonnage</td>
<td>$58,600</td>
<td>$9,800</td>
<td>$19,600</td>
</tr>
</tbody>
</table>

Annual tonnage | Annual tonnage | Annual tonnage
### TABLE 26

COST PER TON FOR CTOL AIRCRAFT AND AIRFIELD

<table>
<thead>
<tr>
<th>Trip Distance Nautical Miles</th>
<th>200</th>
<th>500</th>
<th>700</th>
<th>1,100</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aircraft Cost $/ton</strong></td>
<td>70</td>
<td>125</td>
<td>205</td>
<td>416</td>
</tr>
<tr>
<td><strong>Airfield Cost $/ton</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 tons/year</td>
<td>5,860</td>
<td>5,860</td>
<td>5,860</td>
<td>5,860</td>
</tr>
<tr>
<td>50 tons/year</td>
<td>1,172</td>
<td>1,172</td>
<td>1,172</td>
<td>1,172</td>
</tr>
<tr>
<td>100 tons/year</td>
<td>586</td>
<td>586</td>
<td>586</td>
<td>586</td>
</tr>
<tr>
<td>500 tons/year</td>
<td>117</td>
<td>117</td>
<td>117</td>
<td>117</td>
</tr>
<tr>
<td>1,000 tons/year</td>
<td>59</td>
<td>59</td>
<td>59</td>
<td>59</td>
</tr>
<tr>
<td>5,000 tons/year</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>10,000 tons/year</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td><strong>Total Cost $/ton</strong></td>
<td>5,930</td>
<td>5,930</td>
<td>6,065</td>
<td>6,278</td>
</tr>
</tbody>
</table>

### TABLE 27

COST PER TON FOR STOL AIRCRAFT AND AIRFIELD

<table>
<thead>
<tr>
<th>Trip Distance Nautical Miles</th>
<th>200</th>
<th>500</th>
<th>700</th>
<th>1,100</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aircraft Cost $/ton</strong></td>
<td>80</td>
<td>145</td>
<td>245</td>
<td>515</td>
</tr>
<tr>
<td><strong>Airfield Cost $/ton</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 tons/year</td>
<td>980</td>
<td>980</td>
<td>980</td>
<td>980</td>
</tr>
<tr>
<td>50 tons/year</td>
<td>196</td>
<td>196</td>
<td>196</td>
<td>196</td>
</tr>
<tr>
<td>100 tons/year</td>
<td>98</td>
<td>98</td>
<td>98</td>
<td>98</td>
</tr>
<tr>
<td>500 tons/year</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>1,000 tons/year</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>5,000 tons/year</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>10,000 tons/year</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total Cost $/ton</strong></td>
<td>1,060</td>
<td>1,125</td>
<td>1,225</td>
<td>1,495</td>
</tr>
</tbody>
</table>
TABLE 28

COST PER TON FOR STOL AIRCRAFT AND AIRFIELD

(Steady STOL airport 1/3 of CTO)

<table>
<thead>
<tr>
<th>TRIP DISTANCE NAUTICAL MILES</th>
<th>200</th>
<th>400</th>
<th>700</th>
<th>1,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIRCRAFT COST $/ton</td>
<td>20</td>
<td>115</td>
<td>245</td>
<td>515</td>
</tr>
<tr>
<td>AIRFIELD COST $/ton</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 tons/year</td>
<td>1,060</td>
<td>1,060</td>
<td>1,060</td>
<td>1,060</td>
</tr>
<tr>
<td>50 tons/year</td>
<td>392</td>
<td>392</td>
<td>392</td>
<td>392</td>
</tr>
<tr>
<td>100 tons/year</td>
<td>196</td>
<td>196</td>
<td>196</td>
<td>196</td>
</tr>
<tr>
<td>500 tons/year</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td>39</td>
</tr>
<tr>
<td>1,000 tons/year</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>5,000 tons/year</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>10,000 tons/year</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>TOTAL COST $/ton</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 tons/year</td>
<td>2,040</td>
<td>2,105</td>
<td>2,205</td>
<td>2,475</td>
</tr>
<tr>
<td>50 tons/year</td>
<td>472</td>
<td>537</td>
<td>637</td>
<td>907</td>
</tr>
<tr>
<td>100 tons/year</td>
<td>276</td>
<td>311</td>
<td>441</td>
<td>711</td>
</tr>
<tr>
<td>500 tons/year</td>
<td>119</td>
<td>184</td>
<td>284</td>
<td>554</td>
</tr>
<tr>
<td>1,000 tons/year</td>
<td>100</td>
<td>165</td>
<td>265</td>
<td>535</td>
</tr>
<tr>
<td>5,000 tons/year</td>
<td>84</td>
<td>149</td>
<td>249</td>
<td>519</td>
</tr>
<tr>
<td>10,000 tons/year</td>
<td>82</td>
<td>147</td>
<td>247</td>
<td>517</td>
</tr>
</tbody>
</table>

TABLE 29

TYPICAL TONNAGES CARRIED TO NORTHERN AIRFIELDS FROM APRIL 1 TO SEPTEMBER 30, 1969

FROM RESOLUTES AND YELCKWITE OIL EXPLORATION ACTIVITY

<table>
<thead>
<tr>
<th>TO FLIGHTS</th>
<th>FREIGHT TONS INTO SITE</th>
<th>PASSENGERS INTO SITE</th>
<th>EQUIVALENT TONNAGE INTO SITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rae Point</td>
<td>164</td>
<td>1,360</td>
<td>419</td>
</tr>
<tr>
<td>Sandy Point</td>
<td>44</td>
<td>657</td>
<td>84</td>
</tr>
<tr>
<td>Sherard Bay</td>
<td>60</td>
<td>529</td>
<td>127</td>
</tr>
</tbody>
</table>

FROM RESOLUTES TO ESKIMOS COMMUNITIES

<table>
<thead>
<tr>
<th>TO FLIGHTS</th>
<th>FREIGHT TONS INTO SITE</th>
<th>PASSENGERS INTO SITE</th>
<th>EQUIVALENT TONNAGE INTO SITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cape Dorset</td>
<td>80</td>
<td>36</td>
<td>449</td>
</tr>
<tr>
<td>Pangirmung</td>
<td>99</td>
<td>72</td>
<td>599</td>
</tr>
<tr>
<td>Lake Harbour</td>
<td>34</td>
<td>8</td>
<td>65</td>
</tr>
</tbody>
</table>

*Considers 1 passenger = 200 lb = .1 ton
LEVEL OF SERVICE EQUIVALENT TO A STATED ANNUAL TONNAGE

FIGURE 37

TYPICAL COMMERCIAL AIR SERVICES - NORTHERN CANADA

FIGURE 38

TOTAL OF 50 AIRFIELDS LISTED & HAVE LENGTHS OF 2000 FEET OR LESS

FIGURE 39

DISTRIBUTION OF AIRFIELD LENGTHS IN THE NORTHWEST TERRITORIES

FIGURE 40

TYPICAL TURBOPROP CTO OPERATING COSTS

FIGURE 41

SOURCE: AIRPORT DIRECTORY, CANADIAN AVIATION, APRIL, 1970
**Figure 41**

Assumed DOC Increase for STOL over CTOL

**Figure 42**

Comparative Aircraft Cost per Ton

**Figure 43**

Construction Effort

**Figure 44**

STOL Airfield Cost vs. CTOL Airfield Cost
AREAS OF PREFERENCE FOR STOL AND CTOL

FIGURE 45

NUMBER OF ROUTES OF A GIVEN DISTANCE AMONG THE MOST HEAVILY TRAVELLED ARCTIC ROUTES

FIGURE 46
2. ASSESSMENT OF STOL IMPEDANCES

INTRODUCTION

In this section technological and other impedances hindering the introduction of viable Canadian STOL Transportation Systems are identified and analyzed. Although the material of this section suggests some possible ameliorative measures and research and development areas, detailed recommendations are contained in Section 3.

This section is divided into five subsections corresponding to the five main study areas: Vehicle Design and Performance; Operational Aspects; Navigation, Guidance and Air Traffic Control; Non-Passenger Public Acceptance; and STOLports. Each subsection was initially written by the study specialist responsible for the particular subject area (see General Introduction); subsequent editorial changes incorporated input from other study personnel.

2.1 VEHICLE DESIGN AND PERFORMANCE

INTRODUCTION

In this section impedances to the design and performance of STOL vehicles are analyzed. From a practical point of view STOL performance can be defined as the ability to operate from a runway of about 2,000 feet in length with a payload suited to the market, with a level of safety equal to or better than that of present transport aircraft, and with operating costs that make the system attractive to airlines. Within this description are included vehicles employing light wing loadings (less than 50 lb./ft.²) and those employing powered lift to achieve STOL performance. It must be emphasized that under the present regulations for certification, lift derived in whole or in part from the powerplant cannot be used in the calculation of vehicle performance. Nevertheless, aerodynamic lift derived in part from the engines is the basis of most STOL design concepts. This is based on the belief that a set of regulations governing powered lift transports is forthcoming in the near future.

GENERAL ANALYSIS

Study of the literature and the personal interviews failed to indicate any major technological impedances to the initiation of STOL service in the 70's based on design and performance considerations, provided that such service is begun with turboprop transports of approximately fifty passenger capacity. It appears that both the de Havilland DHC-7, with its light wing loading of 43 lb./ft.² and the deflected slipstream Breguet 941 could well be operational within three years. At the same time it is recognized that this class of vehicle will be the first generation and as such does not embody all the desired characteristics of STOL transports. It is anticipated that these or similar vehicles will be capable of meeting the low noise level requirement for operations near populated areas, but at present this is difficult to assess since the level of public tolerance for such a service is as yet unknown. (See Section 2.4.)

The limitations of this class of vehicle, while they might not prevent production, could reduce the aircraft's market potential. In particular, the light wing loading can result in poor gust response affecting both the pilot's ability to control the vehicle and the passenger's riding comfort. Turboprop powerplants in conjunction with these light wing loadings result in low cruising speeds by today's standards. While this would be relatively insignificant in the downtown to airport application, and of marginal significance in the municipal feeder and regional service, it remains as a minor impedance to intercity and northern route applications. Finally, the image of propeller aircraft, as somewhat outdated vehicles when compared to jets, may result in a diminished passenger appeal.

It must be emphasized, however, that the importance of these characteristics is not fully understood and that their impact on the market potential of STOL will depend to a great extent on the actual aircraft design and the method of operation. Also, the implications of noise factors, riding qualities, airspeed and their trade-off against the convenience of short access/egress times are not yet fully understood.

In considering the technical development of STOL aircraft from the presently envisaged first generation through the following stages of growth with higher cruising speeds, higher wing loadings, turbofan propulsion and increased payloads, several areas of technical difficulty appear. While these impedances are not expected to prevent the timely implementation of the first generation vehicles, some of them will no doubt receive attention in the construction and testing
of the first production model. The problems anticipated with the larger second generation of STOL vehicles generally arise as a result of the added sophistication required to match the takeoff and landing performance of the small first generation aircraft. In addition, it is almost certain that the initial Canadian STOL application will not involve elevated STOLports. The service will likely begin with grade-level runways, evolving to elevated STOLports if the need arises. Again, this favours the initial application by postponing the added problems of runway barriers and sideline crash shielding.

When the five Canadian route applications are considered, the distinguishing characteristics from the design and performance standpoint are the possibilities of varying noise sensitivity, varying runway surface treatment, and the need for different cabin layouts. The possibility of gravel runways must be considered for the northern and regional services. However, in the light of the successful operation of the Boeing 737 from gravel strips in the Canadian North, it appears that such runways will pose no problem to STOL aircraft. The reduced noise sensitivity may exist on the northern and regional routes and on intercity operations from the perimeter areas of existing jet airports. At the same time, cabin design could possibly be more spartan in the bus-like atmosphere of the downtown to airport route. Perhaps on the longer intercity and northern routes cabin design and service would have to be up to present jet in-flight standards.

It must be reiterated that the design and performance impediments discussed below are not expected to hinder the implementation of a first generation small turboprop STOL vehicle but are likely to present some difficulty in the design of larger second generation aircraft. Naturally, a few of these problems will have to be faced by the manufacturer of the first generation vehicle: they should, however, pose no greater problem than is usually encountered in the production of a new aircraft design.

AERODYNAMICS/HIGH LIFT DEVICES

Short field performance can be achieved through the use of light wing loadings and/or powered lift. In general, the lift produced by STOL aircraft can be divided into three components:

(1) Lift available when the thrust is zero.

(2) Lift derived by deflecting the propulsive stream.

(3) Lift derived from the flow augmentation effect which arises from the propulsive stream drawing additional air over the wing through a viscous mixing phenomenon.

As mentioned above, light wing loadings can result in undesirable gust response and poor riding qualities. The effects of this are reduced by ensuring that the vehicle has sufficient control power to allow the pilot to correct immediately following a gust input. If it should be deemed necessary, it is possible to develop an automatic gust alleviation system based on the use of spoilers to cancel the lift response generated by the gusts.

Examples of powered lift include:

(1) Deflected propeller slipstream.

(2) Externally blown flaps (turbofan).

(3) Boundary layer control.

(4) Rotating cylinder flaps.

(5) Jet flaps.

(6) Augmentor wing.

(7) Tilt wing.

The use of powered lift results in STOL performance by producing large lift coefficients at low forward speeds. This is achieved by using high energy air from the powerplants to delay the onset of stall, allowing the wings to operate at large angles of attack.

The deflected slipstream concept, as used on the Breguet 941, is well developed. Problems of longitudinal pitch trim changes with thrust level can be overcome through linking the throttle and elevator. This technique also serves to reduce the pilot workload during the approach and landing maneuvre. Little development would be required to produce a STOL transport based on this concept. See Figure 47.

Externally blown flap systems have been tested in wind tunnels. This is one of the least complicated powered lift systems based on turbofan engines because no ducting is required: the engine exhaust is simply allowed to impinge upon a slotted flap system. The main technical problem is the fabrication of a flap system that will withstand the fluctuating loads induced by the high speed, hot turbofan exhaust. Some difficulty may also be experienced in the design of an exhaust nozzle that adequately immerses the flaps in the flow. See Figure 48.

Boundary layer control is achieved by energizing the boundary layer of the wing in the region where separation tends to occur. This retards the onset of stall,
allowing the wing to operate with a large lift coefficient. The most successful technique employs high energy bleed air from the jet powerplants blowing over the leading edge of the flap. This air must be directed to the flap by a set of ducts within the wing structure. This system has been successfully flown on an experimental STOL version of the Hercules C-130 military transport by employing auxiliary jet engines to supply the blowing air. See Figure 49.

The rotating cylinder flap involves a mechanically driven cylinder built into the wing structure. The cylinder is rotated such that its exposed surface is moving in the direction of the air flow at the leading edge of the flap. Viscous effects result in the energizing of the boundary layer in this critical region in much the same manner as the boundary layer control outlined above. No manufacturer appears to be seriously considering this design, presumably because of its mechanical complexity. See Figure 50.

The jet flap is an example of a system deriving additional lift through flow augmentation effects. Here a fairly large amount (roughly 10% of the engine mass flow) of high speed engine bleed air is passed over the upper surface of the flap system. It is seen that this technique provides boundary layer control at the same time. The development of efficient ducting systems which will fit within the confines of a wing is a necessary step that must be achieved if the jet flap is to be economically viable. In addition, the high bypass ratio turbofans that are presently envisaged have low fan pressure ratios resulting in the need for larger diameter bleed air ducting, which is at odds with the need to contain these ducts inside a relatively thin wing. From an aerodynamic standpoint, it is reported that the stalling characteristics of the jet flap need further study and that a large nose down pitching moment is associated with the achievement of high lift. See Figure 51.

The augmentor wing operates in much the same fashion as the jet flap but does not suffer from a large nose down pitching moment. This performance is achieved at the expense of a more complex flap system. In addition it utilizes approximately 33% of the turbofan mass flow. Since this bleed air is taken from the fan it results in an engine exhaust not much different from that of a turbojet since little fan air remains to mix with the primary jet exhaust. This results in increased engine noise levels. The large bleed air mass flow coupled with the possibility of low fan pressure ratios compounds the ducting problems mentioned in connection with the jet flap. The development of a quiet augmentor wing appears to depend on the production of a turbofan engine specifically for this application, with perhaps more than a single fan stage. The U.S. Air Force is currently modifying a de Havilland Buffalo in order to study this powered lift concept. See Figure 52.

The tilt-wing concept has been proven in flight by the Canadair CL-84 and the LTV XC-142. Here the complete wing/turboprop system is rotated with respect to the fuselage, directing the thrust downward. When operated in the STOL mode no major problems are evident. However, studies by Canadair indicate that this technique is most competitive at runway lengths below 1500 feet. This would tend to rule out its application on the presently envisaged STOL routes. See Figure 53.

The theoretical value of maximum lift coefficient depends upon the thrust levels assumed for the powerplants. The chart in Figure 54 indicates typical values of lift coefficient for several types of high lift device (from "Control Requirements Affecting STOLs", R. E. Kuhn and A. D. Hammond, Astronautics and Aeronautics, May 1965).

These possible values of lift coefficient are limited to considerably lower levels in practice when allowances are included to cover safety margins and engine failure. Figure 55 illustrates the implication of these restrictions (from "VTOL and STOL Technology in Review", the Staff of NASA Langley Research Center, Astronautics and Aeronautics, Sept. 1968). This indicates that the maximum usable lift coefficient for light wing loading STOL is 2 and that for powered lift STOL is 4. The relationship between approach speed and wing loading is also illustrated.

**PROPELLION SYSTEMS**

The basic problem is to produce a quiet propulsion system with the required thrust characteristics that is at the same time economically viable. It appears that the lowest noise level that can presently be achieved is 95 PNDB at 500 feet (claimed for the DHC-7). To achieve this level with larger turboprop vehicles or with turbofan engines is beyond the present state-of-the-art. However, Hamilton Standard feels that a reduction in propeller perceived noise level of the order of 25-30 dB should be realized in the time period 1975-80. Tables 30 and 31 prepared by Hamilton Standard indicate the anticipated improvement based on advanced materials development and variable camber propellers. The use of variable blade camber allows the propeller to achieve an optimum match between takeoff and cruise requirements.

In the turbofan field only Rolls-Royce is claiming that their proposed high bypass ratio designs will achieve acceptable noise levels in the near future. At the
same time General Electric is making no such promise. The extent of the problem is illustrated in Figure 56 which gives the source of the noise produced by a turbofan engine with no noise treatment (Rolls-Royce).

At the present time more work is required in several other areas. There is a problem in matching cruise and takeoff performance. A somewhat similar difficulty arises when the desire for thrust modulation for glide path control is considered. Finally, as mentioned above, a solution is required that will provide the necessary bleed air to drive some of the powered lift devices.

**HANDLING QUALITIES/CREW FACTORS**

Generally speaking the low approach speeds used by STOL aircraft produce poor lateral handling qualities. This results in the need to pay careful attention to the lateral control system characteristics. For example, the Breguet 941 utilizes a combination of spoilers and differential thrust to achieve satisfactory lateral control. The impact of the characteristics of the control system on pilot acceptance is indicated in Figure 57 (from NASA TN D-5594).

The complex interactions involved in the assessment of handling qualities are not well understood and considerable work must be carried out on each new design to ensure pilot acceptance. These difficulties are compounded by the influence of vehicle size. At the present time actual handling qualities experience with powered lift STOL vehicles is quite limited (much of the effort in this area has been directed towards VTOL).

From the reports of paper studies of various advanced STOL concepts it appears that the American manufacturers envisage the use of stability augmentation systems and control power assistance (such as boundary layer control on the control surfaces) to help them achieve good low speed handling qualities. To date little time has been logged on such systems installed in STOL aircraft.

When these handling qualities problems are coupled with instrument flight conditions and steep glide slopes it is generally agreed that unless suitable cockpit displays are employed, the pilot workload will be intolerable. At the present time no standard STOL cockpit display has been determined, but it is known that angle of attack, glide slope deviation and flare information are important.

The nature of the turbulence, crosswinds and wind shear expected to be encountered in the STOLport area are not understood. These effects are expected to be especially critical in the case of STOLports located downtown. Here a complex airflow pattern can result from the interaction of surface winds with the STOLport itself and with neighbouring structures. These factors will influence the assessment of STOL handling qualities.

**CERTIFICATION**

Powered lift STOL aircraft cannot be certified under the current regulations which are based on power-off aircraft characteristics such as the power-off stalling speed. Hence these regulations do not recognize the lift coefficients that can be generated with the aid of engines. Before powered lift STOL aircraft can be certified a new set of regulations will have to be formulated. To achieve this goal data obtained under actual flight conditions will have to be recorded and analyzed. Such data will also serve to establish handling qualities criteria and regulations governing the operation of STOLports. (See also Section 3.)

**THRUST ASYMMETRY**

The problems of handling the result of thrust asymmetry following the failure of an engine increase with increasing thrust level. In the case of powered lift STOL aircraft, this thrust asymmetry can produce both a yawing and a rolling moment. When this failure occurs at low speed the generation of sufficient control power to overcome these effects is a problem because the effectiveness of aerodynamic controls decreases with airspeed (thus control power can limit low speed operations). De Havilland feels that based on their experience with the Buffalo, this problem can be handled by standard aerodynamic controls on the DHC-7. On vehicles with higher thrust levels various techniques have been suggested: cross-shafting or cross-ducting to spread the power of the remaining engines uniformly over the wing, or boundary layer control on the rudder to allow the generation of large yawing moments to compensate for the asymmetric thrust. When the latter technique is employed the designer must ensure that the engine out condition can be detected and corrected in time to prevent an upset. These systems have all met with some success, on the Breguet 941, the experimental Boeing 707 with boundary layer control and on the experimental Hercules with boundary layer control, respectively.

**LANDING**

The control technique found to be most effective for STOL aircraft using glide path angles of the order of 7 1/2° is to fly at constant angle of attack and to maintain the glide path angle through thrust modulation. On turboprop aircraft this can be accomplished by controlling propeller pitch. With turbofan engines the thrust
response to throttle changes is too sluggish and some other means of flight path control must be found. This could take the form of fan blade pitch control, aerodynamic control of the powered lift, or thrust reversers.

Tests performed by the NASA on presently available STOL aircraft have indicated that they are not capable of performing approaches in crosswinds exceeding 40% of the approach speed. This could pose a problem since STOLports are expected to have only one runway. These results may not apply to future STOL vehicles but they do indicate an area that may require further study. From their past experience with STOL aircraft de Havilland sees no difficulties with the landing gear to be used on the DHC-7.

In considering elevated STOLport operations, an acceptable arrester system must be designed to prevent aircraft from falling over the edge. To date no system trials have been reported. This aspect could impede the introduction of elevated STOLports. However it is not at all clear that elevated STOLports will be required in any Canadian application, and consequently this problem can probably be ignored.
### TABLE 30 TYPICAL V/STOL PROPELLER COMPARISON

<table>
<thead>
<tr>
<th></th>
<th>1960'S</th>
<th>EARLY 70'S</th>
<th>LATE 70'S</th>
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<td>500</td>
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<tr>
<td>WEIGHT, LB</td>
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<td>2000</td>
<td>1350</td>
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<tr>
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<td>96</td>
<td>93</td>
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<tr>
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<td>0.55</td>
</tr>
<tr>
<td>STATIC THRUST, LB/HP</td>
<td>3.8</td>
<td>3.8</td>
<td>3.8</td>
</tr>
</tbody>
</table>

*WEIGHT INCLUDES: PROPELLER, GEARBOX, CROSS-SHAFT DRIVE

**4 PROPELLERS @2800 SHP**

### TABLE 31 EFFECTIVENESS OF VARIABLE CAMBER

<table>
<thead>
<tr>
<th></th>
<th>LATE 70'S TECHNOLOGY</th>
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</table>
DEFLECTED SLIPSTREAM
FIGURE 47

BOUNDARY LAYER CONTROL
FIGURE 49

JET FLAP
FIGURE 51

EXTERNALLY BLOW FLAP
FIGURE 48

ROTATING CYLINDER FLAP
FIGURE 50

AUGMENTOR WING
FIGURE 52

TILT-WING
FIGURE 53
TECHNIQUES FOR ACHIEVING VERY HIGH-LIFT COEFFICIENTS

1. Limit circulation lift
2. Theory-experiment
3. Deflected slipstream circulation
4. Jet flaps
5. Mechanical flaps
6. Blc
7. Free circulation
8. Plain wings

WING ASPECT RATIO $b^2/s$

FIGURE 54

STOL PERFORMANCE RELATIONSHIPS

LIFT COEFFICIENT USED IN APPROACH

FIGURE 55
PILOT'S CONTROL INPUT

ILLUSTRATION OF DIFFERENT CONTROL SYSTEMS

When an abrupt increase in roll response occurs as the control deflection is increased, as in the right-hand sketch, there is a marked tendency for the pilot to overcontrol the aircraft laterally; this tendency has not been noted in those aircraft for which the non-linearity was in the opposite direction, as in the middle sketch.
INTERCITY AND MUNICIPAL FEEDER TRANSPORT

The dividing line between the intercity and municipal feeder applications is not fundamental: rather, it is one of degree. Therefore, these applications are discussed jointly. These services, linking the larger populations centres, have the potential to benefit the greatest number of people. Accordingly, their technological and economic impedances are particularly relevant to STOL aviation.

Metropolitan STOLports do not presently exist in Canada. Naturally, operators are reluctant to commit themselves to the purchase of STOL aircraft until they are shown concrete evidence of the availability of STOLports in major traffic generating areas. Reasons for this lack of a firm commitment to STOLports include a delayed awareness in Canada (as compared to the U.S.) of the benefits offered to the travelling public by STOL transportation; the attendant savings in the construction of airport facilities which would be possible; and the possibility STOL presents in the alleviation of the aircraft noise problem. An additional factor is an uncertainty as to the actual physical specification of a STOLport, and its cost. It is important that this situation be clarified as soon as possible so that firm policy and plans regarding the construction of STOLports can be developed thereby enabling construction decisions to be made. It is fortunate that there appear to be a number of good STOLport locations existing in Canadian cities that are both convenient to the traveller, unobtrusive to the community and available at reasonable cost. (See also Section 2.5). Sites in Toronto, Montreal, Ottawa, Vancouver, Victoria and Quebec City could provide the nucleus for development of a local STOL system.

As to the availability of suitable aircraft, it seems that an aircraft such as de Havilland's DHC-7 could become an attractive vehicle with which to develop widespread STOL services. This view is increasingly accepted in the aviation industry, and is supported by a number of particular studies focussing on this point.

When the need for second generation aircraft is considered, the elasticity analysis of Section 1 shows that additional travel can be attracted by at least three mechanisms: development of faster aircraft, location of additional STOLports in the major cities to improve STOL access and egress times, and reduction of costs.

The development of faster STOL aircraft primarily depends on the development of quiet jet engines which fulfill the requirement for some form of powered lift and achieve acceptable riding qualities. Riding qualities are related to the parameter 'Wing Loading/Speed' so that if the speed of an aircraft is increased the wing loading must be increased to prevent a deterioration in riding qualities. However, an aircraft's landing distance is related to 'Wing Loading/Maximum lift coefficient' so that if the wing loading is increased the maximum lift coefficient must be increased to maintain a constant field length. Since passive flap systems are presently operating near the limit of their potential, the need to use the powerplant to augment wing lift is clearly indicated. In addition, some means must be found to generate the thrust for high speed cruise without producing unacceptable noise levels.

The fare that a traveller pays is the result of both the direct operating costs of the vehicle in which he flies and the indirect costs of the airline providing the service. In addition, a portion should be available for a profitable return on investment. While aircraft manufacturers can design specialized aircraft to minimize the costs of short haul operations, the major element of costs on short stages is due to the indirect cost structure of the airline. It is reasonable to question whether any airline that is primarily a long haul carrier can profitably operate a short haul STOL system. Consideration should be given to the development of carriers specializing in short haul operations in order to achieve the best opportunity for minimum fares consistent with a profitable service.

DOWNTOWN TO AIRPORT TRANSPORT

The major technological problem likely to impede the implementation of downtown to airport transport is the provision of STOL runways on major airports. These runways must be capable of independent IFR operations on a non-interfering basis with CTOL traffic yet be convenient to the terminal area so that the STOL aircraft do not have to taxi long distances once on the airport. This problem does not receive a high priority with airport operators and planners because of the uncertainty surrounding full scale implementation of STOL services, because proper guidelines for the phasing in of STOLports are lacking, and because of uncertainty concerning the level of traffic expected.

Economic viability of downtown to airport operations can reasonably be assumed on the basis of the profitable services demonstrated by STOL operators in the U.S. In assessing both the economic viability and the feasibility of beginning such a service, as mentioned in Section 1 (modelling investigation) few points are served which are less than 25 miles from the airport, so that one would not expect service to the
The fact that STOL aircraft are currently hence can operate with a lower capital investment would then fall within the range proven feasible in the U.S. Experience in the U.S. has shown that such services tend to develop whether or not they are specifically planned by the regulatory authorities.

**REGIONAL TRANSPORT**

The discussion in Section 1 implies that the development of services to smaller communities revolves around improving the attractiveness and economics of small aircraft, and in reducing indirect operating costs.

Commuter airline experience has established that the traveller is attracted to frequent service in attractive aircraft serving points convenient to his destination. The aircraft that accomplishes this at the lowest cost determines the smallest town that can support these services. Improving this position is basically "doing more of the same".

Indirect costs result from both customer and technical services and from management. Community participation appears to be the key to minimizing costs in this area. The formation of Pem Air is an example of this. It was reported (Canadian Aviation, July 1970) that Pembroke together with 11 townships and villages in the area formed an airport commission and paid out $76,000 for land and $15,000 for a small terminal, non-directional beacon and 2800 foot dirt runway. The municipalities provided the labour and equipment; the local construction association built the terminal. It would appear that Pem Air executives contribute freely of their own time as is typical of commuter airline executive officers. Thus indirect costs are held far below those that could be achieved by a conventional airline serving the route.

**NORTHERN TRANSPORT**

The fact that STOL aircraft are currently operating in the north provides a basis for analyzing this route type and for assessing some of the limitations of the model developed in Section 1.

A major consideration in the model was the cost of operating aircraft. Any cost differences between CTOL and STOL are emphasized by the purchase of used CTOL aircraft. Because there is less emphasis on the glamour of new equipment in the north an operator is not encouraged to provide the latest model of aircraft and hence can operate with a lower capital investment. In markets where utilization is low or variable, reductions in fixed costs by this device are often one of the few ways to achieve a profitable operation.

Low fixed costs make it easier to keep backup aircraft on hand. In many ways this impedance is similar to that described under Regional Transport.

Another method of reducing the cost of operating CTOL aircraft, especially jet equipment, is to serve the North with off-peak period utilization of southern main line equipment. This is possible again because northern travellers are much less sensitive to the time of day at which they travel than are southern business men, and travel in an off-peak period can be a small price to pay for the speed and comfort of modern equipment.

A related problem is that the choice of available CTOL aircraft models exceeds that of STOL. Frequent requests are received by manufacturers for larger STOL aircraft, with greater payload, range, speed, and volumetric capacity. Until such aircraft are available operators have no choice but to use CTOL aircraft.

These impediments are only relevant prior to and during the initial operation of a STOL system. Once STOL receives widespread acceptance a wider choice of aircraft will follow and eventually used STOL aircraft will become available. Indeed there are presently a number of smaller STOL Twin Otters on the used market, many of which are finding their way into Alaska and the Canadian North. Thus this is an initial impediment which can be expected to disappear in time.

The development of STOL transport in the north depends upon the establishment of a suitable network of STOLports. At some locations a new facility will not be required, since a large number of operations in the future will continue to take place at existing strips. In addition the STOL airlines will be able to take advantage of new strips to be built and paid for by other users such as the armed forces.

In general, STOLports will cost less to construct than CTOL airports. The cost saving depends, to a large extent, on the terrain at the site. In many of the flat areas found in the north it can be argued that the construction setup costs are of primary importance and that the cost of constructing 2000 feet of extra runway would add only a relatively small increment to the expenditure. On the other hand, a recent DOT study indicated that it was not possible to build a 4000 foot CTOL strip at approximately 50% of the northern sites considered because major cost escalations result from the necessity to cut through large hills of rock or fill in gullies and steep dropoffs over cliffs.

Another factor favouring STOL strips is the small size of most northern centres of activity (be it a village, mine site or drilling rig). Thus the system should
probably serve individual points and not whole regions. This is emphasized by the difficulties of constructing access roads. In many instances the relatively short STOL runway allows the STOLport to be established close to the point served while still retaining optimum orientation with respect to wind and soil conditions. In addition, the chances of fitting a second runway (if required) are improved.
INTRODUCTION

This section analyses the impedances to the development of STOL transportation in Canada that involve navigation, guidance and air traffic control. The impedances considered centre around requirements for new technology and economic problems anticipated in the various route structures; intercity, municipal feeder, downtown to airport, regional transport and northern transport.

COMMUNICATIONS

There are few, if any, technological impedances to STOL development in the communications area. The equipment presently existing is quite adequate. There is general spectrum crowding, but this is apparent everywhere. It is doubtful that reducing the channel spacing to 25 kHz would be advisable; the standard 50 kHz separation probably being adequate for some time to come. However, if traffic growth leads to the overloading of the presently assigned channels, additional ones could be created by resorting to 25 kHz spacing. Such additional channels would require more controllers to man them. This situation will not be upon us for some years yet, but provision for it, in the overall picture, should be made. (See ATC subsection.)

No major technical impedances seem to exist for the intercity and municipal feeder. There are sufficient communications facilities to handle the expected STOL traffic growth during the next decade for most routes that one might consider. The problem becomes an economic one at some of the terminal points where only 122.8 MHz or a limited number of communication channels exist. The required facilities would have to be provided: possibly additional frequencies to handle approach control, ground control, plus an operating tower.

For the downtown to airport application servicing the downtown area presents no greater communications difficulties. There will, however, be complete new tower facilities required at each site: an economic impedance. The cost of the equipment can probably be kept low, as only a tower and ground control frequency would be needed. Approach and departure control could be handled by the main centre controlling the major airport traffic into which the service is operating. Toronto departure control, would for example, handle Oshawa, Toronto Island and possibly Muskoka, if these were on the route structure.

Again no technological communications problems prevent the implementation of a regional transport service linking smaller centres; only economic ones, since many outlying towns which presently have an airport lack adequate communications facilities. Often only a small installation handling Unicom on 122.8 MHz, is available. This will not be satisfactory for regular airline transport work, although it should not stop a limited flow of traffic into the airport (say 2 to 4 flights per day).

Most of the facilities presently available will be useful in future expansion of northern services to include STOL. New sites will require new equipment and antenna installations. There is a problem of maintenance, as the severe weather conditions require extra care in equipment installation to allow for power failures—these can be handled by standby power systems which come on-line automatically. Where the new site is at a remote location, additional equipment such as HF SSB may be a necessity for long range circuits. VHF will not be satisfactory in all installations resulting in cost and weight penalties for aircraft operating in these areas.

NAVIGATION

Navigation systems for en route operation are well developed and have many years of past service. The standard VOR/DME and ADF are generally sufficient for most services, and, except in special cases, no great technological or economic problems need be overcome.

In the terminal area, the problem is a much different one, and less easily solved. Area navigation is a relatively new technique which provides much greater flexibility than the standard airway structure and navigation. Additional equipment onboard the aircraft is required but the cost (about $30 - 40,000) is fairly modest, considering the flexibility it affords. Simply stated, the area navigation system (RNAV) allows the pilot to navigate his aircraft without following the standard airway patterns. Two systems, Decca Omnitrac and Butler National Vector Analog Computer (VAC) provide RNAV capability. The Decca system provides a chart presentation of the area over which the aircraft is flying and a trace over this map showing the track the aircraft has flown. The Butler VAC system provides standard course and distance information from a "waypoint" (WP) sometimes called a phantom VOR. This waypoint is located by using the range and bearing information to a selected VOR/DME from the aircraft and then computing a new VOR station location now defined as the waypoint. The bearing and the distance to this waypoint, are displayed in the cockpit. The advantage is immediately apparent in that an
infinite number of waypoints can be selected, thus allowing the pilot a great improvement in his navigational freedom. This also helps the ground controller, in that he can leave the navigation to the pilot, who now has the ability to control his own routing.

To clarify, RNAV using the Butler VAC two dimensional equipment, Figures 58, 59 and 60 show the salient features of the vector triangle solution. In Figure 58, the phantom station is presented as a distance and a track angle between the aircraft and the waypoint. The vector computation is carried out by an on-board computer which has the radial distance and bearing from the VOR/DME station entered into it, as shown by Line A in Figure 59. The navigation receiver (VOR/DME) provides radial distance and bearing information between the aircraft and the VOR/DME as an input to the computer (line B). From these two, the VAC computes line C, the distance and bearing from the aircraft to the waypoint. It continuously computes this vector.

Since the waypoint position is pre-selected by the pilot, an infinite variety of courses and waypoints are available to him. An additional advantage is presented by the VAC system. Linear rather than angular deviation is available, as shown in Figure 60. This allows lateral separation of two aircraft on the same track. On the coarse scale setting (low sensitivity) one dot or hash mark on the course deviation indicator represents 5 NM. With a standard VOR, one dot represent 5° angular displacement from the VOR course line; thus, an undesirable variable separation of distance from the station.

So far, 2-D RNAV has been described. By providing altitude control and command signals (as in Butler's ADD - Ascent Descent Director), a 3-D presentation is available. The ADD receives signals from the aircraft's altimeter and inputs from the VAC. In addition the following inputs are set into the computer by a pilot-operated control head:

(a) The station elevation of the VOR/DME
in use for the VAC portion of the system
(b) The horizontal distance before or after passing a waypoint where the selected altitude is to be achieved
(c) The desired altitude at this distance
(d) The desired ascent or descent angle (set angle).

Pilot commands are presented in standard form on pitch command bars or on a glide slope deviation indicator. Figures 61a and 61b show typical examples of the use of an ADD. In 61a, two waypoints are used and two altitude changes are effected. The pilot inserts the distance \(D_a\) from the airport to waypoint 1 and the height \(H_1\), the altitude he wishes to reach at waypoint 1. The ADD computer then determines the ascent angle he must make good (A) in order to achieve the selected flight path. Having reached altitude \(H_1\) he flies to WP2 and then wishes to climb to a new altitude \(H_2\) at a distance \(D_b\) from WP2. These values are entered and the ADD determines the required climb angle B. The pilot then checks to see whether the required climb is within the capability of his aircraft in its present configuration, amending, if necessary, either \(H_2\) or (more probably) \(D_b\) to achieve a reasonable climb angle. An alternate approach would be to select a climb angle, and then let the ADD compute a new distance \(D_a\) from waypoint 1 where he must commence his climb in order to reach \(H_2\) at a given distance from the airport.

Figure 61b shows a descent profile. In this case the pilot has descended from \(H_1\) to \(H_2\) at an angle C. To make good this new altitude, \(H_2\), over the waypoint, he commenced the descent a distance \(D_d\) from the waypoint as computed by the ADD. He can then carry out (for example) a straight-in-approach at a new angle E from the waypoint to a position short of the outer marker (OM) that puts him at the correct altitude for final approach to the airport. Thus the third dimension of area navigation has been added - altitude changes in relation to waypoints that may be arbitrarily selected.

The Decca Omnitrac system has a different presentation, but provides the same RNAV capability. A map of the area moves in the vertical (see Figure 62) and an indicator of the aircraft position (bug) moves laterally. Thus a two dimensional picture of aircraft position appears on a map of the area. A line is drawn on the translucent chart face, and may be easily erased at any time. VOR/DME, doppler or hyperbolic inputs may be selected, the latter where Decca stations are operating. The entire system is considerably more sophisticated than the VAC discussed previously and three waypoints may be selected and preprogrammed for any chart thus allowing off-airway legs to be set up. A typical omnitrac RNAV routing between La Guardia and Boston Logan field shown in Figure 63 emphasizes the direct routing capability of the RNAV System.

For the intercity application the standard VOR system is quite adequate and provides the accuracy needed for most of the navigation functions. RNAV would be impractical at first but should be planned for the next two decades of growth as traffic density increases. It would certainly be of advantage in the terminal area and should be introduced.

For the municipal feeder service, that
would likely operate in somewhat congested areas, direct routings would be very advantageous. In this case, it would be worthwhile to consider RNAV at the outset. For the operator, this offers an economic obstacle which must be paid for by higher fares that would be the case with more modestly equipped aircraft.

RNAV is virtually essential, however, for the downtown to airport application. The distances are sufficiently short that with (hopefully) a dense traffic situation and the problems of interfacing with CTOL piston and jet, it will be necessary to use a wide variety of departure and arrival routings. The RNAV equipment is available, but for improved accuracy the more expensive Decca HARCO (Hyperbolic Area Coverage) could be used. Initially, a Butler VAC with ADD would probably be satisfactory. The navigational impedance for this class of services is primarily economic. The capital cost of installing Decca chains (assuming there is sufficient coverage from the existing eastern seaboard system) will be substantial. In the opinion of people interviewed, and the experience gained by the Eastern and American Airlines STOL demonstrations, RNAV is a necessity for operations in dense traffic with mixed speeds as found in short-haul services such as downtown to outlying jet port.

The existing system of VOR/DME and non-directional beacons for ADP use is considered adequate for the regional transport application. However, on route navigation presents a technical problem in the north. The cost of providing a VOR/DME chain to handle the outlying areas would not be economically justified: yet some means of accurate navigation is essential. As a first choice, inertial navigation would solve the problem, but it is very expensive. An expanded Decca chain would be the second choice, and OMEGA, when it is in world-wide service, could be satisfactory as well. Loran is another possibility. The problem, then, is primarily economic with a technical challenge to choose the correct system, or develop one that is inexpensive and reliable.

APPROACH AND LANDING AIDS

The greatest technical and economic problems exist in the area of final approach and landing aids. No existing microwave landing system suitable for immediate use as a STOL approach aid is yet ready for airline use. The GPL TALOR (Tactical Landing Approach Radar) is a simple, portable system which has had considerable military use and has been used by American Airlines during their STOL demonstration programs as well. TALOR operates on 15 GHz, has a lightweight transmitter unit located on the ground and an airborne receiver and antenna with a combined weight of 8.5 lbs. The advantages are small size, light weight, very rapid set-up time and an accuracy in excess of CAT I ILS. A typical TALOR beam pattern, which provides localizer and glide slope information on a standard cross-pointer format, is shown in Figure 64. The ability to simply and rapidly adjust the elevation angle (up to 6° in present models, 7.5° with modifications) makes TALAR an ideal STOL approach aid in this respect. An additional advantage is that the far field monitoring distance is short (in terms of the actual distance between transmitter and monitor).

There are varying opinions about the limits to which STOL must fly to provide an acceptable level of service. For the Manhattan STOL operation, 700 foot ceiling and 1 mile visibility are considered by the FAA to be acceptable limits for RNAV approaches, and will handle 90% of the weather conditions, without the use of a precision approach aid. RNAV has been used to CAT I on a number of trials, but is far from proven as reliable under all conditions. The FAA has issued advisory circular AC 90-45 which defines some of the aspects of RNAV for the U.S. National Airspace System. Some of the RNAV approaches conducted to date show accuracies well within the error budgets presently assigned, but consistent, long-term performance in this mode has yet to be substantiated.

Other systems exist such as Airborne Instruments Laboratories' AILS, also a microwave landing aid, which has somewhat greater flexibility, but is more complex and (presumably) costly than the TALAR system. In any case, the question of whether the CTOL approach limits should apply to STOL as well is still unresolved. Thus if the STOL service is to provide transport between the main jet airport and outlying towns or a downtown area, CAT III capability may be required. On the other hand, CAT I may be quite adequate for most (90 - 95%, say) of the time for a STOL intercity service. CAT III is still a long way off, even for CTOL. As a general comment, the 2.5° glide slope for existing ILS is quite adequate for some STOL work. STOL does not necessarily imply a steep approach angle of 7.5°. However, a swing to a microwave landing system may well require dual receiver capability on the aircraft. If so, both standard and microwave systems could be used until the transition was complete; an extra economic hurdle.

While there is a gap between the desirable steep approach aid for STOL and the presently available ILS equipment, the intercity service can probably make do with the existing ILS at the present airports on an intercity route. New airports should be considered in the light of a more advanced STOL approach aid, such as TALAR.

Attempts to upgrade CAT I capability to CAT II will meet both technical and
economic impedances. The problem is primarily economic, however. How much money are we prepared to spend to do enough testing to prove the suitability of a new microwave landing system? Once sufficient flight data are available the commissioning of such a system is virtually assured.

For the first few years of operation the existing systems, with improvements assumed for the future, will provide the necessary services. The impedance to new-airport operation is simply that a suitable approach aid must be made available.

Virtually the same comments apply to municipal feeder operations. If the service is going to survive, it must be capable of conducting operations in adverse weather. Hence all the outlying airports—new and existing—will require approach aids—an expensive proposition.

Downtown service has some additional technical problems associated with night operations. If the airport is to be located in the heart of a downtown centre, then special consideration must be given to the profusion of confusing and bright lights that exist around the landing area—VASI is a necessity in this location. A highly accurate, high angle ILS, probably microwave, will be needed. Such a system is technically available, operationally tested, but not "airline qualified" as yet. The conventional ILS will not be satisfactory here, as there simply isn't room to install it. There is both technical and an economic impedance to downtown operations until this problem of using a microwave system is resolved.

Consideration must also be given to departure guidance. The aircraft will have to circumnavigate a built-up area with far more potential hazards than exist at the CTOL airports. It is doubtful whether this problem can be easily solved without some sort of on-board radar, with transponders, or beacons located on the navigation hazards. Also, weather resulting in CAT II conditions at sea level could produce CAT III conditions at an elevated STOLport.

Small communities serviced by regional STOL will require at least CAT I aids if they do not exist at the time service is planned. As the advantages to be gained from STOL are greater when weather conditions are poor, making automobile transport difficult (snow conditions, etc), an extension to reliable CAT II equipment may be necessary for future planning. In either case, the impedance is mainly an economic one, with the technical problems of a reliable CAT II system representing an obstacle to successful and continuous service under severe weather conditions.

There should be no more additional impedances to supplying adequate approach aids for northern airport installations than for regional services. Possibly, due to the availability of land, a standard ILS could be used with slightly increased runway length to accommodate a more shallow approach if necessary. The severity of the northern winter makes the maintenance of approach aids much more costly. This will certainly have an influence on the design of any new microwave ILS system, or the modification of an existing one for northern service.

**AIR TRAFFIC CONTROL**

The ATC function of preventing collisions is presently accomplished by ground controllers spacing the aircraft on predetermined air routes at assigned altitudes and tracking them by surveillance radar. The intense concentration required of the operators along with heavy workloads results in a system prone to errors. Surprisingly few ever lead to mid-air collisions. In Canada, even in the Toronto and Montreal areas, the traffic density is low compared to, say, the New York - Boston - Washington area (the Northeast Corridor). It should therefore be possible to sustain a considerable traffic density increase before the system becomes overloaded to the danger point.

When STOL is introduced into the picture, already involving a mixture of Prop, Jet, SST, Jumbos and the wide variety of approach speeds attendant with such an operation, the ATC problem is aggravated. At present there is adequate equipment to handle STOL service, but an improved and updated ATC capability with computer ties for clearance delivery and automatic reporting at compulsory reporting points will be required in the future. When controllers become used to the concept of RNAV, their workload will be considerably reduced: the navigation function being placed in the cockpit, allowing the pilot to provide his own routing based on standard RNAV procedures. These must be implemented before the system is put into actual revenue operation. As an example, consider the clearance to be issued by a controller at Toronto Island Airport (or Toronto ATC) clearing an aircraft for departure from the Island to Oshawa:

**ATC (or tower)** "STOL#1 cleared Oshawa airport via Victor 98 direct Oshawa to maintain 3000'. Cross Leslie not above 2500'. Takeoff runway 26 left turn out to a heading of 031° . Departure 119.9" **STOL#1** (Reads back entire clearance) **ATC** "STOL#1, roger. Cleared takeoff". **STOL#1** "STOL one".

Using area navigation techniques, the clearance becomes exceedingly simple:
The entire clearance transmission and readback time has been cut from in excess of 30 seconds to about 5! Additionally, that is the only clearance (under RNAV) that STOL 1 needs to get from runway 26 at the Island to a final landing clearance at Oshawa. He uses his RNAV equipment, a waypoint or two to position him for an approach at Oshawa, and does not transmit information and data to the extent required under present airways procedures.

As far as hardware is concerned the impedances are mainly economic. It will, however, take considerable planning to implement a viable RNAV routing system for the terminal area. Such planning should start now, with flexibility to allow progressive changes and improvements as the system grows and develops. The present ATC system, up-dated with RNAV routing could handle the intercity service with little additional workload. Without RNAV, speed differences will tend to cause congestion and conflict between STOL and CTOL. Controllers will have to become familiar with this mix and how to handle it. It is not meant to suggest that the system will not work without pre-training and experience in this area, but only that the integration is likely to be practicable without it. The equipment exists, the implementation procedures do not. The former present economic impedances, the latter, technical problems and obstacles of a significant nature, mainly in the procedural planning. This latter area has often been underestimated with the result that a system thought to be suitable for rapid arrivals and departures of STOL aircraft quickly becomes unworkable as the traffic density increases.

The municipal feeder and regional transport applications present problems no more complex than the intercity service. There may be more sectors to be covered, and this means a heavier controller workload; but these problems can be overcome with RNAV equipment. There will be a need for tower and approach control staff at many of the fields servicing the smaller population centres. It is possible to omit the latter in some cases, but tower operators are a necessity on controlled airfields; representing an economic impedance to those cities with uncontrolled airports. The problem is a minor one in the total scheme, however.

With respect to the downtown to airport application, the economic hurdles of providing adequate control to handle the traffic density plus the technical problems of an aircraft mix with widely varying airspeeds at the main jet airport are anticipated.

ATC procedures must be developed to allow the insertion of arriving STOL aircraft into a traffic pattern or approach path for a STOL runway on the airport, while keeping CTOL traffic moving normally. Attention will have to be paid to ATC procedures for RNAV approaches, in addition to ILS-type approaches. One might not class these as real impedances to STOL development, as they can easily be overcome by timely planning. But because they don't yet exist as procedures, they would certainly have to receive attention before a full-scale operation in this class of service could be considered.

The ATC problem in the case of far north transport is possibly more of a technical one than economic, although both affect this service to a great degree. First, ATC in the far north is virtually nonexistent. New sectors and controllers will have to be provided at many sites. On the other hand, the density of traffic is far less than the southern regions, and the requirement for close control is not as necessary. Approach control can be performed by the local tower operator, but we must be prepared to install approach radars and other necessary ATC equipment to meet suitable IFR control standards. This implies economic obstacles to be overcome in providing new equipment and facilities, operators and maintenance technicians.

The severity of weather conditions will also present some technical difficulties. The real technical problem, however, is how to use existing southern sector facilities to also provide northern ATC. Perhaps the use of computer terminals with data linked by a microwave chain to a central control terminal would provide a solution. A hypothetical system is shown in Figure 65. Data on position, height, speed etc. are transmitted by aircraft within a specified distance of a data receiving station. These data are then fed to a computer terminal that is used to determine course and altitude corrections to provide proper separation. The purpose of the computer interface is to automate the control function while allowing programming changes to be made by the air traffic controllers at the main ATC centre via a microwave link. In addition, target information would be presented on the controller's PPI display based on the
transmitted aircraft data, eliminating the use of northern radar sites. The pilot would receive his instructions either by hard-copy printout in the cockpit or by voice link with the controllers. To proceed in this direction, it will be necessary to develop a compatible computer system with a data link chain. The technical problems are significant, as there are long routes over which to transmit the data, and an outage will cause a complete loss of ATC information to the centre. Without this system, long range HF SSB may be the answer, but this will require high power and heavy radio equipment in the aircraft (assuming a more southerly central control location).

In summary, the economic problems to air traffic control are the result of a lack of facilities and equipment at many of the potential sites. Technical impediments include the maintenance of suitable equipment and the development of long range data and radio transmissions by either microwave or HF to a central sector control located in the southern portion of the country.

As the growth of northern transport is likely to be somewhat slower than the other STOL route structures considered, there should be sufficient time to plan the ATC system, and the equipment needed, for this class of service.

**Cockpit Instrumentation**

As lower landing limits and improved equipment allowing the pilot to make approaches under extremely poor visibility conditions are developed, visual information concerning the aircraft location with respect to the runway threshold must be presented in a form that is easily understood by the pilot. This must be in the context of visual cues used for a VFR approach. As yet, a satisfactory model of a pilot landing an aircraft under VFR conditions does not exist. The standard cross pointer showing deviation above or below the glide slope and left or right of the localizer is still a very good "deviation indicator". What is needed is a CRT or EADI (Electronic Attitude Director) which shows the position of the aircraft with respect to the runway threshold and centreline, but presented as it would be seen from the cockpit under VFR conditions. Sperry Flight Systems Division has done considerable work on EADI's and has flown a CRT version in their Twin Beech (Aviation Week and Space Technology, 4 May 1970, p. 49). This particular system has both a TV camera mounted on the outside of the aircraft to display a picture of the actual approach situation and an attitude director superimposed on a simulated ground-horizon-sky presentation.

Are there any major technical obstacles to be overcome in the instrumentation area (particularly horizontal situation and attitude indicators) before STOL operations could begin? The answer is obviously 'no', at least for CAT I and II limits. CAT III is a different situation altogether. Automatic landing on a regular basis for CTOL is a long way off (and for STOL it is not even visible at this point). The CAT III landing must be conducted with considerably better attitude directors than presently exist. This however, should in no way impede the introduction of STOL in Canada for any of the route structures considered by this study.

**Collision Avoidance Systems**

The collision avoidance systems (CAS) presently under development in the United States are some way from final acceptance. The time-frequency system proposed by the Air Transport Association is extremely complex, expensive, and prone to false indications. RCA's SECANT-B which has yet to appear in prototype form, (computer studies show great promise) presents the possibility of a really low cost system. The problem with a very complex and costly CAS, is that only a few operators can afford it: if so, the chances of collision are almost as great as they were before its introduction. The observation has been made by a representative of American Airlines that when RNAV is used, a CAS is essential. Certainly in the terminal area and on high density routes this is true. For future STOL operations, the lack of an adequate CAS is an impediment to the expansion of further STOL service.

The route structures have little influence on the choice of cockpit instrumentation and CAS except that downtown-to-airport and intercity operations will need some form of CAS when RNAV systems are used. The lack of close control on the aircraft by ATC and the shifting of the responsibility for collision avoidance into the cockpit makes this system desirable under these conditions.
FIGURE 58 AREA NAVIGATION TWO DIMENSIONAL FORMAT

FIGURE 59 GENERATION OF WAYPOINT

FIGURE 60 LATERAL DEVIATION

FIGURE 61A ASCENT PROFILE USING WAYPOINT

FIGURE 61B DESCENT PROFILE USING WAYPOINT
FIGURE 61 TYPICAL TALAR BEAM PATTERN

FIGURE 62 DECCA OMNITRAC TRACE SHOWING DEPARTURE FROM TORONTO ISLAND AND AREA NAVIGATION TO APPROACH ON 23L AT TORONTO INTERNATIONAL. ONE ASYMMETRY SHOWN

FIGURE 63 SIMPLIFICATION OF ROUTE STRUCTURE USING AREA NAVIGATION

FIGURE 64 INSERTION OF COMPUTER AND DATA LINK IN ARC CHAIN
GENERAL ANALYSIS

Like other new technologies, a STOL transportation system may have profound effects on the lives of people who are neither direct producers nor consumers. Favorable effects are possible: increased land values near STOLports, stimulated local business. The principal effects, however, will be deleterious: noise, pollution, risk of injury from crashes. How can economic and social benefits to operators and users of a STOL transportation system be balanced against social and environmental penalties to non-users?

The need to assess technology from a broad frame of reference has recently become a subject of urgent concern due to a growing catalogue of technological developments causing real or potential injuries to increasingly large segments of the population. These include pollution of the atmosphere and natural waters by industrial wastes, pesticides and automobile exhausts; cumulative damage to buildings from repeated exposures to sonic booms; potential hazards involving transportation and disposal of nuclear materials; alteration of the earth’s stratosphere by the exhausts of supersonic transports. Unfortunately, the overall costs and benefits of a new technology cannot be reduced to an objective measure. Traditionally, initial assessment of these costs and benefits has been undertaken by those seeking to exploit the new technology: the presumption has been that a technology should be allowed to proceed as long as it yields a profit to its exploiters. Government agencies, with restricted aims, such as the development of new transportation systems, are no less likely to suffer from a limited frame of reference than are manufacturers trying to introduce new products.

According to traditional practices, then, assessors of a new STOL technology need take into account undesirable social costs only to the extent dictated by the existing legal system. Airlines, for example, have by and large been able to inflict noise on airport neighbours with very little associated cost. In the United States, at least, the legal system is moving rapidly to alter existing relationships: laws and court decisions are shifting the burden of noise reduction (hitherto borne by the public) onto the users. It is clear that in Canada, too, public reaction against the adverse effects of technology is stiffening. In a recent Gallup poll, for example, 69% of those sampled rated Canadian pollution problems as very serious: only 3% did not feel at all threatened by pollution. In another poll, carried out in British Columbia, 71% of the respondents indicated a willingness to pay higher taxes to control pollution. It may be anticipated that future legislation will progressively force producers of noise and pollution to assume the cost of disposing of their objectionable byproducts.

Other sections of this report indicate that technical impediments to the establishment of a viable STOL transportation network in Canada are well under control. The material in this section will show that the same happy conclusion cannot be immediately extended to sociological impediments. It seems that acceptance or rejection by the non-passenger public may well prove the major impediment to a number of otherwise viable Canadian STOL applications.

It is apparent that the rising public disenchchantment with the harmful byproducts of technology will manifest itself through resistance to the intrusion of noise and pollution into populated areas. This implies an impedance to the downtown and the municipal feeder applications. It is less apparent that rising concern with ecology in general and the Arctic and its wildlife in particular could also lead to impediments to the northern transport application.

SCOPE OF THE NOISE PROBLEM

It is quite apparent from the statements of numerous authorities that the degree of noise intrusion will figure as the crucial factor in determining the acceptance (or rejection) of a future STOLport by its non-passenger neighbours. The California Corridor study carried out by the McDonnell Douglas Corporation in 1966 predicted that noise reduction would be vital to a STOL system. More recently, when the British Ministry of Technology announced an indefinite postponement of an intercity V/STOL system early this year, uncertainty about acceptable noise levels was cited as one of the main reasons. Representatives of de Havilland, the Boeing Company, American Airlines as well as the FAA are all on record pinpointing noise as the chief obstacle in projecting acceptable STOL designs.

The 1969 American Institute for Aeronautics and Astronautics President’s Forum was convened to answer the question “How should civil aviation develop to serve our society best?” In the keynote address H. G. Stever (president of Carnegie-Mellon University, former head of MIT engineering department, chairman of numerous advisory boards) designated noise as a research and development area of critical importance to the continued viability of civil aviation: rating it second only to ground support facilities but ahead of air traffic control. He too cites the noise
problem as a major obstacle to the growth and development of STOL.

Some indication of the growing spirit of revolt against airport noise may be obtained by noting that noise suits and claims aggregating to nearly two and a half billion dollars are presently pending against airports, manufacturers, and operators in Southern California. In May 1970 a California Superior Court issued a pre-trial ruling upholding the liability of airlines and manufacturers for damage from aircraft noise and fumes. It is interesting to note that suits against Los Angeles International Airport have been initiated by groups situated as far as 18 miles away. Of more immediate significance to STOL is the case of Santa Monica Airport, a facility not used by the airlines, only by business jets and propeller aircraft. Local families have brought suit against the city of Santa Monica alleging maintenance of a public nuisance, improper zoning, and personal and property damage.

To put the subject of public acceptance of STOLports into a Canadian context, consider the blistering denunciation of a proposed STOLport on Toronto's waterfront that appeared in the 'Voice of the People' column of the Toronto Daily Star on May 29, 1970. The article, written by a representative of a downtown citizens' group, characterizes the STOLport proposal as "a scheme to rape yet another of Toronto's few remaining natural resources for the convenience of some mythical 'busy executives'." Such a view of proposed STOLports by potential neighbours - that is, that the STOLports will benefit only 'busy executives' who are to derive the advantages without paying the costs - seems to be fairly representative of STOL critics.

The article states further:

"The objections to a STOL airport on the waterfront are identical to the objections to a conventional airport. Is there a proven need for such a facility? What are the implications for the surrounding residential and recreational communities? What will the air, water and noise pollution effects be? Will the public be allowed to participate in the decision making process?"

In a different editorial on the same subject, the Toronto Star asked further:

"To what extent has the federal government considered the impact of a waterfront (airport) on recreational activities, from band concerts to boating; on the bird population; residential property values; ground transportation; congestion and air and noise pollution?"

As a final illustration of the impact of public rejection of aircraft noise, it has been stated by J. R. Wiley, director of the aviation department of the Port of New York Authority, that were it not for noise abatement procedures, Kennedy International Airport's capacity could be immediately increased by 35% (see Astronautics & Aeronautics, Feb. 1969, p. 47).

**SUBJECTIVE RESPONSE TO NOISE**

The subjective response of an individual human being to the single occurrence of a noise is complex and variable. It depends not only on factors usually associated with acoustic stimuli, but also on such other factors as the immediate environment; ambient noise conditions; the experiences, attitudes and opinions of the listener as well as the more obvious factors of age and state of health. Prediction of the subjective reaction of an individual to a given noise remains well beyond the state-of-the-art.

Average or collective human response to the noise from an individual flypast of a STOL aircraft is potentially more predictable. The many factors of variability are in effect statistically averaged yielding a certain spread of uncertainty in the data. Collective human response to a number of flybys is more predictable yet: it is, in fact, the end product of community surveys. The noise itself varies with time and location; due in part to transient effects of wind and temperature and in part to the variability of structures and terrain configurations. Thus further averaging occurs with an increased spread in response.

The larger the population sample (in noise-person exposures) the more reliable are mean quantities such as response percentages. A partial analogy (of a much more extreme situation) may be found in the prediction of traffic fatalities: although the details of individual accidents are highly variable and quite unpredictable, the total number of fatalities on a given weekend may be predicted with accuracy from previous surveys.

The average human response to the noise of an individual aircraft can be usefully described by a single number evaluator termed the Effective Perceived Noise Level or EPNL (measured in EPNdB). A number of physical characteristics of the noise are involved: sound pressure level, frequency distribution or spectrum, time variation. (More specifically, the instantaneous sound pressure level in each of 24 one-third octave bands of the noise is required for a number of consecutive increments of time during the flyover.) These are combined in a complicated but straightforward procedure to arrive at EPNL. As a rough rule of thumb, an increase of 10 EPNdB can be considered as approximately corresponding to a doubling of the
subjectively perceived noise.

THE EPNL concept is a refinement of the older Perceived Noise Level or PNL (measured in PNdB) to include the effects of duration and pure tones. The duration correction, for example, accounts for the intuitively apparent fact that the longer lasting of two similar noises tends to be the more annoying. The PNL rating incorporates an average or standard duration of 15 seconds (that is, the instantaneous noise level is assumed to be within 10 PNdB of the maximum for 15 seconds). Thus, a noise without strong pure tone components lasting for 15 seconds would be rated the same on both EPNL and PNL scales.

In the EPNL calculations the actual duration is calculated. Because of the slow speed of STOL aircraft in terminal areas, the duration at nearby observation points may be longer than the standard 15 seconds. Thus, due to the duration correction the EPNL is larger than the PNL rating. For this reason, some advocates of STOL aviation have heatedly argued against the validity of the EPNL concept. It is believed by the writer and all those consulted who could be judged impartial that these criticisms have been adequately met and that the EPNL is a suitable working concept, flexible enough to incorporate changes as soon as justified by further research or advances in state-of-the-art. (For an excellent discussion of the merits of the EPNL procedure see, 'Aircraft Noise Evaluation' by W. C. Sperry, FAA No. 68-3, Sept. 1968).

The collective human response to a number of noise exposures of different levels occurring at various times is calculated by the Noise Exposure Forecast or NEF Methodology. Again this methodology is a development of an older method: the Composite Noise Rating or CNR. For practical purposes it is equivalent to the "Q" procedure favoured in Great Britain or the German "Q" method. As explained above, the larger the number of exposures the more reliable the NEF results.

STOL NOISE VS. CTOL NOISE

In transferring the experience with reactions to CTOL noise to STOL operations, one essential difference must be recognized. Very compelling arguments can be advanced to show that a healthy conventional air transportation industry is truly essential to the economic and social welfare of the whole nation. To avoid strangulation of this essential industry, it is not unreasonable to make some concessions to the accompanying disadvantages such as noise and air pollution. On the other hand, a commercial STOL system does not yet exist: and in any case there are alternatives such as new and old forms of surface transport. Thus the most cogent argument counselling tolerance to a limited amount of conventional aircraft noise cannot immediately be extended to STOL.

Keeping this warning in mind, some broad comparisons between CTOL and STOL noise can help put the latter in perspective. In general, the noise of STOL vehicles operating out of existing airports will tend to be masked by the higher absolute noise levels associated with the conventional aircraft. (For a chart showing the combined effect of two noise sources see Figure 71.) It must be noted, however, that in the absence of special noise reduction measures the typically higher power-to-weight ratios of the STOL's will mean greater engine noise than that from a conventional aircraft of the same size.

The higher power-to-weight ratio has a mitigating advantage, however. Tending to offset the high noise levels is an associated greater rate of climb which enables the STOL aircraft to climb more quickly to altitudes where ground noise levels are objectionable. Thus the "footprint" of high noise on the ground will be constricted for the STOL aircraft.

The relatively slow flight speeds of STOL aircraft in the terminal area also have both favourable and unfavourable noise aspects. Exposure times are lengthened. However, this disadvantage could well be offset by increased manoeuvrability which allows areas particularly sensitive to noise to be avoided.

Some noise advantages of STOL aircraft cited by A. P. Betti of the FAA Flight Standards Service are:

- It will be possible to shorten the distance required to capture and maintain the localizer and glide slope. Three miles to intercept and capture the localizer and two miles to stabilize on the glide slope will be ample for most STOL's. This contrasts with about six miles required by conventional aircraft to perform these same functions.

With STOL aircraft glide paths of 7½° should be acceptable. With such a steep glide path objectionable noise on the ground should be restricted to the last stage of the approach.

Precision offset approaches which will be possible with some STOL designs may offer another possibility for noise abatement. Approach routes avoiding the critical noise areas could be used. In addition, it may be possible to locate STOLports in areas not feasible with approaches restricted to the conventional straight-in procedure.

Better manoeuvrability in narrow confines will assist noise abatement during such operations as circling to land, final alignment, and turning after missed approaches.
Noise levels under the flight path of CTOL aircraft flying at normal cruise altitudes do not significantly contribute to public annoyance. Downtown to airport STOL operations would, however, involve low altitude overflight of densely populated areas (A 2000 foot altitude is envisaged by de Havilland, for instance). In such cases the noise along the ground track may pose some problems. (Although Pilgrim Airlines has been operating Twin Otters over Long Island at 1500 foot altitude apparently without complaints about noise.)

CHARACTERISTICS OF STOL AIRCRAFT NOISE

Propulsion units of STOL aircraft, that is, propellers, rotors, and engines (reciprocating, straight jet, fan jet) are the dominant producers of external noise. Secondary noise sources such as accessories, gearing, panel vibrations, etc., may be significant occasionally but in such cases noise reduction will involve more detailed design considerations with only minor effects on overall vehicle performance.

A very rough indicator of the relative levels of noise from different STOL powerplants is the disk loading: the noise level rapidly increasing with disk loading (see Figure 66). That is, lowest noise is radiated by a powerplant generating its thrust by giving large masses of air a relatively small velocity increment.

In addition to the sound pressure level produced by a noise the spectrum or frequency distribution of the noise energy is very significant. Characteristic noise spectra encountered in the vicinity of various STOL aircraft are illustrated in Figure 67. The low frequency envelope curve A is representative of propeller aircraft. Propeller noise is generally dominated by low frequency components except in the case of very high tip speeds. The noise from reciprocating engine intakes and exhausts also exhibits similar spectral characteristics. Superimposed on curve A, could be discrete frequency components (very narrow peaks) associated with harmonics of the propeller rotational frequency or engine firing frequency. Actually, curve A is a smoothed plot of what in reality is a series of spikes sitting on a low broad band noise -- as obtained by an octave band analyzer.

The broad band noise spectrum curve B is representative of jet engines with exhaust mixing noise dominating. Spectra exhibiting strong discrete tones in the high frequency range (curve C) are associated with lift-fans or with fan jet powerplants without effective acoustic treatment. The relative vertical positions of curves A, B and C will vary depending on the design and operational features of the particular powerplant (particularly the disk loading as mentioned above).

A further important characteristic of noise sources is the associated radiation pattern. Figure 68 schematically illustrates radiation patterns for jet exhausts, reciprocating engines and propellers. The reciprocating engine exhaust and jet engine intake radiate an essentially nondirectional pattern. The propeller radiates very strongly in and slightly behind its own plane of rotation. The jet exhaust radiates most strongly towards the rear at an angle of approximately 45 degrees to the thrust axis.

The patterns sketched in Figure 68 will be slightly different at high forward speeds. But for STOL aircraft in the terminal area speed effects are generally small except in the case of the propeller.

Figure 69 indicates the sound pressure level distributions as a function of distance along the ground beneath a rotating propeller. If the plane of rotation is perpendicular to the ground the highest noise is heard slightly after the plane of rotation passes overhead. If the propeller plane is parallel to the ground (as in tilt-wing configurations in hover) a double peaked sound pressure level distribution results. Forward speed strengthens the front lobe as indicated.

Some typical contours showing noise levels and directional patterns associated with complete aircraft (extracted from NASA Contractor reports) are shown in Figure 70.

ACCEPTABLE NOISE LEVELS FOR STOL DESIGNS

There has been much agonizing and acrimonious debate over what noise levels will be "acceptable" for STOL designs. A recent feature article on V/STOL ('Unclogging the Short-Haul Corridors', by S. M. Levin, Space/Aeronautics, May 1970, pp. 21-31) quotes a figure of 95 PNDB as being the normal level for city traffic' and as being 'accepted by a number of European and American cities'. Combined with a distance variously taken as either 500 or 1000 feet, this level of 95 PNDB has been considered by some sources as a 'target' for STOL designs.

It is true that present technology will be vigorously strained to achieve this 'target' figure with reasonably economical vehicles (c.f. Figure 70). In the writer's opinion it would, however, be naive to construe such a 'target' figure as representative of what will be 'acceptable' to the non-passenger public in the applications envisaged. This opinion was reinforced by discussion with de Havilland and FAA officials (although they probably wouldn't express it in the same terms) as...
well as by casual conversations with many individuals who could be taken as representative of the general public.

The most general statement about noise levels that can be made with a high degree of confidence is that levels 3 PNdB or more below continuous ambient background levels should lead to no additional concern. The basis for this statement is simply that combination of two noise sources differing by 3 dB results in a noise level less than 2 dB greater than the higher of the levels. Such a small difference will not be perceptible. (A chart for combining noise levels expressed in dB is given as Figure 71). It is possible that in downtown areas with moderate or high continuous background noise levels a more intense intruding noise may be less objectionable than it would be in an area of low background levels. (c.f. 'The Effects of Background Noise Upon Perceived Noisiness', D. C. Nagel et al, Tech. Rep. DS-67-22 AD 663 902).

Figure 72 shows typical continuous background levels for a number of urban and suburban situations. Figure 73 shows typical continuous noise levels produced by heavy surface traffic, while Figure 74 indicates levels typical of intermittent noise produced by surface transportation vehicles. For comparison Figure 75 shows how perceived noise level varies with distance for various aircraft types. (All these figures were extracted from data published by Bolt Beranek and Newman Inc.)

Examination of Figures 74 and 75 shows, for example, that a noise level of 95 PNdB at 500 feet from a STOL aircraft would be louder than the noise from a diesel freight train travelling at 50 miles per hour at the same distance. Additionally, Figure 72 indicates that 95 PNdB is about twice (i.e. - about 10 PNdB greater than) the noise in commercial areas with heavy traffic.

Given a vehicle producing 95 PNdB 500 feet away the figures can be used to estimate minimum separation distances that will be required between the vehicle's flight path and observers under various conditions. Alternately, the figures can be used to determine the noise characteristics required by a STOL aircraft to operate out of a given location.

The conclusion to be drawn is that noise will present a formidable impedance to the location of STOLports near or within residential areas (i.e. - intercity and municipal feeder applications). Noise will be somewhat less of an impediment to downtown STOLports. Mr. Law of de Havilland, for example, believes that it will be feasible to make use of existing traffic patterns to mask the STOL noise in most major Canadian cities.

It is apparent from Figure 70 that current designs have a long way to go in reducing noise--even if the noise standards to be met are very optimistic with regard to non-passenger public acceptance.

**CONTROL OF NOISE AT THE SOURCE**

It is evident that the most straightforward method of controlling the noise of STOL aircraft would be to eliminate it at the source; that is, through basic design. Significant advances in reducing the noise from a number of components are reported in the recent literature.

Recent research done at the Hamilton Standard Company seems to point to the possibility of truly impressive reduction in propeller noise in the near future. The company reports that due to technological advances in propeller design criteria, materials, and aerodynamics, reductions of 25 - 30 dB in perceived noise level, without performance or weight penalty, could be achieved by 1975-80.

The noise reduction is made possible by the variable camber propeller, developed by Hamilton Standard. In this design each blade of a conventional propeller is replaced by a pair of tandem low-camber blades. At low forward speeds effective camber is introduced by differential pitch settings on the tandem blades: thus the required thrust can be generated without incurring the noise penalty associated with high tip speeds. At cruising speed the effective camber is reduced for optimum cruise efficiency. Additionally, static testing of a prototype showed an unexpected reduction in noise of 3-4 dB over conventional propellers of the same thrust and tip speeds. Further benefits are expected from weight reductions made possible by new materials and fabrication techniques. (See also Section 2.1.)

It seems that it will not be economical to achieve the full noise reduction potential for commercial applications, however, perceived noise levels of less than 90 PNdB at the 500 foot sideline could probably be achieved with reasonable economics.

The NASA quiet engine program has also made major advances in reducing the fan noise of existing jet engines through installation of acoustic liners in the nacelles. Such modifications have reduced the approach noise of large jet transports by 10-15 EPNdB. (Albeit with substantial penalties in range, weight and direct operating costs.) It is certain that similar techniques combined with increased bypass ratio to reduce the jet noise will greatly reduce the noise of jet powerplants suitable for STOL application. Refinements in spacing of inlet and outlet guide vanes (or their omission entirely) can also lead to substantial noise reduction with little or no penalty in performance.
Invariably, noise reduction extracts its price in penalties in weight, performance, complexity and cost. These penalties should always be borne in mind when considering reported noise reductions. In addition, alteration of a particular component may lead to unexpected effects on the overall system. As an example, in one NASA study a reduction of 200 ft./sec. in propeller tip speed greatly reduced the propeller noise; unfortunately, no appreciable overall noise reduction was achieved due to an accompanying increase in engine noise.

Clearly, then, design of a low noise vehicle must involve some difficult compromises. In order to give the designer a definite goal, and thus avoid wasting time on unsuitably noisy designs, definite noise certification standards for STOL aircraft would be very desirable.

**NOISE CERTIFICATION OF STOL AIRCRAFT**

One method by which the noise of STOL aircraft can be controlled at the source is through denial of an airworthiness certificate for any vehicle not complying with specified noise requirements. Such noise certification requirements are currently mandatory for transport aircraft in the United States. The American Federal Aviation Agency also intends to introduce STOL noise regulations by late 1971.

The basic American noise certification concept is illustrated in Figure 76. Maximum noise levels at three characteristic points (sideline, takeoff, approach) are specified. The specified noise levels are currently related to aircraft gross weight and range from 93 to 108 EPNdB.

FAA officials have indicated that the three point noise certification procedure will be adapted to STOL by (i) moving the measuring points closer to the runway and (ii) changing the noise level limits. The actual values are still being debated. (Although a figure of 90 EPNdB at the 1000 foot sideline was put forward, in a private conversation, as a 'for instance'. This level is approximately equivalent to the noise of a four engine propeller aircraft at approach power at the same distance.)

An additional certification feature specifying the noise limit under the flight path during cruise was also mentioned as probable for STOL.

The FAA noise limits cannot be construed as indicating that complying aircraft (CTOL or STOL) are in any sense 'acceptable' in their noise characteristics. This apparent paradox is explained by FAA officials as the direct consequence of a federal law directing the FAA to impose only regulations that are 'technologically practicable and economically reasonable'. Responsibility for setting permissible noise levels around any particular airport will remain with local authorities.

The philosophy behind the FAA position may be interpreted to be somewhat analogous to that behind, say, a federal regulation requiring trucks to be equipped with mufflers. Such a regulation ensures, at least, that equipment will take advantage of existing noise reduction technology that is readily available at a reasonable cost. Further detailed regulations, such as restriction to certain streets at night are left to be determined by local authorities to suit local conditions.

**TRANSMISSION PATH CONTROL**

It is apparent that present or impending technology is incapable of reducing noise at 500-1000 feet from STOL aircraft to levels compatible with a suburban community. In this case reduction of noise at the source will have to be combined with other noise control procedures. A further avenue of noise abatement is through decreasing the noise reaching the receiver; that is, through control of the transmission path.

The most obvious way of decreasing noise through transmission path control is to increase the distance between the noise source and the observer. Due to spherical spreading, the sound energy from a point source varies inversely as the square of the distance from the source. This relationship is also approximately valid for distributed sources (such as a propeller) provided that the observer is at a great distance from the source relative to a typical dimension (say, at least 25 propeller diameters away). Due to this geometric attenuation the sound pressure level falls off by 6 dB for every doubling of distance.

Even though there is no simple relationship between sound pressure level and perceived noise level (a high frequency sound being, in general, more annoying than one of lower frequency at the same sound pressure level) the figure of 6 dB per doubling of distance may be used as a rough rule of thumb for perceived noise levels at short distances (500-1500 feet, say). This simple rule is completely inadequate for noise sources with peaky spectra or at greater distances.

A sound wave travelling through the atmosphere also loses energy through the action of viscosity, heat conduction, and diffusion. Such losses are termed 'classical absorption' and are proportional to the square of the frequency. Further losses are due to molecular relaxation. These are a function of humidity as well as frequency. The combined effect is very complicated; little can be said by way of generalization except that the total absorption coefficient is expressed as a
fixed number of dB per 1000 foot increase in distance (in contrast to a number of dB per doubling of distance) and that these losses are negligible below about 200 cps. and are very large above 8000 cps. Additional complications arise from wind and temperature gradients and from atmospheric turbulence.

It is apparent that atmospheric attenuation can be utilized to reduce the noise of STOL aircraft capable of steep approaches without high engine power. For designs utilizing high thrust levels during approach increased engine noise may negate the beneficial effects of high approach angles. Operational procedures making use of the high maneuverability of STOL vehicles to avoid overflight of particularly noise sensitive areas have already been mentioned.

A further obvious way to abate noise through transmission path control involves modification of the characteristics of the receiver. The noise transmitted through noise insulation of structures. Simple storm windows can reduce interior noise levels by 2-3 dB. NASA sponsored studies have shown that in areas exposed to less than 100 PNdB interior noise levels can be reduced by up to 10 dB through structural modifications; in areas exposed to greater than 100 PNdB a bearable interior environment can still be achieved albeit only through major reconstruction.

The Los Angeles International Airport has successfully used fiberglass shields to muffle engine noises during ground run up. Such devices may also prove beneficial in STOLport applications.

**RECEIVER CONTROL**

After abatement measures on the noise source and the transmission path have been exhausted one remaining option for noise control involves modification of the characteristics of the receiver. The notion that the public eventually grows accustomed to noise after repeated exposures is often advanced in various forms — sometimes in almost poetic terminology. Witness the first paragraph of an FAA pamphlet (Federal Aviation Agency Planning Series Item No. 3):

"Our world has become progressively noisier since 1900. Yet, even then the quiet of early morning was shattered by steel wheels rumbling against steel rails, by shrill whistles and snorting engines; sleep was broken by the clop-clop of metal-shod hooves; by street cars, subways, and elevated trains. However, as these sounds became familiar, they evoked little protest even from those who at first found them disturbing. Later, as automobiles and trucks added their sounds to the rising cacophony, they too became familiar and were accepted by urban and sub-urban populations alike. Then came the aeroplane, the true herald of the twentieth century. City after city, welcoming airports, anxious to be included in the onrush of progress."

It is well known that repeated exposures to intense noise can cause loss of hearing; presumably followed by an increased tolerance for noise. Of course, here we are concerned only with annoying noise at levels causing no permanent ear damage. Will or will not the acceptability of such noise change due to acclimatization?

Despite the contrary opinions, in the present writer's opinion there is evidence to indicate the existence of an absolute standard for acceptability of noise which does not change due to acclimatization. Some evidence is contained in the results of recent subjective response tests ('Judgments of the Acceptability of Aircraft Noise in the Presence of Speech'; William C. E., Stevens K. N., Klatt M., J. Sound Vib., Vol. 9, No. 2, March 1969, pp. 263-275), indicating that listeners largely judge aircraft noise in terms of potential interference with speech communication. This suggests that our reactions to noise may have been 'wired in' through a long sequence of evolutionary events tending to reinforce the human need for effective communication. At any rate, as was mentioned previously, there is a very strong tendency for increased public resistance to noise of a given annoyance level due to current sociological trends. It seems clear, to the writer at least, that no increase in tolerance to noise from any segment of the public is to be expected without the injection of further compensating factors.

One such factor would be financial compensation. I. H. Hoover, former director of FAA's Office of Noise Abatement, proposed, for example, a sliding scale of real estate tax reductions based on the noise exposure of people living near airports or STOLports. Lost tax revenues, Hoover suggested, could be made up from airport user charges or by a slight increase in the real estate taxes in parts of the community remote from the STOLport but still benefiting from its existence.

More generally, compatible land use patterns around STOLports (achieved through local zoning regulations or comprehensive regional planning or eminent domain) can be used to keep people from high noise regions while they are engaged in noise sensitive activities.

A serious impediment to this type of control is that the noise affected areas around a STOLport will regrettably be administered by a multiplicity of government agencies with various levels of authority. Zoning regulations, for instance, are invariably controlled by the lowest level of government: as a result, major conflicts of interest can be anticipated in cases where
the aircraft noise extends across municipal boundaries.

As an example, Etobicoke (a Toronto suburb) recently approved rezoning of an area close to the end of a major runway of Toronto International Airport. The rezoning is to allow development of 1,727 apartment units and 50 townhouses in an area where (by the writer's calculations using DOT data) by 1972 there will be about 40 overflights a day producing 100 EPNdB.

Since zoning regulations are made at the municipal level, frequent weaknesses exist due to lack of expertise in their preparation, enforcement and defence in court. Additionally, large numbers of exceptions and amendments are often made, usually in response to developers or other special interest groups. To further confuse the matter boards of appeal, such as the Ontario Municipal Board, have wide powers to overrule local ordinances. It is often claimed (in editorials in local papers, for instance) that these boards fail to grasp the relationship between their activities and general community goals.

AIR POLLUTION

Pollution from aircraft exhaust emissions is still a secondary factor in determining public reaction to conventional aircraft operations. What reaction there is seems to be directed against the conspicuously visible exhaust smoke mainly on esthetic grounds. Still many 'bitter complaints' from residents under and adjacent to flight paths include nauseating odors, soiling effects, impaired visibility and eye irritation.

It appears that design solutions to greatly reduce exhaust emissions are or shortly will be available. Rolls-Royce has reported detailed design changes in engine combustion chambers which can essentially eliminate smoke. Significant reduction of contaminants is also possible by using various additives in the fuel. As in the case of noise reduction, a price has to be paid for reducing air pollution. Unfavorable side effects of combustion design and fuel additives for eliminating pollution include higher specific fuel consumption, difficult ignition or increased wear and reduced engine life.

It is probable that in STOL applications, too, air pollution problems will not be as serious as noise problems. Potential difficulties can, however, be envisioned for STOLports located very close to densely populated areas. Conventional airports normally contain enough land area to allow gases and odours to diffuse to tolerable levels within the airport grounds. For small STOLports this might not be possible. The important point to note is that peak emission rates can be dangerously high for short periods of time even in spite of very low daily averages.

It is anticipated by the writer that the most serious potential pollutant around STOLports would be the exhaust smoke. Deposition of carbon particles at ground level would be particularly objectionable in suburban areas. Odours from evaporating fuel will also have to be controlled.

OTHER IMPEDANCES

The non-passenger public may object to STOL operations in their neighbourhoods for a number of reasons involving neither noise nor air pollution. Fear of injury from possible accidents is one such factor. Conventional aircraft accidents involve non-passengers outside of the airport boundaries very rarely indeed. Accidents around STOLports in crowded downtown locations could, however, pose severe hazards to non-passengers. Adverse publicity from the crash of a STOL vehicle into a building or a surface vehicle would undoubtedly prove a serious impediment to STOL aviation. Less serious accidents involving fuel spillage or minor fires would also be more conspicuous to non-passengers and hence result in more than usual adverse publicity.

Fear of crashes could also have an adverse effect on property values near STOLports. Should the presence of STOLports prove to have a depressing effect on local real estate values, organized resistance against their introduction could naturally be expected. From STOL experience, however, it seems that in fact the presence of an airport slightly enhances near-by property values (except in extremely high noise regions): it seems fairly safe to generalize this to future STOLports.

The increased surface traffic generated by a suburban STOLport could also beresented by non-passengers. Careful planning of access and egress routes in cooperation with local authorities should be adequate to minimize this impediment in most cases. This aspect is further elaborated in the section on STOLports.

A further impediment to the introduction of STOL involving the non-passenger public warrants consideration. There has recently developed a vigorous grass-roots tendency among local citizens and rate payers groups or organize and rally to a common cause, usually to resist some government action: the 'Stop Spadina' and 'Pollution Probe' groups in Toronto and Ralph Nader's various consumer action groups in the United States are examples. The phenomenon is too well known to need belabouring. It is quite likely that this type of group will, as a matter of course, oppose the introduction of STOLports. The protesting group could
well be quite remote from the actual STOL-port and the target attacked could be the most unlikely: the 'alligators vs. aviators' contest over the site of the Miami International Airport should give some idea of what can be involved.
FIGURE 66 NOISE LEVEL AS A FUNCTION OF DISC LOADING
(from 'Lockheed Horizons', July 1967)

FIGURE 68 TYPICAL NOISE RADIATION PATTERNS

FIGURE 69 PROPELLER NOISE RADIATION PATTERNS

FIGURE 70 PROP NOISE RADIATION PATTERNS

FIGURE 71 CHART FOR COMBINING NOISE LEVELS
FIGURE 72 TYPICAL CONTINUOUS BACKGROUND NOISE LEVELS

FIGURE 73 TYPICAL CONTINUOUS NOISE PRODUCED BY HEAVY SURFACE TRAFFIC

FIGURE 74 TYPICAL INTERMITTENT NOISE PRODUCED BY SURFACE TRANSPORTATION VEHICLES

FIGURE 75 TYPICAL NOISE PRODUCED BY VARIOUS AIRCRAFT TYPES

FIGURE 76 NOISE MEASURING POINTS FOR STEEL AIRPLANE TYPE CERTIFICATION
Since the final report to the Canadian Transport Commission was completed in July 1970, the author responsible for this section of the work has had the privilege of coordinating a further study on STOLports commissioned by the CTC. This additional work has shed a good deal of light on many of the points still at question in July. In addition, continued developments in the industry, and the issuance of a new version of the U.S. Federal Aviation Administration's guidelines on metropolitan STOLports have put one or two matters into a new context to some extent.

The more recent STOLport study contained input from Canadian authorities in the fields of civil aviation, airport management and operation, telecommunications, meteorology, and airport engineering and architecture. In addition, economic, sociologic and geographic factors were balanced in the study to the extent possible. It cleared up essentially all the STOLport related uncertainties identified in the final report of July 1970, with the very notable exception of locality-oriented questions, e.g. of real estate costs, of local wind shear and turbulence phenomena, of optimum system configurations to fit available sites, and so forth. Such questions cannot be tackled except perhaps on the basis of pure hypothesis, and generalizations, until such time as specific site studies may be undertaken.

The possible significance of what unfortunately remains still unknown may perhaps be illustrated by comparing expected STOLport construction costs with possible STOLport land costs. On the basis of a list of assumptions too lengthy to detail here, a typical at-grade (not elevated) urban STOLport having one runway, ground level automobile parking, and an annual capacity of one million air passengers (enplaned and deplaned) would cost about $4.6 million to build (August 1970 dollars) and would occupy roughly 60 acres of land. If the land in question were worth, say, $1 million per acre, it will be readily seen that the construction costs which have been determined may well be relatively insignificant in relation to the possible $60 million real estate cost implied.

THE LAND COST FACTOR

Land costs of $1 million per acre, as suggested above, may not be particularly excessive in the vicinity of the downtown cores (Central Business Districts, or CBD's) of large metropolitan communities. Land does drop rapidly in value with distance out from the CBD, however, and at the cost of some loss of centrality it may be expected that good potential sites may have much lower costs than has been suggested above. If the travel market should justify the development of more than one STOLport in a given metropolis, these several facilities may be so located as, between them, to make up for the lack of central service within or at the CBD itself. The cost of several decentralized STOLports might well be less than the cost of a single facility placed close to the highest-cost zone. Further research, however, seems to be called for in this area of enquiry.

It is obvious that investments in compact construction of STOLports may pay off handsomely at sites where land costs are very high. For example, a multi-level parking garage might well be cheaper overall than an open parking lot at some locations.

In addition, the implications of aircraft performance might be brought clearly into focus here. On the assumption of a 900 foot wide clear zone (airport owned land, of width as required for Category II IFR operations), although a 200-foot increase in field length requirements would involve only about $40,000 extra in runway, taxiway and concomitant construction costs, the increase in length also would entail the acquisition of about 4 acres' extra land which, at the hypothetical $1M/acre figure, could cost an extra $4,000,000, or 100 times the construction cost figure.

Besides the cost of land, one should also consider the question of land availability. It is easily conceivable that some sites will be of limited ultimate potential length, and may not be able to accommodate "stretched" STOLports at all. From the STOLports viewpoint, then, it is extremely important that (1) STOL aircraft have the best possible performance characteristics, and (2) quasi-STOL aircraft not be allowed to bring about increases in STOLport length requirements.

GENERAL ANALYSIS OF TECHNOLOGICAL IMPELANCES

Ports in general are often looked upon as exchange interfaces between different modes of transport. All airports, STOLports included, interface ground transport with air transport. The only peculiarities of STOLports in comparison with CTOLports arise in connection with the somewhat different characteristics of the air transport vehicles involved. As far as the ground transport vehicles are concerned, there is no new problem; nor need STOLport terminal buildings and other structures involve any questions which have not been met many
times before. Technological impedances are therefore not anticipated in respect of most parts of the total STOLport system, since the problems involved have already been met and overcome in connection with CTOLports. In fact, because certain innovations such as scanning microwave ILS seem to be accompanying proposals for STOLport development, certain former impedances to airport planning and development may be in the process of disappearing (conventional ILS has involved some very difficult problems of beam reflection from building faces, seriously constraining many airport planning efforts).

Here it should be noted that at one time, all aircraft were STOL by today's definition. The CTOL characteristics accepted as "normal" today have arisen in company with such apparent improvements as the adoption of the monoplane form of airframe and the high-speed thin wing, and with increases in aircraft range without refuelling. The evolution of CTOL out of STOL has been a rather continuous one, without a break capable of invalidating much of today's available CTOL technology for STOL applications.

It is obvious from some decades of experience with the development of CTOLports that various aircraft parameters, and changes thereto, have a strong influence on the course of port planning and development. This influence may be illustrated by the notable recent impacts of the Boeing 747 and SST, which have brought about requirements not only to modify existing airports, but also to build some completely new ones. It may thus be said that unknowns connected with STOLports could necessarily derive directly from unknowns connected with the aircraft to be accommodated. Additional technological fields could also have their influences on STOLport questions. Just as aircraft development may be affected by terminal apron design, for example, so also developments in radio and/or visual aids to navigation could affect certain other parts of the total STOLport system. Similarly, airspace considerations may well have an important bearing on the spacings between, and thus indirectly on the ideal sizes of, urban STOLports. It must consequently be pointed out that some STOLport factors are in general knowable only to the extent that parameters may have been fixed in certain related technological fields. Changes to such parameters may well change what we understand about STOLports today.

DEVELOPMENT TIMESCALE

A further important factor which should be considered here, whether or not it can properly be thought of in terms of an impedance, is the fact that new major airport systems always take a good number of years to bring to realization. It has not uncommonly been found, in the U.S. and elsewhere as much as in Canada, that a major airport project takes as much as ten years, from conception or statement of requirement to the opening of the completed new facility. Seven or eight years would in experience today probably be regarded as a very creditable performance, for even getting agreement on a specific conceptual plan can take years. Once a conceptual plan is finally decided upon, there are still the phases of functional planning, design, preparation of specifications and drawings, calls for tenders, award of contract, mobilization of forces equipment and materials, and at last, a period of years of actual construction, followed by finishing, furnishing and commissioning.

High priority jobs can of course be expedited somewhat, but at the same time, the low priority jobs will slip behind, and who is to say that a STOLport might not turn out to be a low priority job in comparison with, for example, a new major international airport? Priorities being a major policy matter set largely at the top administrative levels, it is impossible to speculate fruitfully here on what the outcome will be for STOLports, but it is at least possible to point out that a single STOLport, much less a network of STOLports, of the kind we have been discussing will not be made ready overnight, in any event.

STOLPORT SITES

The most vexatious problem the STOLport section of this overall study has uncovered is that of assuring the very availability of suitable downtown STOLport sites within several major Canadian cities. For example, a proposed Montreal STOLport development at Expo 67's Victoria Carpark has been rumoured to be in danger from a plan to build Olympic facilities there; an alternate, equally attractive STOLport site may perhaps be hard to identify in the area. Similarly, a potential downtown Vancouver STOLport site is understood to be the subject of current redevelopment studies by the City of Vancouver; since the City has not yet been advised, as far as is known, of any STOLport potentiality of the area, one may expect that the eventual redevelopment plan will not provide for the inclusion of a STOLport, unless active steps are soon taken at least to communicate the nature of the problem to the City. Similarly, public redevelopment of certain lands in both Toronto and Ottawa could imminently cancel the availability of potential downtown STOLport sites in both of these cities.

This is not to say that adequate alternative city-centre sites will in no case be found, but the course of current events
does seem to pose certain practical dangers. A do-nothing policy therefore cannot be recommended in this matter. It is suggested that the candidate cities for downtown STOLports should be alerted to the possibilities as soon as possible, along with other governmental bodies, e.g. the respective provincial and regional governments and, in the case of Ottawa, the National Capital Commission. In addition, the regional offices of the Canadian Air Transportation Administration should be briefed on the current STOL studies and be brought thoroughly into the picture so as to be equipped to work locally with the cities and other governmental organizations to prepare locally-oriented proposals within the overall system framework which current studies should provide.

Mention should be made, at this point, of the situation regarding non-urban STOLports. STOL operations might potentially be established at existing peripheral airports now serving commercial, military or private CTOL aviation, and might in such instances involve all five route types under consideration. That is, in every known class of service application it is conceivable that civil STOL aircraft would utilize existing non-urban CTOLports (including General Aviation airports) at some point or points on the routes flown. Special technological impedances are not foreseen in this connection, beyond such matters as the need for suitable navaids at CTOLports which could also be utilized by STOL aircraft, and the need for adequate system capacity to handle the new services. Development of STOL services under these circumstances would probably not be subject to the timescale difficulties mentioned in the previous section of this report.

In some areas, entire new STOL systems may be developed in preference to CTOL, for reasons of economic advantage and/or physical feasibility. An area particularly thought of in this regard is Canada’s North. If anything, the impedances to STOLport development would be less in such applications than those to CTOLport development. The main exceptions to this rule might again be connected with the availability of suitable navaids, in particular.

Thus the really significant problems are all connected (but not necessarily exclusively) with metropolitan STOLports, and can in general be adequately discussed in the latter context alone, for the sake of simplicity. It does not follow, though, that non-urban STOLports will closely resemble urban ones; some non-urban sites may, for example, even allow the luxury of multi-runway layouts, and may in other ways reflect the lower cost of non-urban land. Again, northern and remote sites are scarcely likely to involve the terminal facilities needed for urban services.

**GROUND CONGESTION**

Questions concerning public nuisances such as noise, pollution and crash hazards must figure prominently in discussion of any airport activity, STOLports not excepted. These important matters are fully discussed in Section 2.4. However, the nuisances of general ground traffic congestion and of port access costs and delays are not treated elsewhere, and it is appropriate to point out that these important factors may have a significant bearing on the strategy of STOLport deployment.

It would seem to be a mistake to attempt to centralize STOLport operations as has in the past been done with CTOLport operations, since the downtown traffic arteries feeding the STOLport might well be unable to bear the extra traffic burden, and the public would not thereby receive the optimum services most competitive in average total trip times and costs with other modes of travel. Furthermore, it may well be that land restrictions will preclude the development of sprawling STOLports (e.g. with parallel runway) close to the central business districts of most cities, or even within much of the built-up area.

September 1970 study performed by the Construction Engineering and Architectural Branch of the Canadian Air Transportation Administration for the Research Division of the Canadian Transport Commission was designed to determine the approximate cost and typical configuration of a conceptually "modular", single-runway, at-grade, downtown metropolitan STOLport, to have an assumed annual capacity of one million passengers, enplaned and deplaned. The "modular" concept in this exercise implied that, when one STOLport will have reached capacity, a new one would be opened elsewhere, located strategically to give local service to a new segment of the total potential market. This may perhaps seem a bold idea, but the assumption has at least allowed reasonably dependable costing and configuration studies to get underway; up to the present time, one distinct impedance to STOL system progress has been the lack of dependable studies of this type. The essence of the findings of the investigation, based on the assumptions made, is contained in Table 32 and Figure 77. Readers are cautioned not to attempt to apply the indicated cost estimates to situations other than that assumed in the study. It is particularly to be noted that land acquisition and clearance costs have not been included.

**STOLPORT CAPACITY**

There may be argument over the above selection of an annual STOLport capacity of one million passengers as the basis of this additional investigation. Some will consider the figure too large, while others
whether there will be two aircraft or what is, or what is not "economically feasible".

VEHICLE RELATED PARAMETERS

As of July 1970, certain unsettled aircraft-related parameters still constituted impedances to tying down STOLport costs and configurations. Aircraft dimensions necessarily affect parking apron dimensions and layouts, as well as affecting the shape and length of the apron/terminal building interface. The use of high aspect ratio, lightly loaded, monoplane aircraft wings tends to spread the aircraft parking positions apart from one another, and thus to require extra land, extra pavement, extra service utilities, extra terminal building length, and in summary extra capital costs at the port, and possibly extra passenger and operator inconvenience. As a mitigating factor in the STOLport case, however, STOL aircraft should have short turnaround times at the ramp, and hence it may develop that only a few aircraft positions will have to be provided at any one STOLport site. So, a compact arrangement may be feasible despite the unusual wing spans currently associated with STOL aircraft. The unsettled parameter, then, is turnaround time; for example, it is not certain whether there will be two aircraft or ten on the apron. (In the September STOLport study, an aircraft turnaround time of 15 minutes was assumed, with an average 5-minute delay in the spotting of new aircraft at the recently vacated stands. On the basis of a 48-passenger aircraft three active stands were required, plus one stand-by. The resulting layout has proved to be reasonably compact, and does not call for mobile lounges, moving sidewalks or other "people mover" devices.)

In another example, it is obvious that factored airfield length requirements will largely determine the major STOLport land costs and some aviation pavement costs; in some instances, factored field length requirements may well determine whether a STOLport will be feasible at all within a certain land parcel, as already noted.

An immediately attractive idea which may not be obvious at first is to use soft field undercarriage to reduce the prospective costs of STOLport pavements. However, at least for smaller aircraft (e.g. 48-passengers' size) it is necessary to design typical Canadian airport pavements more for frost resistance than for bearing strength, meaning that only a minor reduction in pavement cost can in fact be made if high-flotation tires are specified. Special conditions may vary this finding, however. For example, given a frost-resistant subgrade soil such as sand, the pavement design would presumably be predetermined mainly on the question of strength; the potential saving might still be slight, though. In another example it might be possible, at one actually proposed site located atop an unstable garbage fill, to use a series of expendable light pavements rather than an expensive permanent arrangement of reinforced concrete slabs bearing on piles, if soft-field undercarriage, designed in part to absorb heavy shocks, were to be used. This is a matter to be studied further in connection with specific site-related investigations; meantime, great overall economies cannot realistically be expected to arise out of the use of special undercarriages on first-generation STOL airliners, under Canadian conditions.

In general it may be stated, then, that until such time as STOL aircraft parameters become absolutely fixed, there will remain certain unknowns as far as STOLports are concerned. These unknowns will chiefly inhibit the cost estimating and planning phases leading toward any development of a practical STOL system. The phases of design and construction will be affected mainly to the extent that the planning which must precede them may be held up.

The optimization of the parameters in question to the greatest benefit of the aircraft and port system jointly seems advisable if total costs are to be minimized and benefits maximized. The costs considered should not be restricted to operators' costs alone, but should also cover all net costs to the community at large, to the travelling public and to the governments involved.

NAVIGATION AIDS

Important impediments to successful IFR STOLport development within the urban environment could result if various aids to navigation (navaids) cannot be improved
from the viewpoint of tolerance of the presence of structures and other obstructions. Whereas a CTOLport of thousands of acres' area, such as Toronto or Montreal International Airport, may well be able to absorb conventional ILS localizer and glidepath restrictions, PAR (precision approach radar) restrictions, AASR and ASR radar restrictions, antenna farm restrictions and so forth, each covering a zone perhaps 2,000 feet across, it is clear that downtown STOLports will be unable to do so. It is to be hoped that the new scanning microwave ILS being developed in the U.S. may solve an important part of the problem, but the situation concerning other aids needs further consideration.

Fortunately, PAR apparently is already on its way out, even at major CTOL sites. The remaining local-coverage radar antennae may have to be mounted on high buildings in the downtown area, possibly at some distance from the STOLport site. ATC (air traffic control) facilities, however, may be adequately housed at the terminal building, provided that a view both ways along the flightway is assured. Some electronic information can be "piped in" from the major CTOLport serving the area: area radar coverage may be handled in this way, for example. In summary, only local radar coverage may create problems within the downtown environment. Specific site studies will, it is hoped, in due course provide the answers to such problems.

SYSTEMS APPROACH

Beyond the specific subject matter discussed it is emphasized that the STOLport must be, and must be regarded as, a complete system. This approach may at times contrast with the tendency of some persons to think of "airports" only in terms of runway, ATC and navaid systems; or of certain other groups to think of "airports" only in terms of passenger terminal buildings or some other particular features. One should in fact consider a long list of factors including at least the following: land, runways, taxiways, aprons, visual aids (lights, markings, signs et al), non-visual aids (ILS et al), air traffic control and communications facilities, terminal facilities (including equipment) for passengers, baggage and cargo, aircraft servicing and maintenance facilities, port maintenance and operation facilities including crash/fire protection, snow clearance and similar equipment and related garage facilities, utilities (electric, water and sewer, field drainage, heating, cooling and ventilating, fueling), and ground access system facilities including internal and external roads, curb areas, car parks, traffic interchanges, lighting, signs, signals, markings and so forth.

If some of the foregoing items were not to be carefully considered, the total system might not function acceptably for commercial operations of the calibre required today. The plurality of the essential features should be noted; no single item should be fixed upon as the indispensable factor.

It follows that a balanced comprehensive approach, often referred to as "The Systems Approach", should be taken for proper individual STOLport development planning. Furthermore, the same approach should be taken to extend the study beyond local boundaries and to consider how the port in question ties into the national and regional transportation networks.

WORKING COMMITTEES

CTOLport planning experience has shown that the only practical means of achieving this goal to the satisfaction of all interested parties is to constitute interdisciplinary working committees. The work of such committees calls for considerable investments of man-hours of staff time; any shortage of available man-hours must in this context be seen as an important potential impediment to the satisfactory carrying out of such work within a suitable time frame.

On a closely related point, the chairmen of working committees of the type in question are in a position to "make or break" their respective committees' work, and accordingly the chairmanships should be closely controlled via guidelines and reviews of progress. Chairmen should be selected for their knowledge, ability, fairness and objectivity, and should be given to understand from the outset that their portfolios carry no implications of absolute authority or of power to make unilateral decisions, but rather that they must conduct meetings in such a way as to bring forth all pertinent views for discussion and for group decisions. In addition, chairmen should be prepared to resist undue pressures. The negation of working-level committee efforts through applications of power politics has plagued progress in certain studies in the past, and this hazard stands as a potential practical impediment to future STOLport progress unless it can be circumvented in some way.

AIRLINE SPACE REQUIREMENTS

An important unknown in airport planning sometimes is what facilities the various operators will demand, and will pay for. Should extensive and expensive STOLport facilities be required by these groups, spiralling land requirements, facility costs and possibly public dissatisfaction can be foreseen. There is reason to hope that demands will be kept very modest for
STOLport facilities, in recognition of the foregoing point. Our current comparative lack of certain knowledge in this area must at present be seen as a matter for consideration if perhaps not as a definite constraint on progress toward STOLport developments.

OFFICIAL GUIDELINES

Guidelines and criteria affecting the aircraft operating areas on, and airspace at, STOLports apparently have not yet been firmly fixed anywhere in the world, although the FAA in the United States is approaching this goal in respect to metropolitan STOLports at least, with their Advisory Circular 150/5325 - at the "working draft" stage (at the time of writing). Attention needs to be turned to developing a similar official guidance document applicable within Canada, and not only for the metropolitan STOLport case. Whether the current lack of the necessary official guidance can be defined as a "technological impedance" seems a moot point; there is every indication that such guidance is in an advanced state of preparation, and that it could be published at rather short notice if this should be required in future. Indispensable aid to the September 1970 STOLport study was in fact provided by the Civil Aviation Branch of the Canadian Air Transportation Administration in the form of quite well developed, if provisional, STOLport planning criteria.
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<tr>
<td>VASIS</td>
<td></td>
<td></td>
<td></td>
<td>20,000</td>
</tr>
<tr>
<td>Car Park and Roadway Lighting</td>
<td></td>
<td></td>
<td></td>
<td>96,000</td>
</tr>
<tr>
<td>Power Supply</td>
<td></td>
<td></td>
<td>Including ticketing spitters</td>
<td>300,000</td>
</tr>
<tr>
<td>Water Supply</td>
<td>16/9/70</td>
<td>CBEP/CBED</td>
<td>Including building unit substation and emergency power unit</td>
<td>40,000</td>
</tr>
<tr>
<td>Sanitary Sewers</td>
<td>16/9/70</td>
<td>CBEP/CBED</td>
<td></td>
<td>30,000</td>
</tr>
<tr>
<td>Landscaping</td>
<td>16/9/70</td>
<td>CBEP</td>
<td>Including security fencing, flagpole, etc.</td>
<td>60,000</td>
</tr>
<tr>
<td>Buildings</td>
<td>15/9/70</td>
<td>CBAD</td>
<td>Terminal Construction</td>
<td>1,131,000</td>
</tr>
<tr>
<td>Control Cab (installed)</td>
<td></td>
<td></td>
<td>Control Cab (installed)</td>
<td>49,000</td>
</tr>
<tr>
<td>Composite (services) building</td>
<td></td>
<td></td>
<td>Composite (services) building</td>
<td>160,000</td>
</tr>
<tr>
<td>Tests, furniture, consultants, admin. etc.</td>
<td></td>
<td></td>
<td>Tests, furniture, consultants, admin. etc.</td>
<td>360,000</td>
</tr>
<tr>
<td>GRAND TOTAL</td>
<td></td>
<td></td>
<td></td>
<td>$4,600,000</td>
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</table>
3. RESEARCH/RECOMMENDATIONS

INTRODUCTION

The analysis of Section 2 suggests that the impedances hampering introduction of a Canadian STOL transportation network are mainly economic and institutional. Technological impedances to the development of first generation STOL vehicles have been, on the whole, largely eliminated by an intensive worldwide research effort during the course of the past decade: as of now, only refinements and the normal development involved in the introduction of any new aircraft type are required. Although the associated air traffic control and navigation equipment are not quite as well developed, only moderate levels of further research and development will be required.

It is quite clear that American industrial and government laboratories will continue to vigorously and competently pursue STOL research and development to meet the challenge of remaining technological problems. The present study did not uncover any area that appeared to require large scale research and development due to individually Canadian conditions. Some Canadian research will, however, be essential: if for no other reason than to monitor the American work and to maintain the level of technical expertise needed to exploit American developments. If Canadian industry wishes a share of the STOL market beyond the first generation system it must keep abreast.

Research carried out elsewhere will not be immediately available to Canadian manufacturers or operators. Further, it will always be necessary to interpret foreign research in the context of typically Canadian conditions. This remark applies in particular to research concerning social factors such as public (both passenger and non-passenger) acceptance. In view of these considerations, it was the opinion of the project staff and consultants that a moderate level of Canadian research effort in all STOL areas will be mandatory to ensure the future viability of the Canadian STOL aviation industry. It was also felt that such research would be most effective if carried out through complementary programs involving government, industry and universities.

Accordingly, the exact level of research effort and whether the research should be predominantly basic or 'mission-oriented' will be more a matter of government policy than of strict necessity for the introduction of a viable STOL transportation system. It must also be pointed out that many relevant questions cannot be answered through research alone. For instance, the level of subsidy to operators serving unprofitable but politically important routes is clearly in this category. As another example, operationally meaningful answers to questions such as "By what yardstick are permissible noise levels around a STOL port to be determined?" are not available. Such answers will have to come from public policy considerations that will be greatly influenced by whether the term "public" is to be applied at the local, provincial or federal level.

The research and recommendations outlined below presuppose the necessity for high calibre STOL research in Canada. At the same time it is recognized that Canada's precious national resources must be utilized in a cost-effective manner. Existing capabilities and special competence in Canadian institutions must be utilized in a program that avoids needless duplication of foreign research.

COLLECTION AND DISTRIBUTION OF DATA

In a number of areas, impedances to STOL aviation are exacerbated by a lack of Canadian data and the poor distribution of existing data. For example, the model studies described in Section 1 are subject to a number of limitations, previously noted, due to a lack of suitable passenger origin and destination (O & D) data. Such data do not exist for cities other than Toronto and Montreal and, in fact, deficiencies exist in the data even for these cities. Local O & D information is needed for all centres where STOL service is contemplated. More precise data on the 'waiting time' parameter (to which the downtown to airport model of Section 1 was highly sensitive) are also needed. The gathering of such data should be organized by a central agency. Some of the work could be done at the universities by graduate students of the Masters' level in connection with studies in the transportation field.

The collection and distribution of data would also be of great benefit in the regional transport application. A striking feature of third level airlines is the high rate of business failure, often blamed on poor management. Since a major part of the driving force behind such airlines often comes from community participation it would be worthwhile for management to be aware of the pitfalls that have caused previous failures. Means of assembling relevant information and disseminating it to potential operators should be studied. At the same time, information relating to technical support functions could be distributed. This program should be continuing and of broad coverage, perhaps under the guidance of the Department of Consumer and Corporate Affairs.
Estimates of public reaction to STOL aircraft noise could also be rendered more reliable through the acquisition of data. Canadian data relating complaints to Noise Exposure Forecast levels are not now available. Such information would be very helpful in discussions with citizen groups concerned about possible noise levels around a proposed STOLport. It is suggested that such data could result as a useful by-product of graduate research connected with either noise or sociology.

STOL SYSTEM OPERATIONAL STUDY

A STOL system operational study using actual vehicles and STOLports under typical service conditions could form the basis of a comprehensive research program, implementing a number of the recommendations to follow. Such a program would involve the use of STOL aircraft and variable stability helicopters to determine field requirements, flight path gradients, manoeuvring space, operating margins, and go-around and crosswind capabilities. STOLport layouts could be field tested. Navigation and guidance aids and air traffic control procedures could be developed. In addition, vehicle noise characteristics would be measured under operating conditions. Non-passerenger public reaction could be surveyed and correlated with Noise Exposure Forecasts. On site measurements of STOLport turbulence and its effect on handling qualities could also be made and correlated with theory. The project would involve fully instrumented aircraft and STOLports to obtain the maximum amount of data from each flight. A small network of simulated STOLports could be utilized, with one located at a major airport to determine the effects of STOL/CTOL interaction. In order to establish the proper atmosphere, an airline with appropriate experience should be hired to provide pilots and consultation concerning operational aspects. The STOLport side would involve the MOT, and STOL vehicles are available from de Havilland, Canadair and the NAE.

The flight phase of the program would be of about a year and a half in duration using three instrumented aircraft operating 500 hours each. Evaluation of the results would need active cooperation from several government departments, industry, airlines and universities and would take an additional one or two years.

REGULATIONS

In most STOL designs short field performance is realized through use of aerodynamic lift derived, at least in part, from the vehicle powerplants. (See Section 2.1). Present airworthiness regulations (as of July 1970) do not, however, allow such 'powered lift' to be used in the performance calculations required for certification. Accordingly, STOL concepts have been based on the belief that (now non-existent) powered lift regulations and certification procedures will be soon forthcoming. Section 2.5 has already noted some impedance to STOLport development caused by lack of definition of the aircraft. The following, from an LTV design study performed for the NASA indicates the present regulatory problem:

"The (power-off) stalling speed of the airplane is (presently) considered an operational limit, and many other flight characteristics are based on this speed, for example the minimum allowable takeoff and approach speeds are functions of the (power-off) stall speed. Such requirements are not appropriate for V/STOL aircraft because they are designed to operate safely below the (power-off) stall speed.

"Numerous V/STOL concepts use gas generators to drive thrust producing devices through interconnected transmission systems... The existing Federal Aviation Regulations are concerned with engine failures where propellers are connected directly to the engine. The Federal Aviation Regulations must be modified to take cognizance of these interconnected transmission systems and establish regulations which assure safety after a failure occurs anywhere in the propulsion system."

The work of the American FAA in this field could serve as the basis for Canadian regulations. Regulations restricting the noise of STOL aircraft are also required. In Section 2.4 it was explained how noise certification of STOL aircraft could be used to partially control the noise around STOLports. In order to give community planners an indication of what noise levels to expect and to give designers definite objectives for noise reduction, it is urgently recommended that noise certification regulations be adopted in Canada. (Even regulations as insipid as the current FAA transport aircraft noise regulations would provide a start.)

Research and development results helpful in the framing of the regulations could be drawn from the STOL system operational study as described above.

ADVANCED STOL CONCEPT SELECTION

Over the course of the past few years a number of advanced STOL concepts having various attractive features have emerged. Numerous paper studies comparing their relative merits have been carried out, and a variety of wind tunnel tests and actual flight tests have been performed. Continuation on this broad front would appear unduly expensive. It would make sense to gather together all the available information and rank the concepts in an overall effort to establish the most promising. This program would utilize the results of the other research areas in order to reach
as enlightened a decision as possible. It would seem that this effort should be co-ordinated by an unbiased central agency such as the National Aeronautical Establishment while in turn would subcontract out parts of the job to the manufacturers, airlines and universities. Following the selection of the most promising concepts, they should undergo extensive wind tunnel testing: the NAE 30 by 30 foot V/STOL tunnel would be ideally suited.

An exhaustive selection study could take up to ten researchers a period of two years. The wind tunnel phase could take an additional two years.

**COMMUNICATIONS**

Even though at present the communications portion of the air traffic control system is satisfactory, increasing traffic density will undoubtedly necessitate more automatic to reduce communication time lag and to speed traffic flow. Further research is needed in the application of the computer to automatic clearance delivery, data link and position reporting. This work is underway in the United States and there appears to be no special reason why Canada should enter the area. It is recommended, however, that the Canadian Government monitor American research and that provision to incorporate future communication improvements into Canadian STOL service be adopted from the outset.

**NAVIGATION SYSTEMS**

There can be little doubt that area navigation would greatly facilitate STOL operations in the terminal area. (See Section 2.3.) Further research and development is still needed to improve and lower the costs of existing systems. Canada has an excellent record in the area of navigation systems (R - Theta, moving map displays, inertial guidance systems) and this expertise could be put to good use in improving and further developing presently existing area navigation systems. Such work will, however, proceed in the U.S. with or without Canadian participation.

Further study should be directed at selection of the most suitable method of terminal area navigation for STOL service in the larger metropolitan areas. Specifically, a study of approximately six months duration, involving two or three professionals could examine the use of various systems for the Toronto and Montreal areas, and possibly Vancouver.

In a further study of navigation systems, companies could be invited to participate in the development of an accurate navigation system for northern routes. This should include consideration of Decca chains, Loran-C in a version applicable to a STOL aircraft with a two-man crew (it is noted that suitable Loran sets appear to be available) and the Omega system.

**APPROACH AIDS**

The work underway in the U.S. on microwave ILS systems is so advanced that it is doubtful that Canada could make a cost-effective contribution. Research and development centres around production of a microwave approach aid for CAT II conditions with sufficient capability and reliability to make it suitable for airline use. In conjunction with this, a reliable area navigation system should be developed which can be used for at least CAT I approaches, with the possibility for eventual improvement to CAT II. An area where Canada might well participate is in development of a system rendering the standard VHF/UHF ILS signals compatible with scanning beam microwave receivers without the necessity for two separate on-board systems.

**AIR TRAFFIC CONTROL**

Canadian computer hardware and application specialists could well use their expertise to study the use of computers to automate the aircraft clearance delivery and reporting functions. Such research would go beyond that needed for the introduction of STOL services, but would result in adequate preparation for the more dense traffic situation in the 1980's. It must be noted that research into methods of incorporating the computer into the air traffic control loop are being vigorously pursued in the United States: thus care must be taken to ensure that Canadian research will be complementary.

Development of air traffic control procedures for area navigation is also required. It is anticipated that FAA work in this area will need to be supplemented by additional Canadian development. Tests will have to be conducted to ascertain the suitability of procedures before STOL airline service can begin.

**HANDLING QUALITIES**

From the pilot's point of view the STOL aircraft handling qualities are of paramount importance as they influence system performance under operational conditions. Handling qualities are a complex function of such things as vehicle stability, response to disturbances, control system characteristics and cockpit displays. To date a considerable amount of effort has gone into the study of V/STOL handling qualities, but this area of research has not yet produced a set of guidelines sufficiently complete to allow the design of an advanced concept STOL aircraft with any degree of certainty. It appears that the most productive application of this research would be to study the handling qualities of the particular vehicle.
concepts selected as most promising. This program could involve variable stability helicopter flights and ground based simulator studies plus support staff for a period of about three years. Both the NAE and Canadian industry have suitable facilities and the universities have personnel interested in this type of work.

The results of such a study should include the desirable ranges for vehicle stability derivatives, control system characteristics and the necessary instrument display layout.

INSTRUMENTATION

There is a very real need for improved visual displays and flight directors to assist pilots making instrument landings. Existing Canadian competence in the field of human operator performance could be used to advantage in the design of such displays.

It must be noted that much research and development is yet needed to produce effective, reliable and inexpensive collision avoidance systems. Especially in view of the fact that area navigation may increase the risk of collisions. Unfortunately, there seems to be scant Canadian capability to conduct effective research into such systems.

STOL simulators for pilot training will also be needed. The development of practical hardware with the flexibility to cover a wide variety of STOL situations, instrument and procedural training would be most useful to the STOL operator. The economics of such a simulator would have to be carefully assessed if it is to be used by STOL airline operators.

STOLPORT DEVELOPMENT

Studies of 'modular' urban STOLport configurations have already been completed for the Canadian Transport Commission (see Section 2.5). However, STOLport concepts suitable for downtown sites in large cities need not necessarily set the pattern for STOLports at smaller communities served by regional airlines, since much of the emphasis at downtown sites is on extreme compactness, with good capacity. Simple packaged STOLport concepts complete with various degrees of IFR capability should be analyzed and the results made available to all interested communities. The emphasis should be on convenience, reliability and low cost, whatever the circumstances. In this connection all reasonable methods of minimizing airfield capital costs should be investigated. These might include further developments of soft and rough field gear to minimize surface strength requirements (but see remarks in Section 2.5). Outside the urban environment, dust may not present a problem, and gravel-surfaced strips may be possible; such strips may be regraded as often as necessary, and may therefore need less protection against frost heaving than their urban equivalents. In this case, though, capital cost will be saved only at a sacrifice in continuing maintenance costs and possibly in delays for grading, especially in springtime. Then again, the cost of special gear has to be considered.

To ensure the viability of any program of STOLport network development over the years, however, a small continuing design-oriented study related to specific sites might well be required on a continuing basis, its continuity depending in part upon the pace of developments and the spread of STOL services to the various parts of the country. The importance of land costs (as brought out in Section 2.5) must be considered in conjunction with such a program. An initial survey of possible sites should establish costs per acre and available land in and adjacent to large traffic generating areas across Canada. A continuing program should establish cost trends with time and the rate at which land at possible sites is becoming unavailable due to other developments.

It is recommended that community noise studies be made an integral part of the specification of STOLports. Typical Noise Exposure Forecast (NEF) contours associated with various levels of operation should be included. For possible suburban applications, separate NEF limitations should be available for daytime and nighttime operations. In addition, the effect of climatic variations on the NEF contours should be investigated.

Note should be taken of the important fact that STOLport development may most realistically be expected to take several years, whereas the aircraft to use such ports could probably be put into service relatively quickly. The Boeing 747 has lately illustrated how easily this relationship can arise. Consideration should therefore be given to what decisions may have to be made at a very early date, if the lead time required for STOLport development is not to produce a good deal of trouble in future.

STOLPORT TURBULENCE

In conjunction with handling qualities studies it would be very desirable to determine the nature of the STOLport environment with regard to turbulence, wind shear and crosswinds. This information in turn would serve as a realistic input to the handling qualities work by providing information about the disturbances through which the aircraft must fly. Such research could involve both theoretical and wind tunnel studies, with support from actual site data. Together the universities and the NAE have the necessary
expertise to carry out such a study.

An appropriate program could involve three professionals, a wind tunnel and support staff for a period of two years.

**PROPELLION SYSTEMS**

Research on various aspects of STOL propulsion should be considered. The problems in need of study include:

1. Quiet, efficient propellers to handle the thrust requirements of large STOL vehicles (necessary if noise restrictions result in the use of turboprops on the second generation aircraft).
2. Quiet turbofan engines.
3. The optimization of engine bleed air characteristics.
4. The optimization of turbofan takeoff and cruise thrust.
5. The development of a technique for effective thrust modulation on turbofans for glide path control.
6. The design of ducting systems and wing structures to accept them in order to direct bleed air to high lift devices.

It is expected that one or more of these research needs may be eliminated through the rejection of certain STOL design concepts, but all require at least some preliminary work to allow the STOL concept selection to be made with the most refined data possible.

Past work on propellers carried out by Hamilton Standard has indicated that studies such as the influence of blade shape on noise, the development of variable camber propellers and the use of lighter materials now under development should lead to a significant reduction in propeller noise by allowing the use of lower tip speeds and larger diameters. Canadian industry has indicated a desire to carry out such a research program.

The research on turbofan engines should concentrate on high bypass ratio fans and acoustic treatment in order to achieve lower noise levels. Variable pitch fan blades to improve takeoff/cruise thrust matching and the thrust modulation required on approach could also be examined. These development programs could probably be best carried out by the engine manufacturers themselves with some basic studies carried out by government laboratories such as NRC. The research should be aimed at development of the system or systems considered most promising.

The recommended Canadian program in the turbofan field would be a modest effort aimed at monitoring advances in the field while at the same time attempting to contribute to the basic understanding of the phenomena.

**FURTHER SYSTEMS ANALYSIS**

It is recommended that the crucial step of deciding just what factors to include in the system analysis be carefully reexamined. For example, very useful results might be obtained from a study into methods whereby the influence of the system on the non-passenger public could be injected into economic models. Similarly, the systems approach necessary for STOLport planning emphasized in Section 2.5 could be profitably injected into the passenger-route-vehicle system employed in Section 1 to establish the impact on the country as a whole and not just on the passengers and operators. This type of research may lead to a way of estimating the cost/benefit relationships of various ameliorative proposals: at the very least it would serve to pinpoint the relevant issues.

In Section 1 the economics of various STOL applications were analyzed by optimizing the combinations of traveller trip time and cost. More sophisticated systems analysis, going beyond the value of time concept, to assess passenger preferences would be particularly useful in analysis of the less densely travelled, short municipal feeder routes where ground competition is very important.

It should also be possible to derive an optimum development path relating the size and speed of aircraft and number of STOLports to forecasted traffic and physical constraints of the STOLports. In particular, a study of the traffic diverted for an IFR STOL strip at a conventional airport should be made for the intercity, municipal feeder and downtown to airport applications. Associated effects on capital costs and community noise levels should be investigated.

Consideration could also be given to studying factors influencing the production base of a second generation Canadian STOL aircraft. Tables 33 and 34 show the predicted size of aircraft that will be needed by 1980 (based on 1969 data and a 12% yearly growth rate) to serve routes between the cities studied in Section 1. Sixteen round trips per day (or approximately one every hour) were assumed with a load factor of 0.5. The effect of providing a lower frequency of service or of operating at higher load factors can be assessed from the data presented. The size of aircraft required depends on the number of STOLports in Toronto and Montreal as well as the frequency of service and the cities served. For the applications studied it would appear that one or two distinct STOL aircraft types might profitably be developed for 1980. One vehicle
would have about 11 to 25 seats, the
other 30 to 60. Both aircraft could be
used on intercity and municipal feeder
routes. It is expected that a system op­
timizing travel benefits and at the same
time providing a substantial production
base for a second generation vehicle could
be defined.
### TABLE 33

**Airplane Seating Capacity Giving 16 Round Trips Per Day to Each STOLport Pair**

*Value of time A, CTOL fares, 2 STOLports in Toronto and Montreal*

<table>
<thead>
<tr>
<th>Route</th>
<th>1969 300 mph</th>
<th>1980 500 mph</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toronto - Barrie</td>
<td>1 0</td>
<td>8 2</td>
</tr>
<tr>
<td>Belleville</td>
<td>7 2</td>
<td>30 8</td>
</tr>
<tr>
<td>Hamilton</td>
<td>0 0</td>
<td>2 0</td>
</tr>
<tr>
<td>Kingston</td>
<td>20 5</td>
<td>81 22</td>
</tr>
<tr>
<td>Kitchener</td>
<td>1 0</td>
<td>9 1</td>
</tr>
<tr>
<td>London</td>
<td>13 4</td>
<td>56 16</td>
</tr>
<tr>
<td>Niagara Peninsula</td>
<td>8 2</td>
<td>33 9</td>
</tr>
<tr>
<td>North Bay</td>
<td>10 2</td>
<td>39 11</td>
</tr>
<tr>
<td>Oshawa</td>
<td>0 0</td>
<td>0 0</td>
</tr>
<tr>
<td>Ottawa</td>
<td>56 16</td>
<td>216 68</td>
</tr>
<tr>
<td>Peterborough</td>
<td>3 1</td>
<td>11 5</td>
</tr>
<tr>
<td>Sarnia</td>
<td>8 3</td>
<td>33 11</td>
</tr>
<tr>
<td>Sudbury</td>
<td>12 4</td>
<td>55 16</td>
</tr>
<tr>
<td>Windsor</td>
<td>35 11</td>
<td>140 47</td>
</tr>
<tr>
<td>Montreal - Ottawa</td>
<td>20 14</td>
<td>77 53</td>
</tr>
<tr>
<td>Quebec</td>
<td>44 27</td>
<td>169 103</td>
</tr>
<tr>
<td>Lakeshore</td>
<td>99 52</td>
<td>116 60</td>
</tr>
<tr>
<td>Malton</td>
<td>20</td>
<td>24</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Route</th>
<th>1969 300 mph</th>
<th>1980 500 mph</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toronto - Barrie</td>
<td>1 0</td>
<td>7 2</td>
</tr>
<tr>
<td>Belleville</td>
<td>4 2</td>
<td>19 8</td>
</tr>
<tr>
<td>Hamilton</td>
<td>0 0</td>
<td>1 0</td>
</tr>
<tr>
<td>Kingston</td>
<td>16 7</td>
<td>50 22</td>
</tr>
<tr>
<td>Kitchener</td>
<td>1 0</td>
<td>6 1</td>
</tr>
<tr>
<td>London</td>
<td>8 4</td>
<td>34 15</td>
</tr>
<tr>
<td>Niagara Peninsula</td>
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<td>North Bay</td>
<td>6 3</td>
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<tr>
<td>Oshawa</td>
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<td>0 0</td>
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<td>Ottawa</td>
<td>35 19</td>
<td>122 67</td>
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<td>Peterborough</td>
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<td>10 4</td>
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<tr>
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<td>80 46</td>
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<tr>
<td>Montreal - Ottawa</td>
<td>11 11</td>
<td>41 44</td>
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<tr>
<td>Quebec City</td>
<td>23 22</td>
<td>87 84</td>
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<tr>
<td>Lakeshore</td>
<td>27 20</td>
<td>31 23</td>
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<tr>
<td>Malton</td>
<td>14 18</td>
<td>17 20</td>
</tr>
<tr>
<td>Don Valley</td>
<td>21 16</td>
<td>24 19</td>
</tr>
</tbody>
</table>
A BIBLIOGRAPHY OF STOL

TECHNOLOGY
This bibliography has been assembled in support of the study of STOL technology sponsored by the Canadian Transport Commission. The available literature in the STOL field has been reviewed and annotated for relevance, quality, and depth of coverage. The time allotted to the complete study was four months which resulted in a two month period within which all the literature had to be obtained and reviewed. This search was carried out under five main headings, each area being handled by a different individual or group of individuals. These areas were:

(I) Vehicle Design and Performance (A. R. Gray and L. D. Reid)

(II) Operational Aspects (R. J. Taborek and D. Yue)

(III) Navigation, Guidance, and Air Traffic Control (L. Steigerwald and T. Ussher)

(IV) Non-Passenger Public Acceptance (L. Filotas)

(V) STOLports (P. T. Hodgins)

Those reports reviewed in detail are contained in these five sections of the bibliography. Within each of the five sections the reports have been grouped under a few main headings as a further aid. Although this attempt at classifying the reports has certain shortcomings it is felt that it will provide a useful guide for readers interested in a particular topic. An appendix to each section contains those reports that were considered to be of interest but were not reviewed as a result of the two month time limit; no rating or comment has been attached.

To provide a simple index as to the relevance of each reviewed paper, a rating of R-1, R-2 or R-3 has been placed at the start of each review. This rating scheme is intended to aid the user in obtaining the desired depth of coverage in the minimum of time.

To ensure a knowledgeable assessment of each field and to allow completion of the bibliography within the limited time it was necessary to utilize a group of reviewers. As a result, each area is characterized by its own style and format despite some attempts to achieve uniformity.

The aims of the bibliography were achieved through the use of the following techniques:

(1) The topics deemed to be of interest were determined through an interaction of all the program personnel. The relative importance of these topics was estimated by developing a 'relevance tree' to serve as a guide to the individual reviewer in his selection of papers to read. In addition, a cooperative spirit was established, encouraging individuals to pass along to the appropriate reviewer any papers thought relevant to his area.

(2) A library assistant (a graduate student in aeronautics) was hired to search through the yearly aeronautical indexes under topics supplied by the reviewers. The abstracts of all papers found under these headings were copied and supplied to the appropriate reviewer who in turn scanned them to determine which reports to study. This search technique was applied to the 1968, 1969, and 1970 listings of the International Aerospace Abstracts (IAA), Scientific and Technical Aerospace Reports (STAR), and the U. S. Government Research and Development Reports (USGDRD). IAA uses subject categories identical with those in STAR and publishes similar indexes. IAA's world wide coverage of books and journals complements STAR's world wide report coverage. The USGDRD Index is produced by computer from records generated by the Clearinghouse, Atomic Energy Commission, Department of Defense, and National Aeronautics and Space Administration and consequently has some overlap with IAA and STAR.

(3) While the library search was in progress, the reviewers began reading the reports on hand. Due to the short time available it was decided that only the most relevant reports were to be reviewed. This ideal had to be compromised somewhat in practice due to the slow arrival of some papers.

(4) The individual reviewers obtained their reports either through personal contacts or through the University of Toronto Institute for Aerospace Studies Library.
These reports were found through the search of the indexes and the bibliographies of reports under review. Some excellent review papers in the STOL field were of particular help in this aspect. Thus with a base of recent papers, the literature review reached back in time to pull in the older material. It was generally found that the most relevant work had been reported in the last 5 to 10 years.

The UTIAS librarian, aided by the study's secretary, did an admirable job in obtaining the large volume of reports ordered by the reviewers. The number of reports obtained and their sources are listed below:

<table>
<thead>
<tr>
<th>Source</th>
<th>Reports</th>
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<tr>
<td>U.S. Department of Commerce Clearinghouse for Federal and Scientific Information</td>
<td>57</td>
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<tr>
<td>NRC Aeronautical Library</td>
<td>129</td>
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<tr>
<td>University of Toronto Library</td>
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<tr>
<td>American Institute of Aeronautics</td>
<td>75</td>
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<tr>
<td>UTAAS Library</td>
<td>87</td>
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<tr>
<td>Other Sources</td>
<td>115</td>
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Of these, some were reviewed and some listed in appendices.

In addition, approximately 82 reports (ordered from various sources) did not arrive in time to be reviewed. Another problem encountered involved the use of microfiche. The quality of these microfilm copies was usually not good enough to allow reading: as a result it was not possible to review or scan some reports until "hard copies" were available.

The introduction to each section indicates the state of the literature in the particular field as it appeared to the individual reviewer. In general, the papers included deal with the concepts and results of studies involving STOL technology and do not treat in detail the theories and experimental techniques employed in arriving at the results. It is felt, however, that those interested in this detailed information can obtain the required references by searching the bibliographies of the papers included herein.

Restriction of this study to STOL allowed the completion of the bibliography within the relatively short time span. This limitation, however, did mean that the many papers dealing with non-STOL commercial flight transport technology which might be applied in part to STOL were not reviewed. Relevant non-STOL papers in the references of the papers previously reviewed and those known to the reviewer are, of course, included. Since the technology of VTOL can often be applied directly to STOL, relevant VTOL papers were often reviewed along with their STOL counterparts.

In a few instances, it was necessary to accept papers which might not have been the most appropriate possible, simply because they were the only ones available at the time. Furthermore, it is recognized that a number of papers of unquestionable merit were omitted because of their highly detailed and theoretical outlook. Although they might add greatly to the general knowledge in the field, the ground rules imposed on this bibliography necessitated their omission. It is apparent from this literature search that the number of papers in the field is expanding rapidly: most being produced in the United States. The large number originating from commercial firms in support of their "product line" has generated a wide variety of outlooks on the various aspects of STOL.

It is the unanimous opinion of the reviewers that the STOL field has been covered as thoroughly as possible within the limits of time and personnel allowed. The extensive specialized background of the program consultants was fully utilized in selecting the latest and most relevant material. Further, the suggestions and comments offered by the CTC project officers during the preparation of the bibliography provided valuable guidance.
I. VEHICLE DESIGN AND PERFORMANCE

INTRODUCTION

This section of the bibliography deals with the design and performance of STOL vehicles. An effort has been made to assemble reports on all aspects of design, from overall aircraft sizing to minor subcomponents. Particular attention has been given to features - such as high lift devices - which are or tend to be peculiar to STOL aircraft. The performance papers deal mainly with handling qualities and landing and takeoff capabilities.

In general, it appears that the field of design and performance of STOL vehicles has been well covered in the open literature. Exceptions to this, however, include subsystems (APU's, landing gear, stairs, etc.), barrier crash survival, internal noise and cabin design, and crew factors.

The reviews are divided into seven sections, as outlined below.

General Perspective

A number of reviews of the state-of-the-art in STOL design have been written which provide an excellent background for the accomplishments and problems discussed in other papers. These have been included in this section of the report. Here also are found the summaries of the STOL evaluation studies carried out with the Breguet 941 by Eastern and American Airlines.

Design Studies

An indication of the general level of confidence within the industry that the major STOL technological problems have been solved is contained within the many detailed design studies aimed at producing commercial vehicles. Chief among these are the reports done for the NASA by Boeing, Lockheed, and Ling-Temco-Vought, which collectively consider a wide spectrum of VTOL and STOL configurations. Much recent effort has been applied in this field, in an attempt to incorporate the various lift devices, propulsion systems, and structural components into a suitable aircraft design.

Aerodynamics/High Lift Devices

This well documented section includes wind tunnel testing of isolated models as well as flight tests of full scale systems. Many types of high lift generating devices have been tested, usually in wind tunnels initially, and then on modified aircraft. Some of the papers in this section are applicable only to the particular technique being examined, while others are of a general or review nature. Recent papers in this field make some value judgements concerning the different systems, a process which is very educational. Some further work on high lift devices may be found in the following section as well.

Propulsion Systems

As indicated above, there is a close link between the papers on propulsion systems, and the papers on high lift devices. The reason for this, of course, is the STOL tendency to derive a significant percentage of lift from thrust, particularly in the more sophisticated designs. Papers in this section consider a number of different propulsion systems and techniques applicable to the STOL situation. Much of this effort is devoted to turbofan systems although no one appears to have an answer to their noise problem. One paper on propellers for STOL aircraft was found.

Handling Qualities

A number of papers have been reviewed which deal with the study of the handling qualities of various STOL configurations. The papers span almost a decade in time and indicate that progress is being made in understanding the dominant factors in this complex field. Stability augmentation and simulator work are included in this section, as well as some papers on variable stability test vehicles. Of particular interest is a set of reports by the NASA on a number of STOL aircraft which they have tested over the years.

Performance

Most of the information on performance uncovered in this literature review is to be found in papers which have been included in the other sections of 'Design and Performance'. There are, however, a number included here which deal primarily with the landing and/or takeoff capabilities of various aircraft, and with the methods of achieving the maximum performance in the terminal area. Little attention is given to cruise or ground performance.

Crew Factors

This section, dealing with pilot workload and cockpit layout was the most neglected in the STOL literature. This is perhaps because the main target of research and development has been to achieve the necessary flight hardware. The only paper included here concerns pilot visibility on landing, although some reference is made to pilot workload in reports under other headings.
This report is a collection of some of the many concepts which are influencing the development of STOL. The emphasis is on a brief description of these factors and thus it is a good report to read to obtain a feeling for the overall picture. The main headings cover The Air Vehicle, V/Stolports, Air Traffic Control Systems, Air Navigation Systems and Certification.

Under the heading "The Air Vehicle" the importance of the interaction between required field length and DOC's is mentioned along with the various means by which short field performance can be achieved. A brief outline of various STOL aircraft is given indicating their main features. In addition Eastern Airlines' V/STOL specification is presented as an indication of the type of vehicle which would fit into the Northeast Corridor transportation network. These proposals are placed in perspective by the findings of the CAB regarding STOL operation in the Northeast Corridor, "The period up to 1974-75 will see the introduction of STOL aircraft types using presently available and proven power plants, essentially turboprop."

The minimum acceptable for initial operations in the Northeast Corridor.

(iv) The aircraft should be able to operate out of runways no longer than 2000 feet.

The safety of the proposed designs was emphasized. There did not appear to be any technological impedances to hinder the inauguration of an STOL system.

This report deals with the American Airlines STOL evaluation programme performed in 1969 with the Breguet 941 aircraft. A series of tests were conducted in four areas of the United States with emphasis on the aircraft, the navigational and ATC procedures, and the operational procedures. Less importance is given to day to day airline compatibility than by Eastern Airlines in their evaluation, and more study is made of the aircraft itself in order to determine acceptable levels of vehicle performance. For this reason, this report is more useful to the designer, and of less use to the operations man. Both reports give about equal attention to navigation and ATC problems.

American Airlines reports on a large number of mostly minor features of the design and performance of this aircraft which make it unsuitable for airline use. This, of course, is an indirect method of giving the specifications they feel are required of such an aircraft. The most serious difficulties involved the turbulence response at low speed, and the IFR approach pilot workload. The oscillations brought on by turbulence are of such severity that a number of Technical Observers were airsick during the tests. The pilot workload was such that safety criteria would be violated in Category I and II landings, and the pilot could be unable to respond swiftly to emergency situations. Another problem area was climb-out on three engines, and severe crosswind capability. In general, it was found that stability and control of the aircraft were good. Taxi was tricky because of the narrow tread, but with a revised checkout list, operations at the gate were good. Takeoff and landing were performed regularly in distances less than 1000 feet, with minimal use of brakes on landing roll-out, and limited power build-up before brake release on takeoff.
results of this test programme indicate that airlines are much more sensitive to handling and riding qualities than are military and production test pilots.

Some work was done in these tests by a stewardess in establishing passenger service requirements, but American did not carry a full complement of seats and little effort was made to simulate the passenger aspects of the operation. Flight tests involved approaches and landings and airwork rather than enroute analysis.

Like the Eastern Airlines evaluation, this report gives the designer important insights into the applicability of his vehicle to the commercial market.

STOL AND V/STOL CONCEPTS FOR FUTURE INTERCITY AIRLINERS
P. G. Kappus
Presented at: AssociationFrancaise Des Ingenieurs et Techniciens de l'Aeronautique et de l'Espace, Congres International Aeronautique, 9th June 1969

This report deals with the new concepts being advanced for short haul airliners, notably the STOL and V/STOL variants. The emphasis of the paper is towards the propulsion and lift systems, and the methods used to increase their performance. The article does not deal with any specific aircraft, but generalizes the characteristics to produce a 'paper' vehicle for each of the CTOL, the STOL, the V/STOL, and the VTOL types. Economics of the types are also presented in order to point up the fact that it is possible to offset cost increases due to equipment complexity by improved utilization and productivity afforded by those complexities.

The paper discusses the introduction of the new STOL services, typical route structures, field performance, terminal compatibility, safety, noise, passenger acceptance, and economics for airlines. A good review is given of the various powered lift devices, and the resulting trends in gross aircraft weight. At this point, the generalized configurations are introduced, with operational techniques and engine requirements being discussed, followed by a brief economic analysis.

It is the conclusion of the paper that STOL should be introduced immediately, and that further, more advanced types should be in the design process to be ready later in this decade. The point is made that the two most serious problems at this time are noise, and low speed handling and controllability. The study provides a very good starting point in the analysis of future STOL feasibility and availability. For this reason it has been given a high rating.

STOL DEMONSTRATION PROGRAM
A. S. Crossfield
Society of Automotive Engineers Paper 690420, April 1969

This report (also published as Eastern Air Lines Report Flight R&D 68-315, and as McDonnell Douglas Corporation Report G984) deals with the Eastern Air Lines STOL demonstration program of late 1968 using the Breguet 941 STOL aircraft in the northeast corridor. This programme was directed primarily at the study of the STOL system rather than at this particular aircraft. For this reason, much of the report would be of interest to those in the operations and electronics phases of the airline industry, rather than the airframe designers. A good report is presented, however, dealing with the performance and handling qualities of the aircraft.

When reading this report and others on the Breguet 941, it is important to remember that the aircraft was originally built as a military vehicle, and therefore does not meet airline standards in all areas of safety margins, riding comfort, and economy. For this reason, it is also important to know the background (military or airline) of the flight test pilots. The main problem encountered on the ground was due to the narrow tread of the landing gear. The rolling tendency caused by this was deemed unacceptable. In takeoff and climb, at high gross weights and high temperatures, the thrust abilities of the aircraft were somewhat marginal for airline use, especially in the engine-out case. In approach and landing, the most serious problem was encountered when flying in choppy air. Some loss of stability and controllability were noted.

Passenger reactions were in general favourable, and no serious difficulties were encountered in the area of passenger comfort. It is suggested that footrests would be helpful in offsetting the sinking feeling from the steep descent. Similarly, no system problems of serious magnitude were encountered from the operations viewpoint, although minor CTOL interfacing and navigation difficulties did arise. It was felt that a faster cruise would be useful in bringing the aircraft into full competition on
the intercity routes.

This report is very important in that it is the first extensive test of a STOL system in everyday operation. Even though it is not primarily concerned with design and performance of the particular aircraft, it is very useful in acquainting the manufacturer with the market situation.

**VTOL and STOL TECHNOLOGY IN REVIEW**
Staff of NASA Langley Research Center
Astronautics and Aeronautics pp. 56-67
September 1968

This is a well written article describing the design and performance realities of VTOL and STOL vehicles. The data used has been derived from flight and wind tunnel tests and the application of reasonable assumptions concerning regulations. Comparisons are made among the various techniques which have been proposed in order to achieve short field operations.

The low wing loading approach to STOL allows short field operation with conventional flap systems but suffers in cruise economy when compared with powered STOL (e.g. deflected slipstream). It is cautioned that the use of propeller-driven STOL aircraft with light wing loadings (e.g. 50 psf.) would probably bring back riding qualities comparable to the propeller-driven aircraft of the 1940s and 1950s.

The tilt-wing and deflected-slipstream vehicles both suffer some loss of lift in ground effect and both have limitations on rate of descent, caused by wing stalling when the power is reduced to establish a steep descent path. The technology required for the development of operational propeller-powered VTOL and STOL aircraft of the tilt-wing and deflected-slipstream concepts is effectively in hand.

More efficient vehicles are produced when the distribution of lift over the wing becomes more uniform.

The immediate development of operational turbo-fan powered VTOL and STOL aircraft with reasonable assurance of success would go beyond the state-of-the-art. However, fan-powered aircraft have many potential advantages, and there is no fundamental impediment to their development in time.

**GENERAL STUDIES OF THE CHARACTERISTICS AND PROBLEMS ASSOCIATED WITH V/STOL OPERATIONS**
N. W. Boorer B. J. Davey
The Sixth Congress of the International Council of the Aeronautical Sciences
ICAS Paper No. 58-05 September 1968

This paper discusses in a very general fashion the design and performance requirements of a V/STOL aircraft which is to provide a proper level of passenger service and at the same time is to be capable of competing in the transportation market. The paper opens with some comments on the present transportation system (foot, subway, car, bus, train, plane, ship) and shows where service gaps occur. One of these gaps is located about the 100 mile range, a range ideally suited to a STOL system.

The remainder of the report is devoted to the general requirements of the STOL or VTOL vehicle to serve this identified market. For STOL aircraft, comments are made concerning the cruise, takeoff, and landing performance, noise, landing techniques, lift and propulsion characteristics, and safety margins. A similar discussion of VTOL looks more closely at the different types -- helicopter, compound helicopter, tilt rotor, tilt wing, fan-in-wing, and jet lift. The paper concludes with a discussion of airport and economic considerations.

The paper is not by any means devoted entirely to the design and performance of STOL vehicles, but it has been given the high rating for both its treatment of this topic, and for the inclusion of other relevant features of the whole transportation system. This paper would be of use to others besides the design office types in providing a general acquaintance with STOL.

**STOL AIRCRAFT - A PERSPECTIVE**
R. D. Hiscocks
The Aeronautical Journal, Vol. 72 No. 685, pp.11-33, January 1968

This paper is an excellent review of the development of STOL and the state of the technology as of 1967. The following excerpt from the summary is valid:

"The interest in Canada in the design and manufacture of utility aircraft with STOL performance may be traced back to the difficulties of surface transport in the early development of the country and the widespread use of bush aircraft.

The leading characteristics of the STOL aircraft are examined with
particular reference to design features essential to a short take-off and landing. The choice of powerplants and lifting systems is discussed with emphasis on the requirements for powered lift in the larger sizes of aircraft.

The phases of the takeoff, transition, climb and landing manoeuvre are reviewed to illustrate the relative importance of various parameters in design and operation. The importance is stressed of good stability characteristics and effective controls for manoeuvring in a confined air space and a consistent landing performance."

The author feels that the complexity of cross-shafting of propellers is not justified due to the increased probability of a malfunction in such an elaborate mechanical system. Also, normal aerodynamic controls should be sufficient until the advent of the larger and more advanced STOL aircraft of the future.

The steep approaches used by STOL aircraft reduces their sensitivity to disturbances allowing precise flight path control in landing.

The paper also describes the use of STOL aircraft in para-military operations.

STOL TECHNOLOGY STUDIES
RAX-084-148
Canadair Ltd., Montreal, March 1970

This paper views the STOL situation from the "tilt-wing" viewpoint. Vehicle DOC's for the tilt-wing turbo-prop STOL mode are shown to be comparable to those for a turbofan STOL and the DHC-7. However the comparison suffers from an inconsistent set of field lengths for the vehicles. Noise level estimates for the turboprop tilt-wing STOL give 98 pndB at 500 ft. and 103 pndB at 500 ft. for the turbopfan. The main thesis is that tilt-wing technology is in hand and provides a better solution to the STOL question than light wing-loading vehicle types.

The paper's introduction was as follows:

"This note presents background material and some preliminary results of recent studies on STOL aircraft carried out at Canadair. Interest in V/STOL has been strong at Canadair for over 10 years, and the selection of the tilt-wing concept at an early date was strongly influenced by its STOL performance as indicated by wind tunnel tests and analysis. Flight test experience with the CL-84 has confirmed its unique STOL capability, and the present study investigates the potential of larger aircraft based on the CL-84 propulsion components in the STOL mode of operation. In order to form a basis for comparison, as well as to examine the potential and capabilities of STOL aircraft using turbofan propulsion, a study has also been made on this type of aircraft with external flap blowing. Results are presented showing gross weight, cruise speed, field lengths etc. for 48 and 80 passenger aircraft for both types described above."

PRINCIPLES OF STOLPORT OPERATION
The de Havilland Aircraft of Canada Ltd.
November 1969

This report describes the operation of STOL vehicles in the elevated STOLport terminal area. In particular, attention is given to the takeoff and landing requirements for safe operation. A set of aircraft requirements are presented which depart from current practice in some aspects in order to make full use of the special characteristics of STOL aircraft.

It is proposed that in the case of operations into elevated STOLports no aircraft should attempt a landing unless all engines are operating normally. An arrester hook/cable system should be provided to prevent overruns.

It is proposed that an optical guidance system be employed along with a microwave ILS to minimize landing dispersions. If an approach is low or if the touchdown is not achieved within the touchdown zone the pilot should execute a go-around.

The results of an analysis of the proposed landing technique are presented and shown to be reasonable.

Although the report is sketchy it does cover the factors which influence the takeoff and landing distances required by a fixed-wing STOL vehicle.

DECISION-MAKING TO DETERMINE EARLY ADVENT OF STOL
L. L. Bollinger
Vertical World, July-August 1969

The thesis of this paper is that the technical and economic feasibility of STOL in the commercial market have now been proven. All that remains is to overcome an industry and government
inertia and produce a consistent set of design performance characteristics and operating regulations. The belief is expressed that once airlines can unite to state what they want of a STOL machine, and once government regulatory bodies can accept the manufacturers' word that the STOL aircraft are capable of operating safely within a revised set of standards, then the market for STOL aircraft for commercial transportation will "explode".

As evidence of the health of the potential market, the author cites a comparison between helicopter and STOL operating costs, as well as referring to Eastern Air Lines' recent specifications issued for a 100-150 seat 500 mile range STOL aircraft. Four aircraft sizes are envisaged: 100-150 seat for major (Boston - New York) city centre service; 30-40 seat for most city pairs; 10-18 seat for smaller community service; and 4-6 place aircraft for air-taxi purposes. Various studies of demand are loosely quoted to support these sizes. Several problems are mentioned which might interfere with the introduction of STOL, not the least of which is a lack of organization within the industry.

The paper closes with a commentary on cost, speed, and runway length, in which the point is made that door-to-door times may be significantly reduced by STOL relative to jet transport types at essentially the same cost for short ranges. As guidelines, the cost-speed-runway figures mentioned are 1.5\$ per seat mile, 280 knots cruise, and 1000 ft, and 2000 ft, runways, depending on the application.

Written by an executive of a STOL manufacturing firm, this report is very enlightening with respect to one of the major non-technical difficulties in the industry.

PORTS FOR STOL - SOME OBSERVATIONS
R. D. Hiscocks and R. J. Taborek
SAE-680274, April 1968

This paper discusses the operation of twin engined STOL vehicles. System costs are covered and compared to other means of short haul transport. A suggested change in regulations is outlined which would improve the safety of operation for this class of aircraft. It is pointed out that in order to obtain the full benefit for STOL vehicles, field length margins should be determined from statistical analysis of demonstrated performance.

It is pointed out that landing accident rates in civil transport aircraft vary as the square of the landing speed, thus favoring STOL.

VTOL ADVANCES AS DETERMINED FROM ANALYSIS OF FUTURE NEEDS AND TECHNOLOGICAL POTENTIALS
B. Lindenbaum, R. Mabli, R. Krabal
American Helicopter Society Journal
Vol. 13, January 1968

This paper argues in favour of VTOL as opposed to STOL as the proper route for future transportation systems, both military and civil. STOL is only mentioned with reference to vehicles which have both a STOL and a VTOL capability, and the argument is made that by including STOL operation, the designer saddles himself with a 50\% payload penalty for VTOL uses of the aircraft. This is an interesting reversal of the usual rule of thumb that a V/STOL aircraft operating in the VTOL mode can carry 50\% less payload than STOL because of the different takeoff technique.

A number of technical advances are mentioned in the area of VTOL which quite possibly are applicable in the STOL and in fact the complete aircraft field. One area explored in some detail which is particularly applicable to STOL is STAL (Short Time Additional Lift), including GETOL (Ground-Effect Takeoff and Landing).

The main body of the paper, however, is devoted to VTOL.

STOL AIRCRAFT A CANADIAN CONTRIBUTION TO THE MOBILE FORCES
R. D. Hiscocks
In Preprints of Papers to be Presented at the 1967 Congress of Canadian Engineers, Series D, May 1967

The paper presented here is a condensed version of the Hiscocks paper "STOL Aircraft -- A Perspective", given as the Twenty-Third British Commonwealth Lecture and printed in the Aeronautical Journal Vol. 72, January 1968. The more complete paper is reviewed elsewhere in this bibliography.
This report presents the results of a very comprehensive design study done on the CV-7A transport, the Buffalo. The purpose of the design was to modify the aircraft in such a way that it would be a flight test vehicle for research to be done on the augmentor wing concept. Ground tests of the augmentor wing lift generation technique at de Havilland Canada had shown lift coefficients of 6.5 to be attainable, and further testing was required. The aircraft would be re-built according to the design study recommendations, and the system could be evaluated as to its performance. Also investigated would be the aerodynamics of the installed system, and the ability of the aircraft to operate under specified flight procedures. The vehicle was to be capable of operating out of a 1,000 foot runway.

The study first considers the available propulsion systems for the aircraft, and examines the performance and installation for each. Using these various engines, a set of nine possible configurations are postulated, and each described in some detail. The aerodynamic and STOL performance of each is studied, as well as the flight techniques required to control the vehicles. Speeds, margins, and handling qualities are studied, and the final configuration is chosen. Due to engine considerations, four of the types were easily eliminated, and another two were dropped because of centre of gravity problems, and poor roll characteristics. The vehicle was finally chosen on the basis of engine performance and design considerations. The aircraft has four turbo-shaft engine-compressor units (General Electric T-64) for flap air, and two turbofan Orpheus engines for horizontal thrust. Thrust vectoring was available for the latter two engines.

Having made this selection, a further study was done to optimize the performance and controllability of the aircraft. This section of the report is very detailed and considers propulsion, control systems, the aircraft systems, structures and loads, flight dynamics, aerodynamics, stability and control, and performance. The work in each of these areas is quite extensive as an attempt is made to provide the maximum STOL capabilities.

This volume of the report is very instructive in the design process for STOL aircraft, and presents important ideas which must be considered when evaluating STOL designs. Volumes II and III of the report give the exact specifications for the modifications, the flight test programme, and the modification costs. They are not reviewed in this bibliography.

FEASIBILITY OF V/STOL CONCEPTS FOR SHORT-HAUL TRANSPORT AIRCRAFT
B. L. Fry, J. M. Zabinsky
NASA CR 743, May 1967

This report provides an extensive investigation into five VTOL and two STOL aircraft types. The purpose of the study was to determine any technical problems in implementing the new types, to check on their economic viability, and to provide a rating as to their relative merits. No specific aircraft were studied, but rather the authors created their own aircraft according to a stringent set of design conditions which covered range, fuel requirements, cabin layout, payload capabilities, landing and takeoff performance, flying qualities, weights, and speeds. Thus, the postulated aircraft were all designed for the same mission and could be inter-compared. For each type, the report provides a configuration design analysis in which the inherent philosophy and tradeoffs are explained and many of the 'nuts and bolts' decisions are made; an operational analysis which considers the ability of the types to fit into various approach techniques, manoeuvre patterns, ground procedures, route structures, and other facets of the superstructure of our air transportation system; and comments on public acceptance, acquisition costs, direct operating costs, operation over a hypothetical route, technical risk, required research, technical and economic tradeoffs, and airworthiness requirements.

The two STOL types considered are the fan-in-wing, and the turbofan. The requirements of the study dictate a 60 passenger capacity over a 500 mile route, with a 2,000 foot runway. The study determines that there is no technical impedance at this time which seems to be severe enough to prevent any of the designs from becoming operational, but that obviously some model types are better technically and/or economically than others. The study picks the turbofan STOL ahead of the fan-in-wing, but comments that the
fan-in-wing has short runway advantages over the turbofan. On the hypothetical route, the STOL direct operating costs are consistently lower than the VTOL costs, being of the order of $1.20 per aircraft mile for the turbofan for the 500 mile range. Even for the 25 mile stage the STOL costs are lower ($4.30).

In the design section of the report, information such as wing sweep, thrust line, emergency equipment weight, and other 'non-gross' details are given, and the reasons for the choice made explained. In this respect, the report is very helpful in providing an understanding of the design problems and difficulties which are likely to be encountered in the production of a STOL aircraft.

V/STOL -- A WEIGHTS STUDY OF VARIOUS CONCEPTS
J. S. Wisniewski
Presented at the 28th Annual Conference of The Society of Aeronautical Weight Engineers, Inc., May 1969

This paper presents the weights study done by Boeing engineers on a number of V/STOL concepts: jet lift VTOL; tilt-wing VTOL; lift fan VTOL; and turbofan STOL. The results of this study as reported here are included as part of NASA CR-743, reviewed elsewhere in this bibliography. One must always remember that one of the most important aspects of the design of any aircraft involves the elimination of unrequired weight, and this report shows how it may be done in the V/STOL case, taking into account the particular requirements of the mode.

STOL TRANSPORT DESIGN
W. C. J. Garrard, J. M. Eaton
Lockheed Quarterly, Vol. 4, No. 2, pp. 10-17, August 1967

A preliminary design study was carried out on 2 sizes (60 passenger and 120 passenger) of 3 STOL aircraft concepts. The three design concepts were:

(i) Deflected Slipstream using 4 cross-shafted turboprops and full span Fowler flaps. Low speed control was achieved with a rudder employing blowing boundary layer control and lift spoilers for roll control. It was concluded that an automatic flight control system was required to achieve satisfactory low speed handling qualities.

(ii) Jet Flap design employing blown air to control the boundary layer on the flaps, ailerons, rudder and elevator. Automatic stability augmentation is required at low speed.

(iii) Fan-in-Wing with 4 lift fans driven by the main thrust engines. Stability augmentation required.

All 3 designs employed techniques to overcome yawing effects if one engine should fail.

Tables and graphs provide a range of general information concerning the character of these aircraft. No mention is made of any technological impedances.

REVIEW AND EVALUATION OF BOEING DESIGNS FOR THE NASA SHORT-HAUL COMMERCIAL TRANSPORT STUDY
B. L. Fry,
NASA SP-116 (Conference on V/STOL and STOL Aircraft) pp. 315-338 April 1966

This paper outlines a preliminary design study of some V/STOL commercial transports. The concepts and some typical design tradeoffs are discussed briefly. The designs studied were:

(i) Tilt-Wing turboprop. The tilt-wing concept has little technical risk compared with other VTOL concepts. Required major research and development is confined to the propeller, hub and control system hardware.

(ii) Jet Lift VTOL. Work needs to be done on the aerodynamic interactions between the propulsion system and airframe.

(iii) Stowed Rotor VTOL.

(iv) Lift-Fan VTOL.

(v) Turbofan STOL with blown flap system. An externally blown rudder system may be required.

It is pointed out that such items as stairs, auxiliary power units, and ground air conditioning could be built into the STOLport reducing vehicle weight and DOC's.

A considerable amount of detail is included in this report giving data about the designs and operating characteristics of the vehicles.
SUMMARY OF LING-TEMCO-Vought
FEASIBILITY STUDIES
K. R. Marsh, J. J. Santamaria and
R. B. English
NASA SP-116 (Conference on V/STOL and
STOL Aircraft) pp. 353-388
April 1966

A preliminary design study was carried
out on 3 V/STOL concepts.

(i) Tilt-Wing Turboprop. A high
wing design employing lead­
ing-edge slats and full span
double slotted trailing-edge
flaps. The tilt feature was
required only for operations
out of runways of less than
2000 ft. length. It was felt
that cross-shafting of the
four propellers was necessary.

(ii) Fan-in-Wing Concept.

(iii) Propulsive Wing Concept.
This employs a wing which
acts as the propulsive plant
through the use of 8 turbines
within the wing structure.

Included in the report is a list of
specific research required to further
the development of these concepts. It
is pointed out that regulations must
be updated to permit the development
of V/STOL vehicles.

NASA-LOCKHEED SHORT-HAUL TRANSPORT STUDY
R. Scherrer, W. C. J. Garrard
E. M. Davis and W. D. Morrison
NASA SP-116 (Conference on V/STOL and
STOL Aircraft) 389-407
April 1966

This paper describes a preliminary de­
sign study on the three vehicles used
in the report "STOL Transport Design"
and in addition a tilt-wing turboprop
and a stopped rotor VTOL are compared.

Of particular interest was the selec­
tion of high wing configurations in
order to minimize ground effect, re­
ingestion and damage caused by the
ingestion of foreign objects.

It is reported that cross-shafting in
the turbo-prop design requires less
weight than other means of combating
yaw effects following an engine failure.

The use of multi-slotted flaps is re­
ported to reduce vehicle weight for a
given level of performance. It is
concluded that the turbofan design with
blown flaps is faster but with higher
DOC's, than the deflected slipstream
turboprop. Both vehicles are quite
feasible.

SUPPLEMENT TO FEASIBILITY OF V/STOL
CONCEPTS FOR SHORT-HAUL TRANSPORT AIRCRAFT
B. L. Fry
NASA CR-743 (1), September 1968

This report summarizes the findings of
NASA CR-743 (also reviewed in this bib­
liography). The main purpose of this
supplement, however, is to redesign
the two most promising of the five VTOL
designs (tilt wing and lift fan) accord­
ing to a revised set of requirements
which are both more suited to the ve­
hicle types and more indicative of pro­
bable passenger and airline needs. The
report therefore deals very little with
STOL technology, the only real mention
being made for the purposes of STOL -
VTOL comparison.

AERODYNAMICS/HIGH LIFT DEVICES

WIND-TUNNEL INVESTIGATION OF A STOL
 AIRCRAFT CONFIGURATION EQUIPPED WITH
AN EXTERNAL-FLOW JET FLAP
L. B. Parlett, J. P. Shivers
NASA TN D-5364, August 1969

This report discusses a series of tests
designed to determine the capabilities
and problem areas of an aircraft equip­
ped with jet flaps. The model studied
is a four engine medium size transport
STOL aircraft with a T-tail. The en­
gines are located relatively close to
the fuselage. The test programme in­
volved angles of attack up to 28 de­
grees, sideslip up to 30 degrees,
various flap settings, and various en­
gine thrust levels.

The major difficulty found was the exis­
tence of a serious longitudinal in­
stability for angles of attack greater
than 7 degrees. This was due to the
shedding of powerful vorticies by the
inboard high lift areas of the wing
which created an adverse downwash flow
at the horizontal tail. More even dis­
tributions of lift over the wing were
seen to be the solution to this problem.
The model was laterally stable with
power-on conditions, and retained this
stability at lower lift coefficients in
the engine-out case.

The results of this experiment are im­
portant in identifying areas of tech­
nological difficulty in the development
of the jet flap technique of lift pro­
duction, and can be considered to be
fairly general in their application.
This paper presents a very good discussion of the problems associated with boundary layer control on the flaps of a high speed aircraft. Most of the STOL work done has been on relatively slow propeller type vehicles, but the aircraft studied here is a modified Boeing 707, both fast and large. The paper describes the design and flight test programme for the re-fitted aircraft.

An initial discussion is given of high lift devices and techniques as they are applicable to high speed aircraft. In particular, the control problem is explored for large high speed aircraft operating at very low speed. The modifications done by Boeing on the test aircraft are explained, with attention being paid the engine bleed system which provides the air for blowing.* The flight test programme is described, and the more important features reported. The slowest approaches of the aircraft were made at 75 knots with 70 degrees of flap and maximum blowing. Reverse thrust was used to enable the engine to be run at high power with little thrust, and adjustments to the reverse thrust system provided a method of controlling the glide path. Both the longitudinal and lateral stability were investigated, with particular attention to problems such as trim change in ground effect, turning abilities, and control nonlinearities. The conclusions were that longitudinal stability was good, longitudinal control was good over 90 knots, directional control was excellent, and lateral control and stability would and could be improved.

This paper is important in that it investigates the STOL concept for a different type of aircraft and with a different high lift device than most of the other work. The flight tests have certainly shown the idea to be feasible, and we are thus provided with a different attack on the problem of the trade-off between low-speed operation and high-speed cruise efficiency.

*approximately 20 pounds/second/engine, augmented at the flap by an ejector nozzle.

The abstract reads:

"A methodology has been developed in which aircraft configurations are optimized and systems are compared with cost effectiveness included in the initial stages of analysis. This method is applied to a comparison of propulsive high-lift systems for a STOL configuration with high-bypass ratio turbofan engines. Three basic propulsive lift systems are considered: (1) external blowing of the trailing edge flaps, (2) blowing from the interior of the wing at both the knee and trailing edge of the flap (jet flap concept) combined with thrust vectoring and, (3) blowing from the interior of the wing at the flap knee (BLC concept) combined with thrust vectoring. These systems are optimized for a fixed takeoff distance and then incorporated into a parametric mission-sizing computer program which recognizes the weight aspects of each system. The results of this program are costed and minimum cost configurations are selected and compared."

The vehicles considered were intended for military use and consequently no analysis of the noise levels produced was reported. With the assumed bypass ratio of 6 and maximum thrust in the range of 150,000 lbs. it appears that they will not be quiet. There is a lack of detail in the report regarding engine bleed and the required pressure ratios across the fan.

It was estimated that manufacturing and tooling costs of the wing trailing edge fixed structure and the control surfaces would be from 30-70% higher than a conventional aircraft.

The following comments were made concerning the three designs:

"Even though heavily reinforced in the blast areas the structure will be subject to sonic and lower frequency fatigue cycles. The other two systems are faced with possible failure of the ducts and thrust deflectors. Short of operational experience, studies in much greater depth are required to achieve credible ranking."

The conclusion of the report was that the externally blown flap system was
marginally the most promising concept. One point which was not covered was the problem involved in certifying these powered lift systems should a civil use be envisaged. Nevertheless this paper is reasonably clear in describing the merits of the three systems and is quite relevant to the future development of STOL.

DIRECT LIFT CONTROL FOR APPROACH AND LANDING
R. C. Lorenzetti
AGARD Guidance and Control Panel Meeting
MIT, 20 - 23 May 1969

This paper examines the applicability of direct lift control on aircraft as a longitudinal control technique in the approach and landing phase. The paper does not apply specifically to STOL - it does not even mention STOL - but many of the ideas expressed are in fact used as part of STOL aircraft high lift or control devices. Since the paper was prepared for a panel discussion, it is not exceedingly rigorous, but it does make some good points.

A short history of direct lift is given, followed by examples of some modern commercial transport applications. The advantages of direct lift in approach and landing are listed, among them being control of pitch, elimination of inertia lags, improved gust response, and more accurate flaring ability. The report then describes a computer optimization study which may be used to determine the correct combination of surfaces to use for a particular aircraft configuration.

The ideas for direct lift control are of interest to the STOL designer, not so much as a lift augmentation device, but as a control device in both longitudinal and lateral movement, especially at the low STOL approach speed.

WIND-TUNNEL INVESTIGATION OF A LARGE JET TRANSPORT MODEL EQUIPPED WITH AN EXTERNAL-FLOW JET FLAP
L. P. Parlett, M. Fink and D. C. Freeman, Jr.
NASA TN D-4928, December 1968

This paper presents the results of an initial investigation to determine the effectiveness of jet flaps in increasing aircraft performance. The model chosen for the test was that of a large, four engine transport aircraft, with flap deflections up to 55 degrees. Two airspeeds were simulated, 90 and 135 ft/sec. The experiment was hampered to some extent by the fact that the flaps had originally been designed for a completely different set of tests, but trends were nevertheless recognizable.

With the jet blown flaps, the total lift coefficient was increased to about 4.0, but the usable lift coefficient for practical landings was about 2.2. This increase in lift did not seriously compromise longitudinal stability and trim, as a tail about 1/4 the size of the wing was found to be effective. One engine-out operation was not a problem, as the asymmetries were easily controlled through use of the rudder, the ailerons, and the spoilers.

The report also presents a comprehensive analysis of a set of possible approach, landing, and takeoff regulations for powered-lift aircraft which would allow them to take full advantage of their special features. With this revised set of regulations, this large aircraft (landing weight in excess of 500,000 lbs.) is able to land in about 3300 feet. This is certainly not a STOL landing as we think of it, but this type of system applied to a smaller aircraft might be able to produce the desired STOL performance. Certainly this report shows that the jet blown flap technique can produce significant improvements in lift and landing performance.
The experiment revealed that as the wing tips were extended beyond the slipstream-immersed portion of the wing, lift increased and drag decreased. This is reflected in performance as a decrease in descent angle for a given flap configuration. Spanwise variation of propeller thrust was found to be most useful when the whole wing was immersed. Some difficulty was found with separation of flow between the nacelles, and this was found to define the limit of maximum lift. Leading edge slats were found to be effective in controlling this separation, and provided an increased angle of attack capability, and an increased angle of descent and rate of sink for a given airspeed.

While a designer must certainly test extensively each particular model to obtain its properties, the information given in this report should be helpful in determining the basic design features of STOL transport wings.

THE AUGMENTOR WING--A NEW APPROACH TO JET STOL
J. A. Conway
Presented at the 26th Annual Conference of The Society of Aeronautical Weight Engineers, Inc., Technical Paper #624 May 1967

This paper presents a good discussion of a relatively new device in the high lift field, the augmentor wing. Doubtless further research has been done since the material given in this paper but the concept is described, and some of the design considerations mentioned.

The paper opens with a discussion of the problems of the air transportation system, and the need for relief in the terminal area. The STOL type of vehicle is shown to provide this, if it is capable of true short field performance of a reliable nature. Since some difficulty has been encountered in shortening the field lengths for the larger commercial transports with the ‘standard’ STOL techniques, it is quite possible that a new method of high lift production is the answer. The thesis of this paper is that the answer could quite easily be the augmentor wing approach.

The augmentor wing combines the aerodynamic and the propulsion techniques of gaining high lift, and does so without an excessive addition of equipment or complication to the aircraft. The paper discusses the operation of the device, and some of the test results obtained with preliminary configurations at de Havilland Canada. The conclusion of the report is that the method is feasible and that further study should be undertaken to discover the system capabilities.
nine Technical Notes long, studies different chords, different flap types, different propeller locations, and different propeller rotations.

The only relevance this series of tests has to the STOL applications is through the general conclusions reached. These conclusions are that the up-at-the-tip mode of propeller rotation gives better descent capabilities, leading edge devices are quite useful in controlling stalling, and highly deflected flaps result in significant lift and performance improvements. The up-at-the-tip propeller rotation provides the better descent capabilities since stalling occurs much later (as much as 25 degrees improvement in angle of attack) than for the down-at-the-tip, and when it does occur, it is outboard of the nacelles rather than inboard.

BOUNDARY LAYER AND CIRCULATION CONTROL FOR STOL AIRCRAFT
F. Thomas
AGARDograph 126, pp. 349-382
May 1968

The approach speed used by an aircraft varies as \( \frac{1}{S} \sqrt{\frac{W}{C_L}} \). Since the wing loading \( \frac{W}{S} \) is as large as possible in order to achieve economic cruise, low approach speeds (and consequently short landing distances) can be achieved by making \( C_L \) as large as possible during the landing manoeuvre. This report looks at three methods of achieving high values of \( C_L \).

(i) Boundary layer control by suction: the flow around a wing at high angles of attack is kept from separating by sucking off that portion of the boundary layer that is about to separate.

(ii) Boundary layer control by blowing: separation is prevented by energizing the boundary layer with a high speed sheet of air.

(iii) Circulation control by blowing: the lift of an airfoil is increased beyond that predicted by theory by blowing high speed air over the flap. This causes a redistribution of the pressure field leading to increased lift.

Blowing techniques are less complicated in practice than suction. Blowing systems can be driven by compressor bleed air if turbine engines are used as the aircraft power plants.

LARGE-SCALE WIND-TUNNEL INVESTIGATION OF AN AIRPLANE MODEL WITH A TILT-WING OF ASPECT RATIO 8.4, AND FOUR PROPELLERS, IN THE PRESENCE OF A GROUND PLANE
S. O. Dickinson, V. R. Page, W. H. Deckert
NASA TN D-4493, April 1968

This report deals primarily with very low speed, very low altitude tilt wing characteristics and performance, and for one particular aircraft configuration. Its conclusions as to loss of lift and drag, increased nose-down pitch, and loss of aileron effectiveness for yaw control near the ground are all consistent with other tilt-wing studies. The aircraft type considered in this report is primarily designed for slowing to a hover and then landing, rather than for true STOL behaviour.

EFFECT OF GROUND PROXIMITY ON THE LONGITUDINAL, LATERAL, AND CONTROL AERODYNAMIC CHARACTERISTICS OF TILT-WING FOUR-PROPELLER V/STOL MODEL
K. W. Goodson,
NASA TN D-4237, December 1967

This paper describes a series of wind tunnel tests on a tilt-wing V/STOL aircraft model conducted over a moving belt, in order to ascertain the aerodynamic effect of ground proximity. Various combinations of flap setting, wing tilt, ground speed, and propeller speed are investigated. Smoke flows were used to study recirculation effects.

The results of the tests show that in ground proximity, the slipstream may be deflected forward of the aircraft, creating an unsteady flow area ahead of the vehicle. Lift and drag loss were measured, as well as losses in controllability for some configurations.

The test applied mainly to a tilt-wing V/STOL aircraft at very low ground speeds, and is thus not particularly helpful in the STOL application. The largest height-to-chord ratios considered were 4.2: the effect was much more prevalent for height ratios around 1, and for large angles of slipstream thrust. In the steep STOL approach, the aircraft would be on the runway before any changes in controllability could become important, and similarly in takeoff, the STOL aircraft would pass rapidly through the ground effect region. For these reasons, this report is useful to the STOL designer.
only as a warning of what might be expected to occur in a very transient manner close to the ground.

A SUMMARY OF RECENT LARGE-SCALE RESEARCH ON HIGH-LIFT DEVICES
W. H. Deckert, D. G. Koenig, and J. A. Weiberg
NASA SP-116 pp. 63-79, April 1966

A brief summary of recent 40 by 80 foot wind-tunnel investigations of large scale models equipped with various high-lift devices is presented. The basic high-lift concepts that were investigated were the externally blown flap, the augmentor wing, and the rotating-cylinder flap. The scope of this paper is limited to a discussion of the wind tunnel results in terms of maximum lift, descent performance, and pitch trim requirements.

"For the model with the externally blown flap, wind-tunnel results show a maximum lift coefficient of 4.3 was obtained for a thrust coefficient of 1.36 and indicate the feasibility of utilizing a small rapidly responding auxiliary flap for direct flight path control.

"For the model with an augmentor wing, an augmentation ratio of 1.4 was obtained; for an augmented thrust coefficient of 1.30, a maximum lift coefficient of 6 was obtained which is similar to the maximum lift coefficient achieved by present propeller-driven STOL aircraft; and one problem generally associated with the jet flap concept, namely, the existence of large pitching moments at high lift coefficients, was found to be significantly reduced.

"For the model with a rotating-cylinder flap, a maximum lift coefficient of 9.1 was obtained for a thrust coefficient of 4, the power required to energize the boundary layer was found to be low, and pitching moments were found to be significantly less than those for a plain double-hinged flap."

AERODYNAMIC CHARACTERISTICS, TEMPERATURE, AND NOISE MEASUREMENTS OF A LARGE-SCALE EXTERNAL-FLOW JET-AUGMENTED-FLAP MODEL WITH TURBOJET ENGINES OPERATING
M. P. Fink
NASA TN D-943, September 1961

This technical note describes an experiment conducted in the wind tunnel at Langley Field using a large model (wing-span 32 ft.) of a jet transport aircraft. The model was fitted with two wing-pod mounted operative jet engines of constant thrust. The nozzles of the engines were fitted with rectangular tailpipes, providing a jet sheet which was blown over the full or half-span flap.

Measurements taken for various angles of attack (-8° to 16°) and flap deflections (0° to 60°) included lift, temperature, and acoustic pressure. Effective thrust was varied by changing the Reynolds Number of the wind tunnel flow.

The results of this series of tests showed marked increases in lift through use of the blown flap design. Lift coefficient increased from 1.25 to about 3.0 for the half-span case and 4.8 maximum for the full span flaps, which may be shown to reduce landing speeds by about 50% for the conventional jet transport configuration.
The increases in lift in the full span case over the half-span case were of particular interest, since at all times the blowing occurred only over the half-span. Temperature effects were not important, but acoustic pressure fluctuations were such that an aircraft design would have to consider fatigue problems.

The experiment reported here is basically an early investigation into the feasibility of blown flaps in the creation of lift. It is useful in that it shows the order of magnitude of the effect, but tests such as these are dependent on the aircraft configuration, and the results are therefore not widely applicable.

### PROPULSION SYSTEMS

**THE QUIET PROPELLER - A NEW POTENTIAL**

G. Rosen and C. Rohrbach  
AIAA Paper No. 69-1038, October 1969

The main problem addressed in this paper is the reduction of propeller noise. It is shown that the three main design parameters involved are: Static thrust, Cruise efficiency, Noise level.

STOL vehicles require high value of static thrust. In order to achieve this with a minimum installed power the following steps can be taken: increased diameter, increased blade solidity, increased airfoil camber and increased tip speed. Since the first three techniques all involve significant weight and/or cruise performance penalties, the propellers which were selected for the first generation STOL and V/STOL have all been of high tip speed type (850-1000 fps at takeoff).

Unfortunately high tip speeds result in large noise levels. Present efforts are aimed at reducing tip speeds without compromising static thrust and cruise efficiency.

Noise produced by the stalled portion of the propeller at low forward speeds can be reduced through the use of proposed variable camber propellers. This concept adjusts the camber to suit the forward speed of the vehicle, thus optimizing performance at all speeds.

Studies into the influence of blade shape on noise levels are underway.

Shrouded propellers appear to offer a possible 20 dB noise reduction.

**FAN V/STOL AIRCRAFT**

M. O. McKinney, W. A. Newsom  
Presented at the New York Academy of Sciences, International Congress of Subsonic Aeronautics, April 1967

This paper presents a review of some of the fundamental characteristics of fan powered V/STOL aircraft. Use is made of both wind tunnel results, theory, and flight tests (where available) to interpolate a set of general characteristics which may be attributed to this class of aircraft. Three general configurations are discussed: lift-fan VTOL in which the fans are used only for lift; tilt-fan, in which the fans provide lift and transition as well as power for conventional flight; and, vectored thrust fans in which the fans are fixed, but control surfaces direct the exhaust. The discussion is very general in nature, as the information presented is qualitative and descriptive and concerns typical phenomena, rather than being a strictly quantitative nature. Throughout, the paper places a significant emphasis on the aerodynamics of the situation.

Fan characteristics in hover, ground effects, fan thrust variations with air speed, lift induced on the airframe, effect of fan location, fan drag, wing geometry, low speed and cruise stability, and cruise performance are each discussed for the various configurations, with experimental results used by way of example in many cases.

The paper seems in many ways to be more interested in the VTOL than the STOL concept, but much of the information presented is of use to the STOL designer. The broad qualitative tone of this report renders it easily understandable and of great interest to the 'STOL novice'.
This paper presents a review of the results of a study undertaken to determine the characteristics of the optimum powerplant for a typical externally blown flap STOL transport. The information is presented as a series of graphs which are applicable to a high wing, four engine, 150 seat STOL vehicle capable of 500 mile stages. The article is not extremely rigorous and does not present the methods used in the study being reported, but the significant trends and the relative importances of the design parameters are explained.

The powerplant is examined with respect to requirements for takeoff length, cruise altitude, cruise speed, and range. Engine parameters such as pressure ratio, bypass ratio, turbine temperature, and engine thrust-to-weight are varied, and optimum values indicated. The effect of the different characteristics on operating cost is shown. Mention is also made of the possible engine limitations due to noise profiles, and the increasing importance which this problem may assume.

The conclusion of the study is that the most important variable is the thrust-to-weight ratio of the engine. All of the variables are presented in such a manner as to make it easy to understand the likely implications of changes in powerplant design.

The application of recent technological advances in the production of turbojet engines (with high thrust to weight ratios) to turbofan lift engines with low specific fuel consumption has resulted in the production of lift engines capable of good operational economics.

By configuring the aircraft with the lift engines close to the c.g. and the cruise engines utilized for attitude control, a design results which minimizes the number of lift engines and has the high safety of totally redundant lift and control.

The report provides a general look at a possible second generation V/STOL vehicle. Little detail is included.
A VECTORED THRUST POWERPLANT FOR COMMERCIAL V/STOL OPERATIONS: SYSTEM CONSIDERATIONS AND PRELIMINARY MODEL TESTS
R. A. Tyler, R. G. Williamson

Reprinted: Presented at: The Sixth Congress of the International Council of the Aeronautical Sciences
ICAS Paper 68-25, September 1968

This paper presents the results of a model study of a modified turbofan configuration featuring a sub-divided gas generator with ram intakes. This engine is shown to be potentially useful in solving V/STOL propulsion problems such as: aerodynamic difficulties with generator and fan sizings at high bypass ratios; fan rotational speed restrictions hampering optimum operations of the compressor and turbine; provision of adequate fan root productivity and large annulus areas; and alleviation of the many difficulties associated with debris ingestion, recirculation, and thrust vectoring.

Two hypothetical vehicles are roughly described to show how to incorporate such a system.

The main body of the paper is concerned with the engine itself and the tests done on the externally-supplied model. It is admitted that the model study encompasses only the thrust and aerodynamic characteristics of the engine, and offers no insights into mechanical design. The test programme uses a partial supply technique to simulate generator shut down, and shows this to be a valid technique in fan thrust modulation. The possibility of variable second stage stator stagger angle is also investigated.

The paper relates only to this specific engine design, and is not meant to be instructive in the general problems encountered in STOL propulsion.

HANDLING QUALITIES

AIRWORTHINESS CONSIDERATIONS FOR STOL AIRCRAFT
R. C. Innis, C. A. Holzhauser and H. C. Quigley
NASA TN D-5594, January 1970

This report is based on the experience gained by NASA over the years in the field of STOL handling qualities (as reported in other TN series reports). The ability of a piloted STOL vehicle to safely perform a landing manoeuvre forms the framework for a discussion of handling qualities and safety margins. It was assumed that the vehicles of interest will be flying in the 40 to 80 knot speed regime with descent and ascent angles of at least 60.

Operational envelopes are presented as plots of glide path angle and rate of climb as a function of airspeed and thrust. These envelopes change with vehicle configuration and the region for safe operation is restricted by safety margins. The shape of these plots demonstrates that on the approach STOL aircraft should be flown at constant angle of attack.

It is pointed out that insufficient flight data are available to verify the consistency in STOL landing performance over a range of approach angles and speeds, runway conditions and atmospheric conditions. Instead of single field length factor (such as 1/0.6) required field length should be based on actual operating results.

A section on handling qualities is presented in which it is pointed out that STOL aircraft generally had low levels of stability which were satisfactory provided the damping was sufficient and the mechanical and aerodynamic control characteristics were good. It was found that none of the STOL aircraft tested could be trimmed in crosswinds exceeding 40 percent of the approach speed.

Conflicting requirements of low stability and damping to reduce aircraft disturbance by gusts and of good stability and damping to maintain the desired flight path will be best satisfied by augmenting stability and damping about the flight path axes rather than about the wind axes.

This report is well written and provides an excellent indication of the problems facing the designers and operators of STOL equipment. The results are quite meaningful since they are based on actual flight experience with a range of STOL vehicles.

FLIGHT TESTS UNDER IFR WITH AN STOL TRANSPORT AIRCRAFT
R. C. Innis, C. A. Holzhauser and R. P. Gallant
NASA TN D-4939, December 1968

This report describes a series of flight tests with the Breguet 941 four engine deflected slipstream STOL aircraft. To complement the visual work done as reported in NASA TN D-2231, and to test modifications made to the aircraft since that time, a new set of IFR approaches and landings was conducted at glide slopes of 2 1/2 and 7 1/2 degrees.

This report discusses the results of these tests, comments on the problems
encountered, and evaluates the operation of the STOL aircraft in the terminal area.

The principal modification made to the aircraft was the addition of transparency.* With this, the steep approaches of 7 1/2 degrees (800 feet per minute) could be performed, and the pilots felt quite comfortable descending at rates up to 1,000 feet per minute. The only control problems encountered were angle of attack difficulties at the rear centre of gravity location, and some directional control difficulty at low speed. These characteristics were never-the-less rated as acceptable. Interception of the steep glide slope was made at 1500 feet altitude, with plenty of time for the pilot to lock onto the beam. The pilots also found that under true IFR conditions with break-out at 200 feet, there was more than enough time available to make the necessary pre-touchdown corrections. Tests done on the 2 1/2 degree slope indicated a six minute approach time from the outer marker. This was deemed to be too long, and with the control system designed for STOL operation and the low approach speed (60 knots), the pilots found that some of this time they weren’t even descending. Another difficulty encountered here was the low altitude break-out, with the aircraft at a fair distance from the runway moving slowly at low altitude. As a result of these problems, the 2 1/2 degree approaches were made with intermediate flap deflections, with transition to landing flap occurring on short final. Even in this type of approach there was some tendency for the pilot to fly level and then descend at more than 2 1/2 degrees to re-establish himself.

As was reported in NASA TN D-2231, the Breguet 941 has overcome many of the control problems associated with STOL aircraft, and this was again found in the IFR mode. It was also found that the modifications improved the performance of the aircraft.

The section on terminal area operation concludes that the best approach technique, from the point of view of time, clearance, safety, and pilot workload is the straight-in, steep, non-decelerating method. As well as the IFR tests, a small number of VFR tests were made. In these it was found that circling approaches and tight base approaches were well within the VFR capabilities of the aircraft.

This report is excellent in its analysis of the problems and possible solutions of the STOL approach. The fact that the aircraft is successful further adds to the importance of the report.

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*"Transparency" is the approach power condition when outboard propellers are at zero equivalent thrust, and the inboard propellers are developing the thrust required. The effect is to change the wing loading distribution.
coefficients which may be obtained. Having described the systems, the authors then present some of the reasons why these features cannot always be fully utilized. The remainder of the paper deals with these impedances.

The control and handling qualities criteria are by far the most stringent, and of these, the low-speed lateral, and the engine-out characteristics seem to have caused the most difficulty. Graphs are presented which give speed and lift coefficient boundaries indicative of the limits imposed on performance by the various power and control techniques used on STOL aircraft. Virtually all types of lift augmentation and control surface configuration are included in this discussion. The pitch control problems encountered in longitudinal control are mentioned, and the compounding of difficulties in the engine-out case is emphasized.

Besides handling qualities, the other restrictions on the use of high lift devices seem to come from power limitations on speed, control, and climbing ability. These facets are discussed.

The graphs and charts are very instructive and have been drawn in such a way as to include all of the different systems under consideration today. The paper is completely general in its application, and very thorough in its treatment of the topic. It is a very good starting point for someone interested in the control problems facing the STOL designer.

A FLIGHT INVESTIGATION OF THE PERFORMANCE, HANDLING QUALITIES, AND OPERATIONAL CHARACTERISTICS OF A DEFLECTED SLIPSTREAM STOL TRANSPORT AIRPLANE HAVING FOUR INTERCONNECTED PROPELLERS

H. C. Quigley, R. C. Innis, and C. A. Holzhauser
NASA TN D-2231, March 1964

This NASA report presents a very thorough investigation of the Breguet 941 STOL transport. The information presented was gathered by means of a flight test programme carried out by Breguet and NASA pilots, and includes all flight conditions. The aircraft itself is of the highly deflected slipstream type with full-span triple-slotted trailing edge flaps and a cambered leading edge. The four propellers are interconnected, have opposite rotation, and may be given differential pitch. A number of special flight controls are included on the flight deck to assist the pilot in the operation of the vehicle in the low airspeed condition. At the beginning of the paper a brief description is included of the aircraft and its special features.

The body of the report is divided into three sections, the first of which deals with performance. Takeoff distances to 35 feet, and landing distances from 50 feet were both well under 1000 feet, and with improvements suggested by the test programme could be reduced to values approaching 800 feet. Cruise speed up to 10,000 feet was 225 knots.

Handling qualities are discussed in great detail. In general, everything was rated as satisfactory by the test pilots, except for longitudinal and lateral static stability, and lateral dynamic stability. These were rated as acceptable, and suggestions for their improvement were made in the report. Control sensitivities are given, and special features such as the simultaneous use of ailerons, spoilers, and differential propeller pitch to produce roll are discussed. Some difficulty was encountered with trim changes due to changes in flap or engine settings, but these were largely removed through the use of a throttle-elevator interconnect. In all configurations, rudder control was adequate to control sideslip, a common difficulty with STOL aircraft.

The third section deals with the operational techniques used in each phase of flight. Takeoff, transition, cruise, approach, landing, crosswinds, and wave-offs are discussed. The only difficulty encountered here was in the correct execution of the 'half-flare' at landing, the feeling being that a flight-path angle indicator would be of use in landing the aircraft.

The report as a whole is very comprehensive with respect to both this particular aircraft, and the problems of STOL aircraft in general. The explanation of the control and operational techniques used to overcome typical STOL problems is very instructive. For these reasons, the report has been given a top rating.

RECOMMENDATIONS FOR V/STOL HANDLING QUALITIES
AGARD Report 408, October 1962

This report presents a listing of handling qualities deemed desirable for V/STOL aircraft. They were arrived at through the efforts of a Working Group of the AGARD Flight Mechanics
Panel, and are intended primarily for military aircraft. They are intended for use in the low-speed regime, up to the limit of (more-or-less) conventional flight.

Areas considered include characteristics of the control system, longitudinal and lateral-directional stability and control, hovering and transition (for VTOL), minimum speed conditions, power plant failure, cross-coupling, and boundary layer control systems. The report acknowledges the fact that as a result of the introduction of new systems and techniques desirable handling qualities could change, and therefore, it is quite likely that the recommendations could change over the years. In fact the report suggests a number of areas where research was required to become more familiar with V/STOL work. This report has served as the basis for much of the V/STOL design of the past eight years.

A FLIGHT EXAMINATION OF OPERATING PROBLEMS OF V/STOL AIRCRAFT IN STOL-TYPE LANDING AND APPROACH
R. C. Innis and H. C. Quigley
NASA TN D-862, June 1961

Flight testing of a STOL aircraft (a Stroukoff YC-134A) in the approach and landing mode carried out at Ames Research Center is described. While the paper presents the data of this particular aircraft, the analysis of the difficulties encountered is given in terms of general STOL operation, not specifically dependent on the test aircraft. The aircraft type has two propellers with lift augmentation.

The discussion is divided into a number of well-organized sections. The first deals with the operating envelope and its limits as determined by the physical (aerodynamic and performance) characteristics of the vehicle. Piloting techniques and control methods are then discussed, and then a section gives the modifications made to the flight envelope because of these piloting techniques, and because of pilot preferences. Included here is the ability to perform a wave-off, the stall margin, the ability to flare from steep or high sink rate approaches, and the ability to control path angle. In each of these areas the problems, the reasons for the problems, and possible solutions are given.

Further sections deal with the engine-out problem, the selection of approach speeds, and the determination of an optimum approach angle (a trade-off between obstacle clearance and rollout). The remainder of the paper deals with stability and control difficulties encountered in STOL operation, and the effects of aircraft configuration on the handling qualities.

A set of six conclusions is drawn which summarizes the STOL operating problems in the landing situation. These conclusions are seen to follow logically from the comprehensive discussions presented in the paper, and make note of the following difficulties:

(i) the low airspeed vs. high thrust trade-off
(ii) angle of attack control using one-handed elevator operation
(iii) pilot margin demands compromising the total available aircraft performance
(iv) the air distance vs. touchdown velocity tradeoff
(v) the lateral control difficulties
(vi) the anti-symmetric problems of the engine-out case.

AERODYNAMIC CHARACTERISTICS OF TWIN-PROPELLER DEFLECTED-SLIPSTREAM STOL AIRPLANE MODEL WITH BOUNDARY-LAYER CONTROL ON INVERTED V-TAIL
R. J. Margason, G. L. Genry, Jr.
NASA TN D-4856, November 1968

Experiments with twin engine STOL aircraft had shown two tendencies which were somewhat undesirable: difficulty with longitudinal stability and control and lack of sufficient lateral control in the engine-out case. The purpose of the experiment reported in this paper is to investigate the feasibility of using an inverted V-tail rather than the conventional horizontal or T-tail as a means of producing better handling qualities for the aircraft.

A model (5 foot span) incorporating a V-tail with boundary layer control was tested in the Langley wind tunnel using various values of effective propeller thrust, tail incidence, and elevator deflection. The engine-out case was also studied. The tests were quite successful, and indicated the V-tail to be a possible solution to the above-mentioned problems. Longitudinal stability was satisfactory, and rudder effectiveness was good. Lateral control for the engine-out case could be easily obtained using a spoiler on the powered side, and experimental indications were that the tail BLC could also provide this asymmetric control force with refinement of the system.
The ideas presented in the paper are interesting in that they suggest the feasibility of a somewhat unorthodox system in the solution of control problems peculiar to the high performance STOL vehicle.

CL-84 TILT WING APPLICATIONS
S. Bernstein
The Sixth Congress of the International Council of the Aeronautical Sciences, ICAS Paper No. 68-45, September 1968

This paper presents a comprehensive discussion of the results of the flight test programme carried out by Canadair on their CL-84 tilt wing V/STOL vehicle prototype. The operation of the aircraft is explained, the tests in all flight modes reported on, and possible future configurations and modifications for larger and for commercial aircraft are suggested.

In the hovering tests, the main difficulty encountered was with the Stability Augmentation System, the pilots finding that often it was easier to fly without it. Also, there was some ground effect to be overcome when setting down, but this problem was solved with pilot training. Transition flight, and STOL takeoffs and landings were essentially problem-free, except for minor details which might be expected in any prototype. Control during cruise was less than adequate, but this was felt to be a hardware rather than an aerodynamic problem. None of vibration, noise, or downwash presented any difficulties.

A number of operational variants of the aircraft are postulated, and within each variant, a number of uses suggested. Various military and civilian uses may be made of the aircraft by essentially scaling all components to produce a different sized vehicle. Performance estimates are given for each model, right up to a 70 passenger, 200 mile range commercial transport. It is also suggested that STOL takeoffs would enable the aircraft to exceed its design VTOL payload. For the commercial version, a short discussion of economics for the vehicle is also given.

The paper concludes with a discussion of possible aerodynamic, structural, and control improvements which may be made over the years to further improve the aircraft. This report presents a good discussion of the work being done at Canadair, and provides useful insights into the problems and applications of tilt-wing vehicles. Its main drawback is that it considers only the one aircraft, instead of the aircraft relative to the rest of the V/STOL types currently under consideration.

FLIGHT INVESTIGATION TO DETERMINE THE EFFECT OF LONGITUDINAL CHARACTERISTICS ON LOW-SPEED INSTRUMENT OPERATION
D. J. DiCarlo, J. R. Kelly, R. W. Sommer
NASA TN D-4364, March 1968

This report gives the results of a flight test programme using a variable stability helicopter to investigate and determine ranges of acceptable longitudinal static stability characteristics for V/STOL aircraft. Earlier tests using the same techniques had been performed using levels typical of rotary winged vehicles, and the results reported here expanded these results to include a wider range of configurations. The speed ranges in the tests were 40 to 70 knots, typical of a STOL approach speed.

The tests consisted of flying a set task involving turns, accelerations, decelerations, climbs, and descents using various stability combinations. In the flight sequences, angle of attack stability and pitch rate damping were varied, speed stability was varied, and longitudinal control sensitivity was adjusted. The results are presented in the form of graphical pilot ratings showing the acceptable ranges of the parameters for the low speed manoeuvres.

This report provides useful information for the STOL designer with respect to longitudinal handling qualities.

A SIMULATOR STUDY TO DETERMINE PILOT OPINION OF THE TRIM CHANGES WITH POWER FOR DEFLECTED SLIPSTREAM STOL AIRPLANES
R. F. Vomaske and F. J. Drinkwater III
NASA TN D-3246, February 1966

This report deals with an investigation to determine acceptable levels of trim change due to power change for STOL aircraft making use of a deflected slipstream. Because of the STOL deflected slipstream configuration, changes in the throttle settings can have a very great effect on the trim, the longitudinal stability, and the elevator effectiveness of the aircraft. The investigation reported here involved the use of a simulator programmed for STOL operation in the approach, landing, and wave-off situations. The approach to wave-off transition was treated because it was felt that this manoeuvre required the greatest power change, and was indicative of maximum STOL performance.
During the tests, various combinations of centre of gravity and pitching moment due to thrust were used, and pilots were asked to rate the aircraft considering approach, wave-off, engine failure, stability changes with power, and pitch-up at high angle of attack. In each situation, the pilot opinion boundaries are given.

The overall conclusion drawn was that if the stall margin was not important then the pilots liked to have little or no trim change with power, but if they felt there were close to the stall, they wanted some nose-down pitch with power to increase the velocity stability.

The report presents the data for the particular configuration programmed on the simulator, but the trim change with power is a problem relevant to many STOL aircraft, and the analysis of the results is presented in this light.

LATERAL CONTROL CHARACTERISTICS OF A POWERED MODEL OF A TWIN-PROPELLER DEFLECTED SLIPSTREAM STOL AIRPLANE CONFIGURATION
R. J. Margason, A. D. Hammond
NASA TN D-1585, November 1964

This paper presents the results of a model test to determine if spoilers could be useful in the lateral control of a deflected slipstream STOL configuration. Before making these tests, an investigation was performed to determine the relative effectiveness of aileron deflection and differential propeller thrust. Tests were made with long-and-short-span ailerons and spoilers over ranges of flap deflection up to 75 degrees.

The tests found, as expected, that neither ailerons nor propellers by themselves could adequately control the vehicle laterally at low speeds associated with STOL landing. Both techniques must be used simultaneously. However, the tests indicated that rolling moments large enough for lateral control even in the engine-out condition may be obtained with the full-span ailerons. As with the other methods, there is coupling with yaw to some degree.

The report presents a mass of data graphically, much of which is not fully discussed, concerning the aerodynamics of a deflected slipstream STOL configuration. While the particular numbers apply to the model used, the trends in the curves are indicative of the aerodynamics of this aircraft type.

HANDLING QUALITIES AND OPERATIONAL PROBLEMS OF A LARGE FOUR-PROPELLER STOL TRANSPORT AIRPLANE
H. C. Quigley, R. C. Innis
NASA TN D-1647, January 1963

This paper presents the results of flight tests on a 50 ton four propeller aircraft (Lockheed C-130B Hercules) modified to a STOL configuration with highly deflected flaps, drooping ailerons, and blowing boundary layer control on all control surfaces. The air for this BLC was provided at a rate of 60 pounds per second at a 3.5 pressure ratio by two YT-56A-6 engines driving load compressors mounted on the outboard wing pods. The various manoeuvres associated with landing and takeoff were performed, with both quantitative and qualitative measurements being made. Landings were made in less than 1500 feet. The results are presented for the most part in a generalized form, with the particular numerical details of the test aircraft being used by way of example.

Topics covered include airfield performance, operational envelope, control power and damping, static and dynamic longitudinal and lateral stability, the effect of flaps and thrust on trim, and stalling characteristics. Difficulties were found in various areas, particularly in the control of sideslip and the damping of lateral oscillations.

There is a discussion of operational techniques used in the landing and takeoff procedures. Problems considered include approach patterns, compatibility with ILS (due to low aircraft speed), speed and configuration adjustment from cruise to the STOL mode, control methods for final approach, approach speeds, sink rates, flight path angles, flare, engine-out approach, wave-off, take-off, climb-out configurations, and boundary layer control failure. In some of these areas -- engine-out flare, for instance -- severe difficulties were encountered which prevented completion of the task because of safety considerations.

Throughout the paper, areas of difficulty are fully explained, and by way of conclusion the authors suggest facets of the operation of STOL aircraft which require further research. The applicability of the concluding remarks of the paper is not limited to the test aircraft.
AN EXAMINATION OF HANDLING QUALITIES CRITERIA FOR V/STOL AIRCRAFT
S. B. Anderson
NASA TN D-331, July 1960

This report briefly looks at the complete range of Handling Qualities in an attempt to formulate criteria for V/STOL aircraft. As such it serves as a good introduction to the subject. Since the report is over 10 years old it does not have the benefit of recent research results and flying experience with the newer hardware.

As reported in the summary:

"The results of the study indicate that the majority of V/STOL requirements can be defined by modifications to the helicopter and/or airplane requirements by appropriate definition of reference speeds. Areas where a requirement is included but where the information is felt to be inadequate to establish a firm quantitative requirement include the following: Control power and damping relationships about all axes for various sizes and types of aircraft; control power, sensitivity, damping and response for height control; dynamic longitudinal and dynamic lateral-directional stability in the transition region, including emergency operation; hovering steadiness; acceleration and deceleration in transition; descent rates and flight-path angles in steep approaches, and thrust margin for approach."

THE CANADAIR CL-84 TILT-WING V/STOL PROGRAMME
F. C. Phillips
The Aeronautical Journal of the Royal Aeronautical Society, August 1969

This paper deals with the design, development, and test programme of the first prototype of the Canadair CL-84 tilt-wing V/STOL aircraft. The aircraft is traced from its inception from a series of V/STOL studies through the design process, the wind tunnel and simulator experiments, the flight tests, and the operational trials up to the time of the crash of the prototype. Each area is discussed thoroughly.

As might be expected, much of the work reported in this paper concerns the operation and characteristics of the vehicle in the hover and the transition modes, rather than the STOL mode, but some of this information is useful to the STOL designer. The low rating has been given because of the small percentage of the paper which is devoted to STOL, not because of any fault of the author: the purpose of describing the CL-84 programme and aircraft features is well fulfilled.

RESULTS OF A BRIEF FLIGHT INVESTIGATION OF A COIN-TYPE STOL AIRCRAFT
T. W. Feistel and R. C. Innis
NASA TN D-4141, August 1967

This report presents the results of a test programme carried out by NASA on a COIN (Counter Insurgency) aircraft operating in the STOL regime. The particular aircraft studied is the Convair 'Charger'. Tests are conducted involving the landing, takeoff, wave-off, and engine-out modes, and for each a detailed account is given of the techniques used, the performance of the aircraft, the handling qualities, and the pilot's rating.

The tests found that, if one ignored engine-out considerations, the aircraft could operate effectively in the STOL regime, except for some minor difficulties in various control parameters. However, if one followed normal operating procedures and stayed above the single engine manoeuvre speed during approach, then the STOL capabilities were compromised, and the aircraft performed similarly to any other light twin. Further, cruise was not what had been expected due to high levels of parasitic drag.

Even though normal STOL problems are encountered, such as the development of pitch moments during flap retraction in a wave-off, this paper is essentially relevant to the 'Charger' aircraft only, for which it presents a very comprehensive flight test programme.

A FLIGHT AND SIMULATOR STUDY OF DIRECTIONAL AUGMENTATION CRITERIA FOR A FOUR-PROPELLERED STOL AIRPLANE
H. C. Quigley, R. C. Innis, R. F. Vomaske, J. W. Ratcliff
NASA TN D-3909, May 1967

This report deals with an attempt to improve the directional control and stability of the NC-130B STOL aircraft. As reported in NASA TN D-1647, "Handling Qualities and Operational Problems of a Large Four-Propeller STOL Transport Airplane", reviewed elsewhere in this bibliography, this particular aircraft was deficient in its lateral and directional characteristics. This paper presents the results of the implementation of a Stability Augmentation System (SAS) in the aircraft to operate on the directional parameters and improve the pilot ratings.
A mechanical servo system was connected into the rudder control mechanism, and flight tests made to check turn coordination, yaw rate damping, and sideslip rate damping. Because of mechanical lags and limitations of the SAS, it was felt necessary to perform the flight tasks on a simulator as well, to ensure that no erroneous conclusions were reached regarding the applicability of the SAS to the STOL problem.

The report presents the test methods and the results of the tests, in a manner such that they are really only applicable to the one aircraft. Each aircraft would have its own difficulties and instabilities, and thus generalization is not possible to a large degree with respect to augmentation techniques. The results of the test showed that the SAS had been somewhat effective for this aircraft, but that further improvement would be necessary, and that in any event it was difficult to separate improvements in the directional characteristics from deficiencies in the lateral characteristics.

CONSIDERATIONS FOR REVISION OF V/STOL HANDLING QUALITIES CRITERIA
S. B. Anderson
NASA SP-116 (Conference on V/STOL and STOL Aircraft) pp. 229-247
April 1966

A review of selected V/STOL handling qualities is presented to provide information for updating V/STOL handling qualities requirements. Comparisons are made of recent flight and simulator results with existing V/STOL requirements.

Of particular importance to STOL operations are speed stability on landing approach and angle of attack stability since STOL pilots tend to use angle of attack as a reference. Other factors include control power required for trimming, controlling upset and for manoeuvring and the influence of ground effect and recirculation on stability.

The paper is general in nature with a list of references that is useful for deeper study of the subject.

SOME FLIGHT CHARACTERISTICS OF A DEFLECTED SLIPSTREAM V/STOL AIRCRAFT
H. L. Turner, F. J. Drinkwater III
NASA TN D-1891, July 1963

This paper reports on an extension of the tests of NASA TN D-1430, reviewed elsewhere in this literature survey. The deflected slipstream Ryan VZ-3BX is operated at very low airspeeds down to hovering, with a minimum speed for level flight of 6 knots. The various configurations possible with the large flap deflections and with full-span leading edge slats were flight tested to determine the short takeoff and the short landing characteristics of the aircraft.

The report deals first with the longitudinal and the lateral control systems of the aircraft, as well as the thrust control. Handling qualities are then discussed, combining the results of these latest tests at low speeds with the earlier data. Control power and damping, lateral coupling, stall, and minimum speed characteristics are mentioned, but always with respect to this particular aircraft. In the analysis of performance given, the advantages gained by slipstream deflection, very low speed flight, and steep descents are considered. Takeoff and landing test results are used to obtain a representative STOL operating profile, and limitations on vertical descent because of poor height control are noted. Adverse ground effect was found for the aircraft at speeds less than 20 knots and propeller spindle heights less than 1.5 propeller diameters. This ground effect was seen to be caused by recirculated air at these low clearances. Difficulty was also had with sideslip stability at the low airspeeds.

Like NASA TN D-1430, this paper is limited in usefulness by the fact that it is applicable only to the one particular aircraft configuration.

SIMULATOR STUDY OF THE LATERAL-DIRECTIONAL HANDLING QUALITIES OF A LARGE FOUR-PROPELLERED STOL TRANSPORT AIRPLANE
H. C. Quigley, H. F. Lawson,
NASA TN D-1773, May 1963

This report presents the analysis of the lateral characteristics of the STOL aircraft studied in NASA TN D-1647, reviewed elsewhere in this literature survey. The very serious difficulties in the lateral stability and control of this aircraft found during flight tests, particularly with respect to sideslip, are examined on an approach simulator. Various values for the lateral stability derivatives are programmed, and the resulting configurations rated by the test pilots.

The procedures tested were landings with rudder pulses, sideslip creation,
sideslip elimination, side-stepping, and crosswinds. During these tests, the control parameters considered were the mechanical characteristic of the flight control system, the lateral control powers, lateral damping, and lateral control cross-coupling. Control changes by themselves were found to yield insufficient improvement in the handling qualities.

The report then considers the improvements offered by improved stability and damping, particularly directional stability, yaw rate damping, dihedral, and sideslip rate damping. The physical changes necessary to give the desired values of the derivatives are deemed excessive, however, and the question of stability augmentation is considered.

The information of this report is completely dependent on the NC-130B configuration, and as such is not applicable to any other aircraft except as a guide in design analysis.

LONGITUDINAL TRIM CHARACTERISTICS OF A DEFLECTED SLIPSTREAM V/STOL AIRCRAFT DURING LEVEL FLIGHT AT TRANSITION FLIGHT SPEEDS

This paper gives the results of tests conducted on the Ryan VZ-3RY deflected slipstream test aircraft. The tests were aimed at identifying any longitudinal stability or control problems close to ground (0 to 50 feet) and at transition airspeeds (24 to 80 knots). Throughout the series of flights, no difficulties in control were encountered. It was found that no sudden or large forces were required on the control surfaces, and that no adverse or favourable ground effects existed. Two transition techniques were attempted.

This paper is of little general interest, since it relates specially (and only) to the Ryan VZ-3RY.

PERFORMANCE

THE INFLUENCE OF FACTORED AIRFIELD PERFORMANCE OF LESS THAN 2000 FEET ON STOL SYSTEM ECONOMICS
The de Havilland Aircraft of Canada Ltd. Downsview, Ontario, November 1969

The effect of runway length on operational economics is estimated from results obtained for two proposed de Havilland aircraft; the DHC-7 turbo-prop STOL based on 1970 technology and the augmentor-wing turbofan based on 1980 technology. It is demonstrated that a 1500' runway requirement is not cost effective and that 2000' lengths are more realistic.

Based on current regulations the runway length required for the DHC-7 can be reduced by reducing the wing loading. This can be achieved through off-loading of passengers or increasing the wing area. Both lead to poor operating economies. The aerodynamic and structural implications of increasing the wing area are briefly outlined.

The advanced turbofan design incorporates powered lift since it has assumed that by 1980 such technology would be allowed for in the regulations. In this case the use of 2000' runways would allow either an increase in the wing loading or a reduction in the thrust to weight ratio (since the design runway length was 1,625 ft.) The improvement in operating economy was not as dramatic in this example, however it was significant.

Although the calculations carried out were for two specific vehicles and a specific route structure the results appear to be representative of this class of vehicle.

PROBLEMS OF UNDERCARRIAGE DESIGN FOR V/STOL AIRCRAFT
S. W. H. Wood
The Aeronautical Journal of the Royal Aeronautical Society, February 1969

This report deals with the landing gear problems encountered in the design of STOL aircraft. The point is made that on a conventional aircraft the gear can account for as much as 20% of the structure weight; it is certainly more than this on a V/STOL vehicle where the flare is absent so the ground impact is more severe. In the first part of the paper some of the problems are outlined, and in the second part the author presents some of the actual designs he has had experience with. Much of the report is written from personal experience.

The design proof vertical velocity for CTOL is usually 10 fps, with flight experience showing most landings at less than 2 1/2 fps vertical touchdown velocity. For a STOL vehicle, landing without a flare from a steep glide slope (up to 10 degrees), the design proof vertical velocity would have to be 18 fps or more. The paper mentions the importance of the degree
of airborneness of the aircraft at touchdown, and the relevance of pilot timing to the loads imposed on the gear. The rebound characteristics, gear fatigue, and special features for unprepared fields are also discussed. It is seen that ground manoeuvring and side forces can also be significant in the analysis of loads experienced.

The remainder of the paper discusses the 'kneeling' undercarriage of the Hawker Siddley 748 freighter with its provision for heavy landings, and the telescopic bicycle gear with outriggers for the VTOL Harrier. By way of conclusion, the report makes the important point that at this time, specifications for V/STOL landing gear are somewhat ill-defined, but through research and operational experience regulations must be formulated to enable the efficient design of the civil V/STOL vehicles which are sure to follow from present military investigations.

ACHIEVING CONSISTENCY IN MAXIMUM PERFORMANCE STOL LANDINGS
A. J. Craig
U. S. Army Transportation Research Command

This paper presents the results of a flight test programme to determine the maximum performance landing distance for a de Havilland Otter aircraft. The glide slope used was 7 1/2 degrees, and distances were measured from a fixed point ahead of the threshold at which the aircraft was supposed to be at 50 feet altitude (with high-side error only). The total lengths varied from 250 to 445 feet, with the typical landing taking 400 feet. The 250 foot landing caused excessive tire wear and was not considered to be indicative of operational practices.

The conclusion of the report was that the most significant variable which affected landing lengths was the height at the intended 50 foot mark. The pilot was consistently able to operate the aircraft at maximum performance apart from barrier height, but his control ability to recapture the glide slope by flattening or steepening the descent was insufficient. This, of course, is a function of the characteristics of the particular aircraft. The flare was not deemed to be an important influence on total distance, unless serious 'floating' occurred prior to touchdown.

TAKEOFF TRAJECTORY OPTIMIZATION OF A THEORETICAL MODEL OF A STOL AIRCRAFT
F. H. Schmitz
AIAA Paper 69-935, August 1969

This is a very theoretical, very mathematical paper which reports on a study undertaken to use optimal control theory to determine the optimum trajectory which maximizes the vertical takeoff distance for a fixed ground distance. The study does not refer to any particular STOL airplane, nor to any technique used in improving STOL takeoff performance. The model is built up through a series of increasingly sophisticated assumptions and constraints on the theory. The model in its final form is able to predict the vertical ground clearance at a given point for a given runway length, and it is able to indicate the correct rotation and climb-out (non-accelerating) technique to obtain this. No real insight is given into the design and performance problems associated with STOL operation.

OPERATION OF JET AIRCRAFT FROM GRAVEL RUNWAYS
E. S. Lund

This paper is included in this bibliography because of the expected relevance of gravel runway operation to the Canadian northern and possibly the regional STOL services. The paper itself does not discuss STOL aircraft or application, but rather concentrates on the results of a study of gravel runway operation, and the modifications made to a Boeing 727 as a result of this study.

A number of test runs were made by Boeing with a special jet-propelled truck with a landing gear fixed beside it. Photographs were made of the gravel spray, and special buckets caught the gravel to indicate the most critical impact zones. The study found that takeoff presented no problems, and the most severe part of the landing with respect to gravel spray was right at touchdown until the wheels spun up to the aircraft speed. The design of special deflectors is explained, and other means of protecting the aircraft discussed.

As indicated above, this paper was included here because of the importance of gravel runway operation in the design of STOL aircraft for Canadian applications. It is expected that more recent papers are probably in existence describing the
gravel runway certification of the Boeing 737. Our literature search, concentrating on STOL, did not attempt to find these.

INFLUENCE OF SECONDARY FORCES ON THE TAKEOFF AND LANDING CHARACTERISTICS OF A SHORT TAKEOFF AND LANDING (STOL) JET AIRCRAFT
V. L. Surus,
NASA TT F-12, 181, 1967

This paper deals very briefly with modifications (through the inclusion of extra terms) which may be made to force the balance equations of a lifting-off or touching-down STOL jet aircraft in order to take into account the secondary forces. These secondary forces consist of aerodynamic loads caused by the external flow field of the jet engine exhaust around the wings, the fuselage, and the tail of the aircraft. The paper is very short, and because of this and the fact that its main conclusion is that more work must be done investigating secondary forces, it is of limited usefulness to the STOL designer.

SHORT TAKEOFFS FOR JET AIRCRAFT
N. K. Liseytsev,

This paper deals with the problem of how to shorten the takeoff distance, especially the ground distance, of jet aircraft. It does not examine any physical system in particular, but rather assesses the problem from a general mathematical viewpoint. The technique used is to write the force balance for the aircraft at lift-off, and then determine which parameters should be changed to have the most beneficial effect on takeoff distance. The paper is not concerned with STOL in particular, but rather all jet aircraft. The equations, of course, are never-the-less applicable to STOL.

The analysis concludes that the method of obtaining the shortest ground run is to rotate the thrust vector at lift-off, but not before. Best overall obstacle clearance distance will result from this method coupled with a non-accelerating climb. A constraint on this method is the minimum manoeuvring speed of the aircraft, and if the rotation speed is very low, some artificial stabilization may have to be provided for the aircraft. An equation is presented which yields the takeoff distance for any aircraft type, if the lift coefficient, the thrust-to-weight ratio, the wing loading, and the dynamic pressure head are known.

The mathematical techniques described in this report are useful to the STOL designer because they provide an easy-to-use tool for the quick analysis of takeoffs. He can get ballpark figures without any aerodynamic or flight testing.

LABORATORY LANDING
Lockheed Georgia Quarterly
Volume 6, June 1969

This short pictorial article is included in this bibliography because it indicates one of the STOL-CTOL interface problems which must be taken into account when designing a STOL aircraft. The article deals with a computer study of the STOL pilot's view of his own (short) runway and other main jet transport runways at a mainline airport used by both types. Because of his manoeuvrability and the more 'severe' nature of his approach path, the STOL pilot must be afforded an excellent view from the flightdeck.

RESULTS OF THE BOEING COMPANY WAKE TURBULENCE TEST PROGRAM
P. W. Tracy, and P. M. Condit
(The Boeing Co.) D6-10851, June 1970

The results of a flight test investigation of vortex wake turbulence generated by large jet transport aircraft are presented. Test results showing the dynamic response of aircraft which were flown in the wakes of large jet transports, are discussed. Experimental results are compared to theoretical predictions. Test program results are applied to the problem of air traffic control and specific recommendations are presented for air traffic separations.

FLIGHT-TEST EVALUATION OF THE WING VORTEX WAKE GENERATED BY LARGE, JET-TRANSPORT AIRCRAFT
William H. Andrews, Glenn H. Robinson and Gary E. Krier (Flight Research Center) and Fred J. Drinkwater III (Ames Research Center)
Note: This is a limited distribution working paper.

The conclusions of this paper are given as an abstract:

From the flight tests which have been conducted to date in probing the vortex wake of several large, transport-type airplanes, it is apparent that the wing vortex wake behaviour is significantly different from that anticipated and more comprehensive tests will be essential to separate the variables and assess the deviations.

From the data presented in this paper, the following observations have been made:

There is evidence that the vortex wake may be detected up to separation distances of 20 nautical miles with no apparent reduction in intensity under ideal weather conditions.

The dissipation of the wake intensity or strength is influenced by the generating aircraft speed and configurations. The strongest wake was generated by the C-5A and Boeing 747 airplanes in the clean configuration. When the C-5A was in the landing configuration, there was a noticeable reduction in the vortex influence within the 6.5 to 8.5 nautical mile range.

Radar space-positioning data indicate at holding or landing-approach speeds that the average vertical downwash path of the vortex extends to altitudes of 750 to 1000 feet below the generating airplane at a range of 9 to 11 nautical miles. Atmospheric conditions and generating airplane motions can produce a sinusoidal oscillation of from 100 to 200 feet both vertically and laterally about the radar-defined downwash path.

The CV-990 airplane did not experience any uncontrollable upsets or large airspeed and altitude excursions while surveying the vortex wake of the C-5A, Boeing 747, or B-707-366 airplanes.

The upset and resulting excursions experienced in the U-3A and F-104 tests with the B-52 and C-5A, respectively, indicate that the separation criterion should be considerably expanded for the small, general aviation and executive jet classes of airplanes as compared to that designated for jet-transport airplanes.

The report reaches the following conclusions:

- For ‘clean’ and low flap setting configurations of the Boeing 747, C-5A and 707 aircraft, the maximum velocities of the respective aircraft trailing vortex systems are similar in magnitude, approximately 140 feet/sec, under the existing environmental flight test conditions.

- More persistent, clearly defined ‘tubular-type’ vortex systems are
Generated as the flap setting is decreased on an aircraft.

- 'Tubular-type' vortex systems are very persistent, up to approximately 2 minutes in age, as sighted visually and recorded photographically, in close proximity to the ground (below 200 feet).

- As the trailing vortex system approaches the 'tubular-type' structure, the tangential velocities increase whereas the vortex diameter, i.e., the field of influence decreases. Conversely, as the trailing vortex system deviates from a tubular-type structure, the tangential velocities decrease and the vortex diameter increases. This type of flow is characteristic of the classical free vortex flow.

- Axial flow either does not exist or is insignificant for relatively long-age vortex systems.

**SURVEY OF THE GROUND EFFECT OF V/STOL AIRCRAFT WITH JET PROPULSION:**
**REPORT OF LITERATURE**
(UUEBERSICHT UEBER DEN BODENEFFEKT BEI STRAHLGESTUETZEN V/STOL:
FLUGZEUGEN LITERATURBERICHT)
E. Schwantes
Trans. into English from the German Report, NASA-TT-F-12573 Washington NASA October 1969

A tabular survey is presented of the results of 132 scientific reports on the ground effects with jet lift V/STOL aircraft. The region of the deflected jet is described and the different test conditions are compiled.

**A FLIGHT INVESTIGATION OF SYSTEMS DEVELOPED FOR REDUCING PILOT WORKLOAD AND IMPROVING TRACKING ACCURACY DURING NOISE-ABATEMENT LANDING APPROACHES**
Clarence C. Flora, Gerhard K. L. Kriechbaum, and Wayne Willich

A two-phase flight test program was conducted using the Boeing 367-80 airplane. Concurrently, a supplemental ground-based flight simulator program was performed. This study was directed at evaluating various systems developed to reduce the pilot workload while maintaining tracking accuracy under simulated instrument conditions during noise-abatement landing approaches. Preliminary results showed that steeper than normal approaches could not be performed at the same pilot workload level as a conventional approach without improvements in the path guidance system, flight instrument displays, and automatic flight controls. The results of further flight evaluations showed that when the pilot was given an appropriate combination of systems aids he was able to perform steep, two-beam or decelerating approaches with workloads and accuracies comparable to those of conventional approaches.

**THE HARRIER-AN ENGINEERING COMMENTARY**
(First J. D. North Memorial Lecture)
J. W. Fozard (Siddeley Aviation Ltd)
Kingston-upon-Thames, Surrey England

Description of the design and performance of the Harrier, a British close-support fighter which is capable of leaving the ground with a very short or a zero takeoff run. The development of the Harrier design is reviewed, and design aspects and military productivity of the aircraft are examined. The cruise efficiency of the Harrier is compared with data for other aircraft, and aspects of manoeuvrability are investigated. A description is given of the navigation-attack system. Aspects of the V/STOL design are discussed, and control system performance and problems of maintainability are considered.

**REVIEW OF POST-WAR-RESEARCH AND DEVELOPMENT AT DORNIER**
Silvius Dornier (Dornier-Werke GmbH, Friedrichshafen, West Germany)

Review of general-purpose aircraft research and development during the postwar period, with emphasis on the design and configuration of aircraft for a wide range of transport and utility missions, the reduction of takeoff and landing distances, and the development of safety devices for the greatest possible number of flying and operational conditions. The design and configuration of the single-engined Do25 and 27 are reviewed, and the twin engined Do28 is discussed. Research in the reduction of takeoff and landing distances by slipstream deflection is presented, and the Do32 helicopter is described. British participation in the development of the Do31 VTOL transport is outlined, and a research program for increasing operational safety in aircraft is elaborated.
ANOTHER LOOK AT ACCELERATE-STOP CRITERIA
T. G. Foxworth and H. F. Marthinsen
(Air Line Pilots Association, Washington, D. C.)
American Institute of Aeronautics and Astronautics, Aircraft Design and Operations Meeting, Los Angeles, Calif
Paper 69-772, July 14-16, 1969

Accelerate-stop criteria developed prior to the introduction of the jet transport are reviewed in light of operational experience. Reaction times presently used by the manufacturers in accelerate-stop calculations are examined from the human engineering standpoint. Results of a flight simulator study showing pilot reaction times for transition to the rejected takeoff configuration are presented. Each pilot subject in the study was unexpectedly confronted with a simultaneous fire warning bell and light at some specified time increment prior to attaining velocity one during a simulated takeoff. The resulting times for transition to the full braking configuration and the associated overspeeds above the critical engine failure speed, velocity one, are compared to the certification performance and show a need for revision to the present criteria.

FLIGHT ASSESSMENT OF A VARIABLE-STABILITY HELICOPTER FOR STOL SIMULATIONS AND EVALUATION OF THE INFLUENCE OF SEVERAL LATERAL-DIRECTIONAL STABILITY DERIVATIVES
D. M. McGregor
NRC-NAE-LR-524; NRC-10953, June 1969

A particular STOL aircraft (the Otter) was simulated using a variable-stability helicopter to assess the simulator's capabilities in duplicating the flight characteristics of this class of aircraft. Direct comparisons were made by the pilots through alternate flights in the simulator and on the actual aircraft, and it was concluded that a very convincing simulation could be effected, particularly with respect to lateral-directional characteristics. Using the Otter as the base condition, several lateral-directional stability derivatives were varied to investigate their influences on the handling qualities during a low speed visual manoeuvring and approach task. The results of these investigations are presented in the form of pilot opinion data.

DESIGN CONCEPT FOR A V/STOL INTERCITY JET
P. G. Kappus (General Electric Co.)
AIAA Paper No. 69-200
February 1969

A conceptual design study of a large 200 passenger V/STOL intercity airliner with high productivity is presented. It is intended for commercial operations on high density short haul routes between metroports. The following approach is proposed: Low noise levels through exclusive use of high bypass ratio lift fans in the lift mode. High productivity through high cruise speed made possible by a low drag power and lift system. Engine out safety through complete redundancy of all power and lift components. Attitude control in the lift mode through differential thrust modulation of independent, redundant lift fans instead of power transfer. No mechanical or pneumatic interconnections between lift fans. A tandem wing configuration is proposed. Each of the four wings is equipped with identical power and lift modules consisting of two gas generators used for cruise and two turbopip lift fans. Specific design features, problem areas and advantages of the arrangement are reviewed. Estimates of airframe and propulsion systems weights are given.

AN INVESTIGATION OF THE EFFECTS OF ROLL-SPIRAL COUPLING ON THE LATERAL-DIRECTIONAL HANDLING QUALITIES OF A STOL SUBSONIC TRANSPORT
F. L. Moore, Clearinghouse N69-40101, 1969

For certain new types of aircraft, such as the supersonic transport and V/STOL configurations, an unusual lateral mode of motion is expected to be present. This mode of motion is found when the conventional roll and spiral modes of motion couple and form a second lateral oscillation in addition to the Dutch roll oscillation. The present thesis presents the results of an investigation on the effects of the roll-spiral coupled mode of motion on the lateral-directional handling characteristics of a hypothetical subsonic STOL transport aircraft. The investigation consisted of a general analysis and analytical calculations of the lateral dynamics for configurations of the transport having various types of roll-spiral oscillations. Also, a fixed-base simulator study was conducted in order to obtain pilot evaluation of the handling qualities of the various configurations under instrument flight rules (IFR) conditions. The results of simulator study indicated that the hypothetical transport could have acceptable qualities with a roll-spiral coupled oscillation present provided small lateral inputs are used.
Discussion of the system of boundary-layer control (BLC) by means of wind-blowing over the trailing-edge flaps and control surfaces, which was designed for the STOL seaplanes, the UF-XS and PX-S. The results of the rectangular wing-blowing model tests, which were conducted for comparing shroud-blowing with flap-blowing, and for determining the most effective type of blowing in the presence of propeller slipstream, are discussed. The BLC system adopted for the UF-XS and SS-2, and the procedures which were followed in determining their designs are examined. The blowing tests of actual-size nozzle and duct systems are discussed, together with the flight-test results of the UF-XS.

SOME AIRFRAME AERODYNAMIC PROBLEMS AT LOW SPEEDS
John Williams and Alice J. Ross
(Ministry of Technology, Royal Aircraft Establishment, Farnborough, Hants., England)
New York Academy of Sciences, International Congress on Subsonic Aeronautics, New York, N.Y., Apr. 3-6, 1967

Consideration of the subsonic aerodynamics of fixed-wing aircraft. A few basic aerodynamic problems are examined which are aimed primarily at clarifying their essential features and indicating their practical significance. The appraisal concentrates on aspects related to safe operation under low-speed/high-lift conditions. The basic features and prediction of relative flow characteristics for airfoil sections; unswept wings, swept wings, and sharp-edged slender wings are discussed, with comments on fuselage interference effects. Aircraft characteristics are studied, with a review of basic stability and control considerations. Comments are made on pitch-up/deep stall behaviour and gust effects, which are of particular significance to swept-wing and slender-wing aircraft, respectively.

LIFTING SURFACE THEORY AND TAIL DOWNWASH CALCULATIONS FOR V/STOL AIRCRAFT IN TRANSITION AND CRUISE. Final Report.
Air Vehicle Corp. San Diego, Calif.
E. S. Levinsky, H. U. Thommen, P. M. Yager and C. H. Holland

A large-tilt-angle lifting-surface theory is developed for tilt-wing and tilt-propeller/rotor V/STOL aircraft. The method is based upon an inclined actuator disc analysis in which closed form solutions are obtained for the velocity potential at large distances behind the actuator surface. Both the normal velocity and the nonlinear pressure boundary conditions are satisfied exactly across the slipstream interface. The inclined actuator disc analysis is combined with a discrete-vortex Weisssinger-type lifting surface theory. Wing-propeller combinations at arbitrary wing angle of attack, propeller tilt angle, and thrust coefficient are considered. Multiple slip-stream effects including slipstream rotation are introduced. Agreement between theory and experiment is shown to be satisfactory for small slipstream inclination angles. However, at large angles the theory (with an undeformed, but displaced, slipstream and wake) predicts significantly lower downwash angles in the tail region than shown by the test data, possibly due to slipstream deformation and wake roll-up. Use of only one-half the calculated wake displacement gave improved agreement at these conditions. However insufficient data are available for making a general evaluation of the theory at large angles. Extensive digital computer results are given in chart form, showing span loading, downwash angle, stability parameter, and dynamic pressure at arbitrary points behind the wing for V/STOL configurations with two and four slipstreams.

AIRCRAFT OPERATIONS - V/STOL
George P. Bates, Jr. (Federal Aviation Administration, Aircraft Development Service, Washington, D.C.)

Consideration of V/STOL operations in intercity and intracity service, with reference to technical feasibility and system development. It is suggested that future STOL aircraft will be relatively simple deflected slipstream or blown flap aircraft operating from 1500-ft strips. The characteristics
of rotary wing, propeller, and jet-powered VTOL aircraft are examined, with comments on the noise problem. It is considered that the most pressing need for both military and civil operation is the steep-approach instrument landing system, and various studies to achieve such a system are examined. Problems which arise from the presumption that the V/STOL aircraft can be navigated with great accuracy are discussed, and possible solutions are outlined. Some simulation test results are evaluated.

STUDY OF AIRCRAFT IN SHORT HAUL TRANSPORTATION SYSTEMS

The intercity operation of advanced short-haul transport aircraft were evaluated in several assumed transportation systems in the 1985 period. Three separate areas of the country, the Northeast, West Coast, and the Gulf Coast-Florida areas, were used in assessing the suitability of aircraft ranging from vertical takeoff and landing, through short takeoff and landing, to conventional takeoff and landing types. The figures of merit considered in comparing the relative suitability of the concepts included direct operating costs versus range, vehicle profitability on a systems wide basis, and the extent and magnitude of the noise generated by each concept. The sensitivity of mission performance to changes in the aircraft characteristics and system operations is determined and key problem areas where additional research may improve the aircraft transportation systems are identified.

Contract N00014-67-A-0298-0006
Grant NGR-22-007-068, November 1967

Conjugate gradient methods have recently been applied to some simple optimization problems and have been shown to converge faster than the methods of steepest descent. The present paper considers application of these methods to more complicated problems involving terminal as well as inflight constraints. A number of methods are suggested to handle these constraints and the numerical difficulties associated with each method are discussed. The problem of flight-path optimization of a V/STOL aircraft was considered and minimum time paths for the climb phase were obtained using the conjugate gradient algorithm. In conclusion some remarks are made about the relative efficiency of the different optimization schemes presently available for the solution of optimal control problems.

ENGINE PERFORMANCE MONITORING APPLICATION TO SMALL Fleets AND SHORT-HAUL OPERATION J. Hope and K. Kenworthy (Trans-Australia Airlines, Melbourne, Australia)

Study of engine performance and condition monitoring, with particular emphasis on the problems that arise for the operator with relatively small aircraft fleets operating in the main over short stages. It is considered essential to correlate performance parameters to condition evidence such as vibration level or lubricant deterioration status to obtain a useful perspective. Experience gained with Viscounts, Friendships, Electras, 727's, and DC-9's is reported. The advantages and disadvantages of monitoring systems from the point of view of the small-fleet short-haul operator are examined and logical and practicable means of adopting such procedures are tried and identified.

DESIGN AND APPLICATION PARAMETERS - ORDNANCE ACTUATED AIRCRAFT EMERGENCY EVACUATION SYSTEMS
C. K. Brown (Space Ordnance Systems, Inc. El Segundo, Calif.)

Summary of the influence of various conditions present in a survivable crash, and demonstration that application of present-day ordnance systems can significantly improve the passenger escape potential. In general, survivable crashes are usually 'near-the-airport' accidents associated with landing or takeoff. In some crashes, many people survive the original impact, but die in the subsequent fume and fire conditions in the aircraft. It is shown how ordnance systems, properly applied, can provide lifesaving by offering multiple instant escape routes when a command signal is given.
POSSIBILITIES AND PROBLEMS OF NEW TYPES OF AIRCRAFT DURING THE DECADE 1970-1980
R. M. Clarkson (Hawker Siddeley Aviation Ltd., Hatfield, Herts., England)  
G. Gabrielli (Fiat S. p.A., Centro Elettronico Avio-Fiat, Divisione Aviazione Turin, Italy) and  
A. H. C. Greenwood (Society of British Aerospace Companies, London; British Aircraft Corp./Operating/, Ltd., Stevenage, Herts., England) 
Association International des Constructeurs de Matériel Aérospatial Symposium on Aviation and Technology in the European Economy, London, England  
Paper Sept. 13, 14, 1967

Consideration of European development of sophisticated civil aircraft - i.e., those which have unique qualities. Attention is given to the development of commercial intercity transports, to the use and potential of V/STOL aircraft in military and civil projects, and the use of variable geometry in the military field. In the military field, emphasis is placed on aircraft with versatile tactical battlefield qualities.

NATIONAL FLIGHT SAFETY, SURVIVAL AND PERSONAL EQUIPMENT SYMPOSIUM PROCEEDINGS  
Survival and Flight Equipment Association, September 1967

The papers recorded in the proceedings apply to all types of flight vehicles. Of particular interest are the papers on oxygen systems and escape and evacuation.

The use of chemical oxygen generation systems result in weight and cost savings.

The use of explosive charges can aid in the evacuation of passengers by opening up escape routes following a crash.

AERODYNAMICS OF POWER PLANT INSTALLATION  
Part 2  
Advisory Group for Aerospace Research & Development (AGARD), AGARDgograph 103  
October 1965

Papers relevant to this study:

- Jet VTOL Power Plant Experience During Flight Test of X-14A VTOL Research Vehicle  
L. Stewart Rolls

- Lift-Fan V/STOL Jet Lift Schemes on V/STOL Aircraft at Forward Speeds  
Herbert E. Dickard

- Lift-Fan V/STOL Propulsion and Airframe Integration  
M. O. McKinney, Jr.

- NASA Research on the Aerodynamics of Jet VTOL Engine Installations  
Richard E. Kuhn and U. W. Schaub

SOME RECENT AERODYNAMIC ADVANCES IN STOL AIRCRAFT  
G. W. Johnston  

A brief review is presented of the results of some of the developments carried out recently by the de Havilland Aircraft of Canada Ltd., in two broad areas: 1) basic STOL performance and 2) low-speed control and handling. In connection with basic STOL performance, the case for the classical STOL deflected slipstream configuration and some of its limitations are reviewed. Some evolutionary improvements to this basic design approach are outlined. In addition, the possibility of replacing the classical propeller installation with a true jet STOL aircraft is briefly discussed. Some improvements in longitudinal low-speed control are discussed. Other criteria are reviewed and some observed inherent limitations noted. Finally, the flight-test results obtained with experimental aircraft incorporating a modified longitudinal control system are discussed.

A FLIGHT AND SIMULATOR STUDY OF THE HANDLING QUALITIES OF A DELECTED SLIPSTREAM STOL SEAPLANE HAVING FOUR PROPELLERS AND BOUNDARY-LAYER CONTROL  
C. A. Holzhauser, R. C. Innis and R. F. Vomaske  
NASA TN D-2966, September 1965

Flight and simulator tests were made to study low-speed handling qualities, potential STOL problem areas, and causes of deficiencies and their solutions. Tests of the STOL seaplane were made in
the 50- to 60-knot speed range with Automatic Stabilization Equipment (ASE) engaged and disengaged. During the simulation, several stability and damping derivatives were varied and evaluated.

During the flight tests, takeoffs and landings were made from water at 50 knots, corresponding to a lift coefficient of about 4. With the ASE engaged, the handling characteristics of the aircraft were satisfactory. The ASE provided roll and pitch attitude stabilization and increased rate damping about these axes. With the ASE off, the handling characteristics were unsatisfactory because of low static longitudinal stability, a very unstable spiral mode, and large sideslip excursions during turn entries. Response to control inputs was satisfactory about the roll and pitch axes, but the like rotation propellers reduced the directional control to an unsatisfactory level.

The simulator tests were useful in providing a preliminary evaluation and in studying the causes of deficiencies and their solutions. Good correlation was obtained between the simulator and flight results with the exception that the sideslip excursions during maneuvering were larger in flight than on the simulator.

**VARIATIONS OF LANDING DISTANCE OF FIXED-WING AIRCRAFT IN STOL OPERATIONS**


Statistical information on the variability of approach gradient, threshold height, threshold speed, touchdown speed, coefficient of braking friction, time of initiation of the controls, and aerodynamic drag is used as a basis for establishing the variability of parameters that may be expected in STOL operations. Departures from this statistical information were made to reflect the ability of the aircraft to fly slowly and to touchdown early. Because of the non-normality of the distributions of certain parameters and the nonlinearity of the functions that link the distance $S$ to others, the combination of the distribution is complex. Simplifications are discussed and adopted. The distance $S_P$ corresponding to a probability $P$ can be found, with good approximation, when distances traversed with and without reverse thrust are known. An increase of the aerodynamic drag reduces the variability of the distance. The reverse thrust increases such variability. Thus, an assessment of the merits of a new device not based on consideration of $S_P$ may be misleading. It is regarded as important that further studies of the type presented here be undertaken and that more statistics on the variability of the parameters be collected.

**EFFECTS OF GROSS CHANGES IN STATIC DIRECTIONAL STABILITY ON V-STOL HANDLING CHARACTERISTICS BASED ON A FLIGHT INVESTIGATION**

J. F. Barren, Jr., J. R. Keller and J. P. Reeder

NASA TN D-2477, October 1964

A flight investigation utilizing a variable-stability helicopter was conducted in order to determine the effects of gross changes in static directional stability on V/STOL handling qualities and on requirements for directional sensitivity and damping during low-speed operation. Tasks under both simulated instrument and visual conditions were used for evaluation of the handling characteristics provided by various combinations of static directional stability, directional sensitivity and damping, dihedral effect.

The results indicate that increases in static directional stability, when accompanied by appropriate increases in directional damping, yield improved handling qualities. Minimum satisfactory levels of directional sensitivity and damping correspond to current criteria.

**AIRCRAFT VORTEX WAKES IN RELATION TO TERMINAL OPERATIONS**

Joseph W. Wetmore and John P. Reeder

Washington, NASA Apr. 1963


An analysis has been made, on the basis of present understanding of trailing vortex characteristics, to provide an indication of the possible effects on aircraft encountering these vortices, the circumstances under which encounters might occur in terminal-area operations, and some means of dealing with the vortex problem in operations planning and traffic control.
II. OPERATIONAL ASPECTS

INTRODUCTION

The bibliography in this section is subdivided under the following headings:

- Operation and Economics
- Transportation Demand
- System Cost Studies
- Access and Egress Problems
- Regulations and Safety

The literature covered under these subheadings will be discussed below. It should be pointed out however, that some reports were relevant to several of these topics: in these circumstances, they were classified under the sub-heading "System Cost Studies". Many of the reports referenced deal primarily with VTOL aircraft. This is readily understandable in the light of the intense interest shown in VTOL aircraft by U.S. manufacturers in the 1960's and by the fact that most of the available literature comes from U.S. sources. However many of the factors relevant to VTOL operations are also relevant to STOL, with the result that a considerable body of meaningful data is contained in VTOL reports. The decline in emphasis on VTOL and the rising emphasis on STOL developed in the last few years and reached a significant watershed in the CAB Northeast Corridor Investigation, where the preeminence of STOL over VTOL was clearly established. As for the five principal types of possible Canadian STOL application, most of the papers or reports concentrate on the intercity transport market and to a lesser degree on downtown to airport services. Municipal feeder transport can be treated more or less as intercity transport but for northern and regional services, there is little information available in the literature surveyed.

Operation and Economics

STOL aircraft design philosophy and operating characteristics have been well documented both with respect to existing products and future design studies. Another extensive body of literature outlines preferred requirements for future STOL and indicates technological developments to make the short haul metroflight service increasingly profitable and attractive.

One unfortunate aspect of the literature is that manufacturers are simply taking the opportunity to boast about their products with the result that the report is a thinly disguised commercial. However to balance this viewpoint, by far the most authoritative reports are also offered by the manufacturers, since they are most knowledgeable in evaluating aircraft economic design.

Transportation Demand

The literature describing the traffic that would be attracted to a V/STOL system is generally based on the concept of total trip time and cost, and traveller convenience. It is admitted that there is no satisfactory method of predicting future subjective responses to an undefined transportation system. Nevertheless methods of estimating do exist.

One approach to the subject is to derive regression formulas based on data about current travel habits. Reports from U.S. and Canadian federal government bodies frequently use this technique. Another approach to the problem is the "Value of Time" technique. It is observed that a certain percentage of travellers are prepared to pay more to save time on trips, and curves describing these effects may be obtained either from existing traffic data or from relating a person's value of time to his income. Aircraft manufacturers seem to favour this approach. Finally there are several miscellaneous empirical methods developed by workers in the field.

System Cost Studies

There is no lack of papers on this subject, however many suffer in being too general or elementary in nature. Among the better reports are those issued by the Clearinghouse (USGRDR) and the MIT Flight Transportation Laboratory largely because of the more detailed information contained in them. MIT in particular has conducted many regression analyses on component and system costs and on system optimization techniques such as dynamic scheduling and the calculus of variations as part of their continuing work on air transportation.

Finally the material submitted to the CAB in the Northeast Corridor Investigation Docket 19078 should be mentioned. While not generally available, it is by far the greatest concentration of material on V/STOL systems and costs - representing several years of effort on the part of manufacturers, airlines and communities.

Access and Egress Problems

There is a good deal of literature available in this field but often just descriptive in nature. In estimating the number of air passengers using such short haul central business district to airport services, they favour again considerations of cost, time and convenience. Since it is a particular application, some general concepts may be found from reports listed.
under the previous sections.

Regulations and Safety

Reports on regulations and safety in the open literature are generally accident reports, statistical summaries, or detail design tips, which are not very relevant.

This dearth of open literature is explained by the fact that present levels of safety derive from meeting the design criteria contained in the Federal Air Regulations such as Part 23 and 25. Changes in these regulations evolve from joint government/manufacturer discussions and are not widely reported. One significant exception is a de Havilland report discussing operating techniques and safety margins for STOL operation of small aircraft.

The most significant document on the subject of V/STOL regulations and safety is the FAA "Tentative Airworthiness Standards for Verticraft Powered Lift Transport Category Aircraft, Flight Standard Service Department of Transportation Federal Aviation Administration, 1968".

OPERATION AND ECONOMICS

A METHOD FOR DETERMINATION OF OPTIMUM VEHICLE SIZE AND FREQUENCY OF SERVICE FOR A SHORT HAUL V/STOL AIR TRANSPORT SYSTEM

R. W. Simpson, M. J. Neuve Eglise
M.I.T. Flight Transportation Laboratory
R-68-1, 1968

The study in this report suggests that passenger traffic depends on the frequency of V/STOL service. For a given model of travel market behaviour, a method of determining an optimal vehicle size and frequency of service for a short haul V/STOL air transport system has been determined for assumed market behaviour in terms of fare and time elasticities. By defining total trip time to include the average wait for service, and using a demand model developed for the Northeast Corridor, the air share of total demand in any market can be calculated as a function of N (frequency) and the competing fares. Plotting daily passengers versus N, and relating this to the maximum and breakeven load factors for a family of vehicles of different seating capacities, determines the value of N and C (capacity) which maximize return to the operator. The method here assumes that only one size of vehicle is assigned to a given route and passengers do not know the operation time table (as the frequency is high enough to ensure low waiting time).

The model results have tended to show that frequency of service is important to short haul air systems which are in competition with the automobile and that smaller, more costly vehicles may be more economic in the sense that they generate higher revenues through higher schedule frequency. The travel behaviour model used here has a number of points of agreement with expected traffic behaviour. It is suggested that further experimental verification and statistical testing seem necessary before it can be used with confidence.

SUMMARY AND ANALYSIS OF RELATED FEASIBILITY-STUDY DESIGNS OF V/STOL TRANSPORT AIRCRAFT

Wallace H. Deckert and David H. Hickey
AIAA No. 67-938

This paper summarizes results from the NASA-Ames contracted studies, analyzes the assumptions used to obtain these results, and shows the impact of these assumptions on study results. Various VTOL, STOL transport concepts are compared in terms of design, gross weight, DOC, gust sensitivity and noise levels: the impact on this comparison of design range requirements, auster design philosophy, advanced technology, nonproductive time and other considerations is included. An abstract of the major findings is the following:

The DOC values were computed by modified ATA standard formula, and based on a 10 1/4 minute manoeuvring nonproductive flight time, for stage lengths of 500 miles, and for a 60 passenger vehicle. At this range the DOC of STOL aircraft is 25%--41% less than the DOC of VTOL. For STOL designed to 2000 ft. field lengths, lift fan and turbojet STOL aircraft are competitive with propeller STOL. The margin in DOC is cut to 16%--25% as stage length is decreased to 100 miles. A similar finding is obtained for a larger version of the aircraft. Though the propeller type (quietest) STOL has a lower PNdB than the quietest type of VTOL, STOL has the disadvantage of being more gust sensitive reflecting a poorer riding quality than VTOL. Overall, for 1000 foot field lengths, propeller STOL concepts look most promising because of their lighter weight and lower DOC.

Analysis of the effects of changes in study assumptions and design criteria indicates:

(1) The change in DOC by revising the design gross weight is generally within ±5% of the DOC based on the original company
weight.

(2) The DOC due to maintenance varies from 13 to 33% of the total DOC because different contractors use different methods to estimate maintenance. It is concluded that the technique of assessing maintenance costs needs improving. Excluding maintenance cost from DOC, the relative position of the cost of the aircraft is unchanged.

(3) Large variations in design range yield small variations in gross weight implying negligible effect on DOC.

(4) A reduction of approximately 20% in DOC results when austere design in aircraft is imposed.

(5) Advanced technology will reduce the DOC for VTOL and to a lesser extent for STOL.

(6) DOC is extremely sensitive to the non-productive block time. Effort is needed to determine navigation procedures or facilities to minimize this time.

Conclusions of near-terminal operations are:

(1) Minimum airtime is achieved by decelerating at the smallest descent angle consistent with considerations of safety, noise, terrain clearance and landing aids.

(2) VTOL and STOL should be compared on the basis of equal non-productive times pending flight demonstration.

(3) Aircraft deceleration capability can have a pronounced effect on nonproductive time. Based on the 10° approach profile the descent time of a tilt wing VTOL with 0.2 g deceleration capability is about 1 1/2 min. greater than the descent time of a lift fan VTOL using 0.3 g total deceleration.

The fraction of passenger traffic carried by competing public transportation systems is taken as a measure of economic effectiveness. A correlation of available data shows that economic effectiveness is proportional to average speed from city centre to city centre, and inversely proportional to fare charged. Using this correlation, a method of traffic prediction is illustrated for several advanced vehicle types both existing and proposed. These include SST, V/STOL aircraft and hypothetical high-speed-surface vehicles. It is concluded that future transport vehicles offering an increased ratio of average speed (city centre to city centre) to fare will be economically effective. The V/STOL aircraft could capture up to one third of the common carrier market at ranges from 25 to 500 miles. This estimation assumes that the V/STOL aircraft is not in competition with hypothetical surface vehicles. However at ranges of less than 25 miles, the possible improvement in speed and fare are limited and automobile is expected to continue dominating the market. A final comment by the paper is that the economic effectiveness of any public transportation system, particularly at short trip distances, would be much improved by a reduction in terminal time and that for surface transport systems, they would benefit from new routings if they want to improve their average block speed. The paper is regarded as valuable because of the methodology which could help in assessing the economic effectiveness of STOL aircraft.
Both STOL and VTOL will cost more to operate in both DOC and IOC. This increased cost will result in increased fares but a large percentage of air travellers will use the service because their value of time warrants it.

A mixed system of CTOL and STOL or VTOL aircraft will give about the same net revenues as an all CTOL system, and the mixed system will provide a satisfactory ROI.

The noise from STOL or VTOL aircraft may limit the choice of airport sites and rule out some of these most convenient to the travelling public. Therefore noise reduction will have a tremendous effect on the success of such a system.

However, the conclusion of such a report is not as significant as the method of approach. A section is written entirely on vehicle performance (consisting of a deflected slipstream STOL, a DC-9 CTOL, four different versions of VTOL plus another compound helicopter). The STOL and VTOL types were considered in 60, 80, 120 passenger sizes. They were designed to conform to common ground rules, with their weights, mission criteria, fuel requirements, and performance estimation based on 1970 technology. The flyaway costs composed of the non-recurring and recurring costs were arrived at via McDonnell Douglas Analysis. STOL and VTOL Terminal design concept is the next heading that received attention. The terminal requirements and potential locations are specified for the cities concerned.

One of the important assessments is the IOC associated with these special terminals. To cover this expense, a charge in the form of landing fees was derived from a "present value mathematical model" which took into account amortization of the terminal cost, annual operating expenses as well as revenue from other sources. Noise associated with STOL/VTOL aircraft operations near city centre was also considered. Composite noise rating contours were developed and plotted on land use maps of Los Angeles and San Francisco to evaluate its effect on surrounding areas. The next subject matter is on operating costs. The 1960 ATA formulae were revised to calculate the DOC of these STOL/VTOL aircraft. These DOC's used in the economic evaluation were based on VFR operation, with a variable aircraft utilization dependent on block time and flyaway cost consistent with a 200 aircraft production-run. DOC's were also calculated for IFR operation. The sensitivity of DOC to changes in utilization, the quantity of the production run, and the flyaway cost was also investigated. To derive a measure of IOC, simple linear regression analyses were made. The economic viability of VTOL/STOL system was confirmed.

Vol. 1 is an executive summary containing introduction, conclusions and the summary of method and result. Vol. II develops each step of the method, in other words a magnification of the content in Vol. I. Vol. III contains appendices. On account of the economic technical analysis contained in this report, it is highly recommended.

AN ECONOMIC ANALYSIS OF COMMERCIAL VTOL AND STOL TRANSPORT AIRCRAFT
Richard K. Waldo
AD 614 598, February 1965

The preliminary market analysis undertaken in this study indicates that VTOL or STOL aircraft capable of operating successfully in commercial service in 1975 must have the following characteristics:

1. Seat capacity is about 50-60 passengers which represents a compromise between the need for high frequency of service and the need for low DOC.

2. A cruising speed of 400 mph is the speed at which the vehicle must operate in order to bring time-savings, the prime element that short haul transportation has to offer.

3. A non-stop range of 500 miles would be appropriate in terms of the distances between the bulk of the city pairs analyzed in this study.

4. DOC ranges from 4.6¢/ASM at 100 mile stage to 1.85¢/ASM at 500 mile stage length would permit the system to be economically self-sufficient and retain its competitive role with other modes.

5. It is not likely that V/STOL system could make more than one stop in the same metropolitan area and that direct non stop flights between a city pair is always desirable.

6. On short stage hauls, V/STOL aircraft are outstripped by helicopters, as for instance in intra-urban services.
Overall, the development of V/STOL aviation is encouraged. The report does produce some useful concepts in analyzing the economic aspect of such a system, though some of the techniques could be on the conservative side.

A REVIEW AND ANALYSIS OF STOL SYSTEMS TECHNOLOGY
Aviation Planning and Research Division
Civil Aviation Branch
Department of Transport
S-70-2, April 1970.

This report is merely a summary of the findings of various aircraft manufacturers, aviation authorities, or airlines with regards to their views on STOL system development. Even though being a summary, the report itself is quite comprehensive and up to date. It touches every aspect pertinent to the system: the economics of operation, STOLports, air traffic control and navigation aids and finally STOL vehicles that will be available.

The STOL Transportation system is in the second phase of development in the U.S. due to the continued efforts of Eastern and American Airlines which provided practical STOL demonstration programs. Their results should be treated as an important feedback to determine STOL certification and operating criteria: the passenger market penetration; economics of the system covering both ground and air environment and also other operating parameters. It seems that if the system could induce 10% of the business travellers into STOL aviation between stage hauls 0-200 miles, large aircraft fleet would be required. However we should anticipate that in the initial stage of operation sophisticated STOLports of optimum location would not be constructed because of funding problems. This condition will continue to exist until the market is fully developed.

A summary of technological development in STOL, V/STOL, and VTOL is provided so that trends may be identified and future requirements may be anticipated. A spectrum of STOL aircraft which promise to become commercial transports are next introduced. This list from the familiar Breguet 941, de Havilland's DHC-7 down to the Skyvan and DO-31. The paper also condensed the Eastern Airlines documentation on STOL demonstration program as well as the CAB Northeast Corridor Investigation for requirements to operate VTOL along Boston-Washington Corridor. The first generation of STOL aircraft most suitable for the mission is identified as a 4 engine turboprop, 48 seater, with a cruising speed of 250 knots, range above 400 miles and cruising altitude of 20,000 ft. It is equipped with avionics guidance system that permit precise navigation. It could operate in an airfield less than 2000 ft. under category II conditions and capable of landing in crosswinds 25 - 30 knots, at glide angles 6° - 8°. Noise level should not exceed 95 PNdB monitored 500 ft. from the vehicle for downtown operation, while pollutants emitted by the vehicles must be minimal.

However, as soon as there is a demonstrated demand in short haul travel, the aircraft manufacturers will be ready to go into production of the second generation of STOL which will have a higher speed and a bigger capacity. While it is hoped that the first stage of STOL service will commence by mid 1971 in the U.S., the second stage is estimated to
be between '75 - '80. Eventually the emphasis is predicted to shift towards shorter and shorter runway requirements and eventually towards a VTOL aircraft.

Sections II and III deal with STOLports and air traffic control. These were not reviewed in this section but passed on to the specialists concerned with these fields.

AN ALL TURBOFAN VTOL OR STOL INTERCITY TRANSPORT
T. Gardner Hall
AIAA No. 69-1039

Turbofan powered VTOL or STOL intercity transports with the safety, reliability, speed and passenger appeal of today's fanjets and meeting future noise limitations are now possible. Advances in turbofan engine technology and aircraft design which make them possible are described. Turbofan lift engine designs based on established technology now offer new compactness, light weight, low fuel consumption, and low noise. Predicted noise levels make possible a 100 passenger VTOL or STOL transport meeting a community noise limitation of 95 PNDB at 500 feet. By configuring the aircraft with the lift engines close to the c.g. and the cruise engines utilized for attitude control a design results which minimizes the number of lift engines to four and still has the high safety of totally redundant lift and control. Such a design is estimated to be cost competitive with any other generally known VTOL concept and could be produced in a STOL version for cost savings on routes not requiring VTOL.

IMPLEMENTATION OF SUCCESSFUL VTOL SERVICE
Society of Automotive Engineers, 69-0416
National Air Transportation Meeting, New York, April 21-24, 1969

The paper reviews briefly the benefit of a VTOL service for intercity travel. Generally the community will benefit because it will extend the useful life of the existing CTOL airport for another decade and also it will promote the convenience of intercity travel. Various studies promised that suitable VTOL aircraft will be available by the mid 70's, however, unless an optimized environment is created it will be difficult to realize the full benefits of VTOL and to establish an economically viable system. This environment can be categorized as flight regulations for fuel reserves and weather conditions; air traffic control, navigation and landing systems; VTOLport location. Other than the optimized environment (or more precisely, the optimized location of the vertiport) four other cases are studied and compared. The implement is the 'cost of time saved' by using the VTOL system. It shows that an optimized environment could penetrate VTOL traffic into the air/auto traffic as far as 26% for stage haul of 200 miles. Whereas in the worst possible case, it still carries 10% of the total traffic. The author's conclusion: implementation of a successful VTOL service requires:

1. direct flight from one city to another
2. an air traffic control and navigation system without built-in circuitry and delay
3. an omnidirectional approach and landing system
4. vertiports at strategically located areas

However this paper does not distinguish between a STOL and VTOL system. If the STOL service satisfies the above criteria would a successful STOL service be also implied?

COMMERCIAL VTOL TRANSPORT DESIGN, OPERATION AND ECONOMICS
David L. Posner
AIAA Paper No. 67-970

This paper is the result of a study carried out by North American Aviation which investigated the economic feasibility of a commercial VTOL transport. The design features of this fan lift VTOL aircraft are fully described together with the flight profile that it is likely to operate. An economic analysis is performed which evaluates the DOC under the various assumptions: unit price $5 million, utilization 3000 hrs/year, engine TBO 1100 hours. Hence an investigation was made into factors which contribute to hourly costs and ways in which these hourly costs could be reduced. If the non-productive manoeuvring time while in-flight is reduced from the normal 10 min. down to zero, the DOC is almost identical to that of a conventional jet between 50-100 n. miles. Greater discrepancy begins to show as range increases. A figure is shown which plots per cent reduction in DOC versus non-productive time for various stage lengths. The passenger trip cost is
next compared for VTOL and CTOL. Assumptions made are: (1) load factor is 50%; (2) IOC equal DOC; (3) a profit margin of 10% is allowed; (4) the 10 min. non-productive manoeuvring time penalty is taken. If a differential of $1.50 is levied between the ground transportation charge to a VTOL port and a CTOL port, up to 330 miles, the VTOL fare is less. As the final study, the cost of time saved by VTOL over CTOL is taken into consideration and this cost is added onto this trip cost. With the same block time, the VTOL system is then credited with the difference in terminal access time. This would raise the cost of the trip by CTOL considerably.

The conclusions developed are that to make this system economically feasible it is first necessary to develop a traffic control system which will minimize unproductive manoeuvring time and second to provide VTOLports which permit saving in ground transportation costs and time. Presumably if the same technique is carried out for the STOL system, this system could prove to be superior, due to its lower DOC.

POTENTIAL FOR STOL TRANSPORTATION IN URBAN AREAS
The de Havilland Aircraft of Canada Ltd.
May 1967

This report outlines trends in the development of air transportation that indicate a requirement for short haul STOL transportation in and about urban areas. Because of the increase of air travel, airports must grow in size in order to keep up with the demand. One result is that terminals tend to move further from the city centre to minimize land cost and to acquire the needed space. Simultaneously the growth and congestion of cities has made travel in urban areas difficult.

Helicopters are not the unique solution to urban air transportation in spite of the low cost of city centre heliports. Their advantage is spoiled by the high DOC and low block speed. This report compares present day helicopters and STOL aircraft and shows that the latter system is more economical even when the cost of building STOLports in high cost urban areas is considered. However this comparison is only typical of one case and is not universal, as the system cost depends heavily on the environment. The superiority of STOL over helicopter comes from the fact that in regions of high traffic density, terminal costs are a minor portion of total system cost and therefore the economic advantage of STOL over VTOL is maintained. The report goes on to compare some advanced helicopter concepts with de Havilland advanced STOL concepts. The conclusion is that STOL systems will retain their advantage into the foreseeable future.
THE EFFECT OF SIZE ON THE ECONOMICS OF A V/STOL TRANSPORT AIRPLANE

George D. Ray
Society of Automotive Engineers 66-0316
National Aeronautic Meeting,
New York, April 25-28, 1966

To have good economy aircraft should have a large payload such that the variation of payload as a percentage of gross weight is not affected greatly by a small change in gross weight. To meet this requirement a VTOL airplane can be expected to have a higher gross weight than a STOL or a CTOL. This is because the VTOL needs a greater power plant for takeoff and hovering and higher fuel consumption for the same size of aircraft.

A series of studies were conducted which investigated the effects of size on total cost for future V/STOL transports. The projection indicates that for aircraft having a gross weight of 60,000 lb, there would be practically no payload for a mission of 250 miles. A graphical comparison is also made between STOL and VTOL system costs. It shows that the STOL system is far superior to carry a given payload for a constant distance under equal cruising speed. The gain in a V/STOL transport system is the reduction of total time or in assault tasks where there is no proper landing strips. Thus it would be imperative to evaluate fully the benefit of time saved prior to the selection of V/STOL sizes that will be most advantageous in terms of cost expected. It suggests that perhaps a combination of STOL and VTOL capabilities of the aircraft is one solution.

THE DESIGN IMPORTANCE OF AIRPLANE MILE COSTS VERSUS SEAT MILE COST

C. Peyton Autrey, P. J. Baumgaertner
Society of Automotive Engineers 66-0277
National Aeronautic Meeting, New York
April 25-28, 1966

The paper discusses the aircraft design factors that affect the DOC and aim to make a qualitative understanding of the relative importance of these factors. It is possible to divide these factors into two major categories. The first of these is airplane size and the second one is technology. Aircraft size varies as the range and payload requirements. They combine to dictate the maximum gross weight, body and engine size, wing area, fuel capacity and its total price. The DOC depends on the value of these factors. A small aircraft may have a lower aircraft mile cost but usually a lower aircraft mile cost does not imply a lower seat mile cost. To be economically effective, an airplane must have a high profit potential or better still high economic efficiency which is a ratio between the profit potential to the productivity of aircraft. To select an aircraft with high 'economic efficiency' other operational aspects such as trip frequency, load factor and practical scheduling for maximum utilization are also taken into consideration. A proper balance between airplane size and the number of airplanes in the fleet must also be established.

The second category includes aerodynamic technology, propulsion, structural technology, component life, plus the maintenance costs. All these factors are examined one by one to show how sensitive the DOC is to these factors. No figures are made available through the second analysis. Only a literal review is done. The report suggests incorporating the most up-to-date technology in order to come up with a lowest cost vehicle.

OPERATING COST OBJECTIVES OF V/STOL AIRCRAFT FOR COMMERCIAL AIRLINE SERVICE

William J. Hogan
Society of Automotive Engineers 65-0243
National Aeronautic Meeting,
Washington, D.C., April 12-15, 1965

This is one of the earlier papers which discusses operational and economic characteristics desirable in V/STOL designed for commercial service over routes of 150 miles or less. However at that time (1965) the operating cost of the helicopter was still too high to justify its service on short haul routes. A simulation is carried out to investigate its total operating cost for four different stage lengths, and the results show that it is twice as expensive as the existing CTOL fares. Trends show that since 1953 the DOC of helicopter per ASM has been dropping rapidly. Though the gap between the DOC of a helicopter and a CTOL aircraft (DC-6) is still large, it is expected to narrow down especially on trips of 100 miles and less. There are a number of indirect benefits which V/STOL aircraft could yield trunk lines e.g. reduction of CTOL terminal congestion: elimination of additional airports: shortening of total travelling time; but the ultimate test of V/STOL efficiency will be its operational and economic characteristics. To meet the operational aspects requires an all weather landing capability, an improved mechanical reliability and a large payload of the V/STOL aircraft, whereas for the economic requirements, a low DOC must be achieved. Various means of reducing DOC are suggested. From the sensitivity chart it can be seen that DOC per seat mile are
most sensitive to changes in aircraft size, speed, and maintenance in that order and to a lesser extent to fuel cost and crew pay.

INTERURBAN TRANSPORTATION SYSTEM ANALYSIS
Z. H. Landau and R. A. Margulies
AIAA Paper 69-1037, AIAA 6th Annual Meeting and Technical Display
October 20-24, 1969

This paper introduces some airline operating philosophies and the reasons for congestion in major U.S. airports. The low density traffic between a pair of origin and destination points is usually channelled through feeder links to collecting modes or hub airports. From these hubs, the passenger is directed through high density trunk lines to other hubs and subsequently distributed to their ultimate destination by another feeder link. On some hub to hub links, the transient traffic is as high as 40%. Thus an efficient network would involve selective addition of new nonstop air links to eliminate the congestion at hub airports.

A minimum passenger algorithm is used to distribute passenger flow within a sample network and its expanded nonstop version. Some data came from Civil Aeronautics Board and Official Airline Guide reports. Computerized models were used to determine the impact of network expansion on various segments of the industry. The study showed that the passengers benefited through shorter direct routing; airlines benefited through reduced operating cost; and equipment manufacturers benefited through increased sales of aircraft suitably sized for all route requirements.

This paper describes computer techniques currently available for marketing analysis at the Douglas Aircraft Company. Unfortunately, scant information is given on the structure or formulation of the computer models.

THE AIRPLANE ECONOMIC DESIGN EVALUATION (AEDE) COMPUTERIZED MODEL AND ITS APPLICATION
H. D. Ramlow, R. M. Thatcher

The Aircraft Economic Design Evaluation (AEDE) system is a mathematical model to assist in evaluating airplane improvement programs, new designs and in general, the impact of airplane performance on an airline’s specific route system. It is a relatively brief paper. Its title suggests that it would be an interesting paper. But like most of the other Boeing reports, it’s content is hard to understand because they do not divulge mathematical details.

It would have an important application. The methodology used by AEDE is to simulate the aircraft operation in a realistic route environment, measuring the operating characteristics of the aircraft subjected to these environmental restrictions and then applying economic considerations to convert all information into a single figure of merit, usually based on system cost of profitability. AEDE provides a fair economic comparison between competing aircraft over the same route system. Furthermore use of AEDE can be extended to provide sensitivity studies to:
- changes to aircraft performance
- aircraft sizing
- route system modification
- changes in economic variables
- turnaround times and through stop capability

THE ROLE OF STOL IN THE NORTHEAST CORRIDOR
Lynn L. Bollinger
Society of Automotive Engineers, 69-0418 National Air Transportation Meeting
New York, April 21-24, 1969

The role of STOL in the Northeast Corridor— that is, when, where and how STOL will serve—is now dependent entirely on the decision making process, not on technical or economic determinations. A modernized regulatory framework appears to be the next requirement for progress. Federal authorities, however, are necessarily dependent upon a small amount of industry consensus and guidance. This has today been conspicuously missing. The case studies and commentary are presented to help give industry personnel a better understanding of aspects on which unified action appears desirable, and perhaps also motivate constructive action.

Author’s Conclusions derived from case studies 1 - 5:-

(1) NASA long ago completed and made available to industry all basic research and design data needed.

(2) To make the advantages of STOL aircraft available to the public no government subsidies are needed. Governmental support
of helicopter and VTOL design concepts has deterred introduction of STOL type of service.

(3) A key problem to be solved is to establish the necessary control and stability requirements to permit safe operations within confined airspace.

(4) The key to the log jam holding back the otherwise available STOL technology appears to be the conflicting arguments imposed by industry spokesmen generally lacking first hand STOL design or operational experience.

Assuming the regulatory shortcomings that hold back the introduction of STOL be overcome, the paper goes on summarizing the types of aircraft and operations that could evolve. This is accomplished by reviewing studies done by other authorities. The final part of the paper is a reprint of the proposed California STOLport design criteria.

A REVIEW OF COMMERCIAL V/STOL AIRCRAFT AND THEIR OPERATING ENVIRONMENT
B. L. Fry and R. William in Naecon '68; Proceedings of the Twentieth National Aerospace Electronics Conference, Dayton, Ohio, May 6-8, 1968

A review of past studies shows the promising future of VTOL passenger service. It appears that VTOL service could be viable by early 1970, progressing to a tilt wing VTOL in the late 1970's. It is concluded that the major handicap of the system lies in the operating and terminal environment: factors outside the control of the aircraft designer. This paper attempts to analyze the optimized environments and makes recommendations on those areas where improvements are necessary.

Enroute Operating Environment:
It is observed that present federal fuel reserve regulations (based on helicopter VFR) and present air traffic control system would impose severe economic penalties on VTOL service because of circuitry, delays, speed and payload restrictions. Therefore a new VTOL-IFR fuel requirement regulation is proposed after careful study: this new regulation allows sufficient fuel to cruise for 20 min. and in addition to divert 50 nautical miles. A new ATC system must integrate both CTOL and STOL traffic.

Terminal Environment:
The terminal environment has also been examined. With New York in the year 1985 as a case study, it is found that an overall vertiport size 1000 feet square would be required to cope with the frequency of operation. Such complexes may be restricted to ground level sites on waterfronts. The airspace requirement is next discussed. Some landing aids equipment (e.g. microwave) will be required to permit pinpoint navigation and also to permit simultaneous approaches to a VTOLport of this size.

V/STOL AIRLINE SYSTEM SIMULATION
Joel F. Kahn
AIAA Paper 67-841

SHSS (Short Haul System Simulation) is a computerized simulation model built by Lockheed to simulate economic airline operations. The aircraft being studied are evaluated and they would compete with each other for markets using economic criteria. In addition it also considers the effects of CTOL, rail, bus and auto operating on the same route. Data inputs consist of: aircraft characteristics including performance and cost; route characteristics of distance, yields and various routings; port characteristics such as type, size, and location; passenger preference for out-of-pocket cost, flight frequency, speed, demand and value of time; level of operation defined in terms of both an adequate service to the passenger and a satisfactory return on investment to the carrier. Simulation and dynamic programming techniques are employed. The five steps of the process are:

(1) initialization of input passenger demand
(2) development of route interaction
(3) flight evaluation by aircraft types
(4) flight assignments
(5) system summarization and analysis

The printout consists of a listing of operational traffic results for each input route. For each type of aircraft assigned, the following data are included:

- trip distance and time from port to port
- passenger load factor
- number of flights
- total capacity
- passengers served
- total revenue
- total DOC
- number of aircraft required for routes
- average amount of cargo per trip

However, the major output of the model is the system summaries revenues and expense. From these data, airline ROI may be determined.

Like most of the aircraft manufacturer company's reports, description of their computer programming is abbreviated. Thus this report only suggests what has been done in making a systems economic evaluation but not very explicitly how it was done.

THE SHORT HAUL COMPOUND TRANSPORT AND ITS PLACE IN INTERURBAN TRANSPORTATION

Norman E. Nelson
Society of Automotive Engineers, 67-0830
Aeronautic & Space Engineering & Manufacturing Meeting, Los Angeles
October 2-6, 1967

The paper discusses mainly the 'inter-urban' aspects of short haul transport: compound aircraft are proposed as the ultimate solution to the inter-urban mass transportation problem. Compound aircraft are characterized as rotary wing type vehicles. Representing this family are two of the products from Lockheed: the CL-1026 thirty passenger and the CL-879 sixty to ninety passenger - built primarily for commercial aviation.

Key factors vital to the system are reviewed. They are considered in this order: block time and total trip time, frequency of service, passenger comfort, noise, all weather operation and finally heliport location.

The paper’s aim is to show how the Lockheed aircraft with their inherent stability, high degree of comfort, low speed, low cost of operation, adaptability to any landing area and all weather capability are suitable in this new air transportation era. However it fails to distinguish the major difference in characteristics between interurban operation and intercity operation.

COMMERCIAL V/STOL AND THE CALIFORNIA CORRIDOR

Robert B. Megersburg
Society of Automotive Engineers
Paper 66-0317
National Aeronautic Meeting, New York
April 25-28, 1966

The paper starts off by reviewing the results of another paper "An Analysis of Intercity Passenger Traffic Movements within the California Corridor Through 1980" (FAA-ADS-74) which provides the assessment of future air traffic in California using an econometric model. A V/STOL system is expected to be competitive with automobile for intercity transportation by 1980. To identify the role of this new V/STOL system, the vehicle, airport, air traffic and navigation facilities were studied for the California Corridor. But these studies prove to be very brief and general.

An airline simulation model was made up which determines the sensitivity of passenger traffic flow to fare adjustment. The best system derived is the one that maximizes V/STOL passengers while providing the operator with a reasonable R.O.I. However this simulation technique is readily available in the report "Technical and Economic Evaluation of Aircraft for Short-Haul Intercity Transportation" (FAA-ADS-75). Some of the important conclusions are:

1. A mixed system of CTOL jets and STOL or VTOL would be economically viable in the California Corridor
2. The success of the V/STOL system depends heavily on the location of the V/STOLports.
3. Aircraft noise is a major impediment in choosing the airport site.

ECONOMICS OF BUSINESS AIRCRAFT

Henry Ryan
Society of Automotive Engineers, 66-0210
Business Aircraft Conference, Wichita, Kansas, Mar. 30-April 1, 1966

A business aircraft having an operating cost between $50-60 per hour and a speed around 200 mph is defined as a single or twin engine aircraft capable of landing and takeoff at locations easy to access and capable of carrying a few passengers on a business trip. This paper indicates business orientated passengers on short haul inter-city trips favour a business aircraft to the scheduled airline. The interaction between some of the important parameters of the two types of aircraft such as
speed, operating cost and stage length are discussed via the mechanics of simple graphic methods.

The economics of business aircraft are examined in context of the interests of airplane salesman, prospective purchaser, and the aircraft owner. The economics is in essence, a study of time and money - two of the important parameters that aviation has to sell. The general finding reveals on most routes a maximum of three passengers per vehicle justifies the flying of a business aircraft. On those routes where there is no direct service by the airlines the advantage is more apparent. Other parameters for instance, the flexibility of scheduling, frequency of service, and airport locations are not examined in this article. Presumably this overall picture could be applicable to some extent to STOL transportation in view of their common properties.

**THE ROLE OF THE STOL TRANSPORT IN COUNTERINSURGENCY REQUIREMENTS AND CAPABILITIES**

R. D. Hiscocks
Society of Automotive Engineers 65-0238
National Aeronautical Meeting
Washington, D. C.
April 12-15, 1965

The role of a military STOL transport is identified as logistic support or tactical missions. These call for fast aircraft with capability for flying long range under all weather conditions, as well as STOL performance on rugged short strips. Lengths of available airstrips are compared with the performance of contemporary transport aircraft. Surface conditions appropriate to unprepared field operations are described. Implications in design, low speed performance, stability and control characteristics are noted. Short field paradrop and LOLEX missions are discussed with suggestions for appropriate design measures.

Estimates of the cost of small package and emergency shipments indicate that the STOL aircraft is less expensive than the offloaded conventional transport. Examination of the cost of establishing and maintaining an air logistic system (comprising mainly aircraft and airfield construction costs) shows similar results.

The paper concludes with brief comments on complexity and safety.

**FORECASTING INTERCITY TRAVEL**

Eric Culley
Research Division Canadian Transport Commission

The region under study in this paper is that part of Ontario and Quebec lying between Quebec City and Windsor. A mathematical equation has been developed by multiple regression analysis which aids in the prediction of traffic of various modes. This model is believed to be quite exhaustive. Parameters such as trip time, trip cost, frequency of service, population, family income, distance between the two cities, auto driving time, competitiveness of common carriers to auto, and the effect of language are all taken into consideration. The other factors which are felt desirable but are not included in the modelling are safety, on-time reliability and comfort. The data that this model is based on is a survey conducted in the summer of 1969 plus other information supplied by the carriers. The approach used is to regard the common carriers and the automobile as two distinctive but competitive systems and that auto traffic need not be known in order to determine the parameters of the common carrier model. In spite of the large amount of variables to be handled, high correlation is obtained between the observed and the theoretical value. (The goodness of fit is 0.931). The report could be more complete if it included in the model a prediction of automobile traffic as well.

**A SIMULATION STUDY OF POSSIBLE STOL SERVICES ON THE TORONTO - MONTREAL AIR ROUTE**

R. Dixon, Speas Associates of Canada Ltd.
April 1970, Project No. 450-80

The study is devoted to the impact of STOL aviation on the Toronto - Montreal route in the years 1974 - '80. A series of simulations is done which schedules a pure CTOL and a combination CTOL/STOL system on the study route for a typical summer and winter day. The operational characteristics of the CTOL/STOL system are based upon a linear programming approach to determine the maximum net income. This approach was to give prime emphasis to the airline operator by comparing the combined CTOL/STOL operation in terms of operating profitability and to show that the combined system is better than the pure CTOL.
system. Once this was done, the time and cost savings to the passengers and Government facilities cost were then evaluated.

It is inconclusive after the study whether a STOL operation on the Toronto-Montreal route is profitable or not. It is recommended that further studies should be carried out such as sensitivity analysis for certain parameters in order to determine STOL economic feasibility. Parameters including STOL port locations, traffic volumes, fares, time and cost elasticities etc. are only superficially touched. Again most of the mathematical detail of the computer techniques is concealed and tracing their computation is impossible. Without this information, portions of the report are hard to understand. Below is an account of their significant findings:

The general economics are marginal on a stage length of 335 miles when based upon maximum profitability to the carrier as in this case. All study parameters for all study aircraft show positive benefits for all of the study years through introduction of STOL service except for the DHC-7 which shows negative time savings. (DHC-AW yields a 0.62% decrease in total time per OD passenger whereas DHC-7 has a 0.93% increase in total time.) With respect to total trip costs, cost per OD passenger savings are again very marginal. DHC-7 shows 0.2% whereas DHC-AW a 0.18% reduction. However in terms of operating income, the DHC-7 has an advantage due to the low operating cost of the aircraft. From the simulation study, it is found that two DHC-7's or one DHC-AW or one B-751 would be sufficient to serve this route. Considering the overall "system" benefits for both the airlines and passengers, with the exclusion of Government facility cost trade-offs, it shows that DHC-7 has the least relative attractiveness compared to the DHC-AW and B-751 for each of the forecast time periods.

Aircraft demanded vs price, and selling price vs number of aircraft produced were estimated for six types of VTOL aircraft. The relationship between these two functions indicates the total aircraft program profit or loss as a function of the number of aircraft produced. Results were calculated for the 90 seat size of all six types. The aircraft demand was calculated separately for each domestic city pair and then summed to obtain total domestic demand. The domestic demand was then increased by a constant ratio to account for export sales. Demand is based on air traffic by year, the estimated final year of production for these first generation intercity VTOL aircraft. None of the VTOL aircraft types appear to be economically self-sustaining by 1975; by 1985, three of the six types appear capable of economical operation.

In this study, there is a primary assumption, i.e. problems like noise, air pollution, safety and the availability of vertiports have overcome. The method of analysis is first of all, to determine VTOL passenger city centre to city centre demand. This involves forecasting of passenger traffic by city pair and then a breakdown of city-pair air traffic by segment pair. Local OD's of passengers were related to radial distance from the centre of the city. Survey results allowed a generalized distribution and such a relationship was shown graphically. These basic inputs, together with the ground times and costs vs distance relationship, permitted the calculation of traffic by city pairs, their ground travel times and costs. To split the passenger demand between CTOL and VTOL for all the combinations of segments of a city pair, we required not only the trip cost and time by the two modes, (note the VTOL fare was projected as a function of DOC and IOC of the aircraft plus a nominal rate of investment) but also the value of time were quoted from another previous study - "The Demand For Air Travel by Supersonic Transport". Three different methods were used to simulate air travel by VTOL. One method is based on the relationship between trip distance and the percent of passengers taking the air mode; another is constructed on a statistical relationship between the number of air trips, trip time and other independent variables and a third is based on the implications of the effect of the 1947 change in the location of the airport serving Detroit and other cities. A comparison of the results of all three methods for a 50 min. time saving was made and the "Detroit Airport move" method was finally adopted. The traffic stimulation is applied only to
passengers selecting VTOL service on a value of time basis; in this way, the total traffic stimulation is reduced as VTOL fares are increased above CTOL fares.

The report was also interested in the calculation of domestic aircraft demand. The aircraft productivity determined the number of aircraft required to carry the city-pair passenger demand. The total domestic as well as the total export market were established. The aircraft demand as a function of aircraft price was compared with the supply price of the aircraft to determine the economic feasibility of the program. The aircraft price was varied; this changed the VTOL fare which changed the demand for aircraft. In this way, the number of aircraft demanded could be determined as a function of the price of the aircraft. The supply price curve was determined with non-recurring costs being averaged over varied production numbers of aircraft and recurring costs being estimated with applicable learning curves.

Though this report is devoted exclusively to VTOL, some of the technical analysis, such as the estimation of passengers between two segments for a city pair are equally applicable to STOL aviation. Vol I & II contain the entire context of the report while Vol III & IV present generalized aircraft demand by city pair; 95% of the pages are results from computer printouts.

AN ANALYSIS OF INTERCITY PASSENGER TRAFFIC MOVEMENT WITHIN THE CALIFORNIA CORRIDOR THROUGH 1980

W. L. Metzger
Stanford Research Institute SRI Project No. SEU-5589 April 1966
Prepared for FAA FAA-ADS-75
Clearinghouse No. AD 641 611

The report presents the results of intercity passenger traffic movement within the California Corridor between Sacramento on the north and San Diego on the South, through 1980. The approach is to project passenger traffic between 13 selected city-pair markets within the Corridor. Then this traffic is allocated among the various modes of transportation and finally future technological developments in the intercity surface transportation system within the corridor are assessed. All types of surface transport systems are examined, including systems now serving these markets as well as proposed new types of high speed systems. Allocation of future air traffic is based on the assumption that only CTOL will be in service.

Data required to generate the estimation model is analyzed, including the line haul time and cost for all city pairs on all modes. The variables in the model are identified; a basic assumption being that not only the traffic could be explained by these variables, but also, these variables could be projected with more reliability than the traffic. A multiple regression analysis is applied to formulate the model which has equal applicability to all city pairs. Various growth rates are used to estimate the future rail and bus traffic. The remaining auto and air traffic are divided by the 'value of time' method. It is expected that rail traffic will continue to decline, and bus traffic, termed the 'poor-man's mode of transportation' would have little contribution to the total market. Thus there remains the two competitors auto and air which will continue to dominate. This 'value of time' method illustrates how auto and air will compete on the basis of relative trip time and costs.

A SYSTEM ANALYSIS OF SHORT HAUL AIR TRANSPORTATION
M.I.T.
Flight Transportation Laboratory
August 1965, PB 169 521

A very lengthy but concise report that talks about the potential of V/STOL operation in the Northeast Corridor published in 1965. It is a pioneer in this field of system analysis for V/STOL and it is often referred to as a valuable reference by subsequent reports. It is divided into eight sections covering seven topics, from vehicle design studies; direct operating costs; system network studies; ground facilities; management information system; indirect operating cost and operating characteristics.

Vehicle Design:

Typical direct operating costs and block times for the VTOL, STOL and helicopter are studied. No determination of the preferred size or type of vehicle can be made until some indication of predicted demand is given. In general for trips under 100 miles, the STOL with its block time penalty has higher unit costs. A complete parametric analysis has been conducted as part of the determination of vehicle characteristics, presented graphically as DOC vs stage length.
Direct Operating Cost Analysis:-

Analysis of the 1960 ATA formula indicated that it is reasonably accurate in predicting helicopter transport costs with the only exception being the maintenance costs. But there are no reasons to believe comparable costs could not eventually be achieved. However, for VTOL/STOL aircraft extraneous systems not found in conventional jet transports and requiring considerable maintenance and inspection such as rotor shafting, transmission etc., would always incur an extra maintenance cost penalty. Since VFR conditions exist for more than 90% of the time, no traffic delay penalties have been assumed in estimating DOC.

Transportation System Studies:-

Until good estimates of intercity passenger travel in the corridor are available, the precise schedule of services, frequency of services between cities, vehicle utilization, optimum vehicle size, the size of ground facilities, and the system costs and fares cannot be determined. Provided the fares are low, the air system can provide direct nonstop service at high frequency between all cities in the Northeast Corridor.

Ground Facilities:-

At the same site, STOL terminal facilities will cost between 3 to 4 times as much as an equivalent VTOL site. This larger area makes siting problems more difficult in city centre areas and increases IOC by 50% in the STOL system. A major investment in terminal buildings and passenger handling facilities will be required at the larger terminals to achieve an efficient ground manoeuvring time. Roof top operation from the STOL/VTOL terminals buildings can be expected in city centre areas.

Management Information System:-

With the future development of computer hardware and software from the present airline reservations systems, it will be economically feasible to provide real time loading control, reservations systems, scheduling control, for efficiency in systems operations, and good data for marketing and management planning. This computer system will achieve high employee productivity and low indirect operating costs and aid in insuring good utilization and load factors for the air vehicles.

Indirect Operating Costs:-

For very short haul transportation systems, the IOC’s of the system become dominant over DOC in determining the trip cost. By using a mechanized large terminal to provide efficient and fast passenger loading, the projected Airbus IOC’s are roughly comparable to present helicopter system costs or about 1/5 airline costs, but still roughly twice that of an intercity bus system. The IOC’s derived are for a reservation system from existing airline experience modified to include a computerized scheduling based on demand. These costs could possibly be reduced for a minimum service commuter type non-reservation system.

Operating Characteristics of the Airbus System:-

By using automatic stabilization and guidance systems presently under development V/STOL vehicles will have excellent handling qualities which will allow reliable all weather service operational reliability of 99.5% to be obtained. By dispersing landing sites in metropolitan areas and by insuring sufficient IFR takeoff and landing capability, bad weather V/STOL operations without serious delays can be provided.

AN APPLICATION OF THE GRAVITY MODEL TO CANADIAN DOMESTIC INTERCITY AIRLINE PASSENGER TRAFFIC

P. T. Hodgins

Construction Engineering and Architectural Branch

Department of Transport, Ottawa, 1968

The report calibrates the gravity model that would estimate the intercity airline traffic by relating it to the air fare and the product of the airline effective populations of two cities. The data is extracted from the Canadian domestic intercity airline passenger travel in 1966. The model, presented in a mathematical form is:

\[
\text{Traffic} = 0.15 \times 10^{-4} \times \frac{P_1 P_2}{F^{1.3}}
\]

The constants are estimated grossly since the graphs plotted do not allow any exact determination. Thus this model proves to be quite crude and besides it requires adjustments to the census figures of the metropolitan population in order to arrive at airline effective populations. These involve considerations of extra-metropolitan populations, traffic shadow, competitiveness from ground transport, physical isolation, economic status or average income, city function and conceivably a few more variables. Also poor correlation is indicated for stage lengths under 500 miles e.g. Toronto - Ottawa, Toronto - Montreal, Montreal - Ottawa. A special section
is devoted to account for the unusualness of these three routes. Because there is no rule of thumb as to how the aforementioned variables will affect the magnitude of the effective airline population, even when all these variables are accounted for, it cannot be expected that the model will yield consistent results. It is suggested by the author that instead of using the air fare and population figures to predict the intercity air traffic, perhaps this gravity model may have a more significant application as a method of determining airline effective populations.

Because of the restrictions and the amount of variables that have to be accounted for, it is doubtful whether this formation would have any significant application to our study.

**SYSTEM COST STUDIES**

**THE INFLUENCE OF FACTORED AIRFIELD PERFORMANCE OF LESS THAN 2000 FEET ON STOL SYSTEM ECONOMICS**

The de Havilland Aircraft of Canada Ltd. November 1969

An examination has been made of the variation of operating costs with airfield performance of STOL transport aircraft. Assuming that engine power is fixed, that the $C_L\text{max}$ is the maximum practical and that air regulations and operating procedures are invariant, the field length requirement varies as the wing loading.

Two possibilities are available to change this wing loading. The first approach is to off-load the aircraft to reduce wing loading. Using the 48 passenger DHC-7 as an example, reduction in airfield length by 300 ft. would require the aircraft to operate with zero load--therefore this approach is impractical. The other approach is to increase the wing area to reduce the wing loading. However this leads to an increase in structural weight, drag, weight of fuel as well as aircraft price. All these contribute to the increase of DOC. Typical figures show that by reducing field length from 1925 ft. to 1460 ft. the DOC will subsequently increase by 45.8% per seat mile. In the event that fares are held constant, the increase in DOC will reduce the profitability of the Metroflight system. For the DHC-7, reducing the airfield length from 2000 ft. to 1500 ft. means a loss in ROI of 11%. On the other hand, if fares are increased to cover the higher DOC while maintaining a constant ROI, the number of passengers using the Metroflight system is reduced.

STOLport costs are less important than the DOC or IOC of the Metroflight system. It was determined in the report that by relaxing field lengths from 1500' to 2000' the increase in cost is relatively insignificant. But it does not seem likely that the field length could go beyond 2000 ft. due to strong opposition from other factors. It is concluded that 2000 ft. is close to the optimum design field length. This conclusion applied to either current technology aircraft certified to Part 25 or to advanced technology aircraft certified to Part XX such as Augmentor Wing jet STOL aircraft.

**THE POTENTIALITIES OF VTOL TRANSPORTATION SYSTEMS IN THE NORTHEAST CORRIDOR**

D. S. Lawrence and R. H. Shatz
Society of Automotive Engineers 69-0417
National Air Transportation Meeting, New York, April 21-24, 1969

The potentialities of VTOL, STOL and CTOL systems are examined in terms of cost effectiveness. As the title suggests, the VTOL system is the most advantageous of the three when ground facilities, ground access time and social penalties are included. The air travel times and air travel costs are not very much different from one mode to another, if congestion at the (CTOL) metropolitan airports is neglected. The system costs not associated with the air trip are next examined. It is assumed that the situation that fits the New York hub will apply as well to the rest of the Northeast Corridor. The conclusion reached after making a study of New York is that the VTOL system requires little real estate relative to competitive modes, and that its system cost savings are significant, in spite of the fact that it necessitates seven VTOLports to handle the traffic of 1980.

The STOL system rates next and requires five STOLports. Typical figures for VTOLport facilities cost are $312 million compared to $473 million for STOLports. The inherent advantage associated with numerous VTOLports is the ease of access and the cost and time that a traveller may save by travelling from his origin or destination to the VTOLports. Projecting the short haul passengers in New York to be 53 million and assuming certain distributions of passengers in that area, it is expected that the average ground access cost and time for the VTOL system is $1.71 and 19.3 minutes compared to $2.34 and 25.3 minutes for STOL system.
The last category considered is the social cost. The major item representing this category is the noise pollution. By formulating a measure of the noise annoyance, it is found that VTOL system will affect the least area, consequently the least amount of people.

This paper provides some guidelines to evaluate the potentialities of any system. As far as the three categories are concerned the supremacy of the VTOL system is indicated.

AIRLINE SCHEDULING OF V/STOL AIRCRAFT
Warren Hyman and Larry Gordon
AIAA Paper No. 67-801

A computerized time-of-day scheduling model has been developed which maximizes airline earning considering passenger demand. This model required the following as input:

- route structure of an airline;
- number of aircraft by type;
- block time between cities for each type of aircraft;
- passenger preference function for flight time and frequency;
- potential passengers on each route;
- maintenance requirements and frequency of service on each route.

Human judgement initiates the first city pair of the network to be considered and the computer will carry on the subsequent calculations. The model produces timetables for each city on an airline's route structure and a schedule for each aircraft which not only gives the timetable, destination and origin but also an estimate of the revenue. The only drawback of this paper is the lack of mathematical hardware. One must be knowledgeable in the topic of dynamic programming before thoroughly understanding it.

The prime use of the model is to determine the schedule which yields maximum returns for a given route structure and passenger demand pattern. Potential markets can be investigated to determine the effects of decreasing service, effects due to capacity constraints or other management policies. However the model is claimed to be only a schedule development tool and not a real time program because of unplanned events.

A MULTI-REGRESSION ANALYSIS OF AIRLINE INDIRECT OPERATING COSTS
N. K. Taneja, R. W. Simpson
M.I.T. Flight Transportation Laboratory R-67-2, 1967

A multiple regressions analysis of domestic and local airlines' indirect costs was carried out to formulate cost estimating equations for airline indirect costs. Data from CAB and FAA sources covering 1962-66 was used and the costs were broken down into classification of the uniform system of accounts Form 41, used by the airlines in reporting to the CAB. Thus regression equations were found for: (1) annual system expenses in the categories such as Passenger Servicing, Promotion and Sales etc. as well as an overall indirect operating cost; (2) annual station expenses where the Aircraft and Traffic Servicing expenses for individual stations are examined.

A stepwise regression technique is used to select the best combinations of independent variables for the equations. The results generally showed that a high degree of correlation could be found between the costs and some combination of these variables.

However, due to a lack of statistical data for a system of STOL aircraft, it is not possible to use the technique in this book to estimate the future I.O.C. of an advanced STOL system. For example, if levels of service differ between the STOL system and the domestic or local airliners, in forms such as automation in handling luggage or in ticketing, this would certainly invalidate such cost categories as luggage handling and sales. Thus we would require a new set of data for analysis before we can generate a new predicting I.O.C. equation.

A DESIGN STUDY OF A METROPOLITAN AIR TRANSIT SYSTEM
Stanford Univ.
Prepared under NASA - ASEE Summer Faculty Fellowship Program in Engineering Systems Design, NASA Contract NSR 05-020-151
NASA CR 73362 Clearing House Number N69-41102, August 1969

A design study for a Metropolitan Air Transit System (MAT System) for the San Francisco Bay Area is the subject of this report. Being a design study, not a feasibility study, the report is entirely devoted to research on environment or facilities that would further the success of such service. This includes (1) the search for an optimum design for the type of aircraft with specification for its flight performance
and noise generation characteristics (2) the design of the air terminals required for its operation, (3) a study of the avionics system required for the automatic navigation and control of the airplane, (4) the costs and benefits of such a system. The MAT System is designed to handle 100,000 commuter trips and 50,000 airline connection trips per day. It consists of 24 terminals divided into 3 categories: (a) Metro terminal; (b) Suburban terminal; and (c) Airline terminal. The air vehicle utilized is an 80 passenger compound helicopter having a cruise speed of 250 mph. Although the report covers the whole area of the design for MAT system, only the system cost section is discussed in this bibliography.

It was concluded that such a high speed MAT System is technically and economically feasible. However, this feasibility is derived through comparison with the BART (Bay Area Rapid Transit) System, which is currently under construction. Nowhere in this report is there a competitive analysis of the MAT System with the existing auto, bus or rail market. The aircraft represent 80% of the cost of the system; furthermore this percentage depends heavily on the aircraft utilization hours. At an annual utilization rate of 2000 hours per aircraft, operating cost per passenger is $0.17 per passenger mile. (BART System has an operating cost around $0.122 per passenger mile.) On a long route e.g. San Francisco to Sacramento with low traffic densities, the figures suggest that the MAT System is indeed superior to the BART System. The break even point occurs when traffic flow is about 6500 passenger round trips per day. The traffic demand for this system is based on the important criteria that the passengers are not very sensitive to the fare level. The major market is believed to be the transportation of airline passengers to and from San Francisco airports. In view of the present market, it is assumed by 1980 about 20% of airport passengers and 10% of professional and business commuters (whose time is more important than the additional cost of transportation) will be using the system. On this basis, during the latter 1980's a total of 260 aircraft will be required with a total annual capability of 3120 million passenger miles. Because a huge sum of capital, $1400 million, is involved, the study also provides some solutions to the funding problem.

This report might be useful in an advanced STOL system design study.

PASSENGER AIRLINE ECONOMICS AND SYSTEMS
APPLICATION CONSIDERATIONS FOR AIRLINE OPERATIONS
Robert A. Taylor
Society of Automotive Engineers 69-0415
National Air Transportation Meeting, New York, April 21-24, 1969

To choose the right aircraft for the right routes has become an enormous job in fleet planning, because of the complex nature of the aircraft and the different kinds of routes. Boeing has derived a computer program to predict how a fleet of Boeing jets might perform profitably in the network by simulating each flight on each route.

All kinds of factors are first hypothesized, such as the future traffic markets, the new routes awards etc. A device known as 'Service Complex Index' is utilized to measure passenger preference. Together with the number of stops, frequency of service and number of seats, this forms a basis for assigning passengers to the aircraft on a logical basis. With inputs to the 'Fleet Planning Program' - the characteristics of the aircraft and other operational constraints - it will give printouts for the block time, permissible payload, fuel expenditure and DOC/passenger mile etc. for each route segment.

For the entire network the analysis involves routing all aircraft over the whole system using it to its fullest advantage and the computation will make estimates of the number of passengers on each segment, average load factor, revenue passenger miles, the total available seat miles, average segment lengths, and the types of aircraft required for the network. Printouts of schedules for each airplane are also available. The paper does not describe any mathematical procedure, rather, flow charts are presented.
V/STOL traffic forecasts were developed from results of previous studies ('Economic Analysis of V/STOL Transport Aircraft' Stanford Research Institute). Air traffic system concepts were developed and applied to a high density intercity environment (New York-Boston) based on forecasted passenger volumes for 1975. Navigation system requirements were derived to accommodate the V/STOL air traffic. Finally, candidate systems which met the postulated navigation requirements were selected. An investigation of investment analysis techniques is conducted, and the Payback Reciprocal technique is chosen as a means of evaluating investment opportunities. Aircraft investment costs, DOC, IOC and anticipated revenue to a potential V/STOL operator in this environment were estimated. Investment, operating costs and anticipated dollar benefits to the Federal Government associated with providing an all weather aviation support service were also estimated. These estimates were incorporated in the selected investment decision models to evaluate the economic implications of establishing an all weather V/STOL transportation system in this New York to Boston route. The results indicate a return on investment (before taxes) to a potential V/STOL operator of 24.4% and a present value of 2.68 million dollars which the Federal Government would be justified in investing in the necessary aviation support system. The establishment cost for an all weather V/STOL operation is 1.55 million. This confirms the benefit of introducing this system.

The author points out some of the inadequacies of his thesis due to data constraints. They are (1) the relation between schedule frequency and traffic generation; (2) air fare and trip time elasticities; (3) total intercity traffic; (4) value of time distribution for travelers by mode. If these criteria could be integrated into the modelling, perhaps a more accurate way of assessing the loss of revenue could be derived for a delayed or cancelled flight incurred by a V/STOL aircraft without an all weather capability.

MAINTENANCE COST STUDIES OF PRESENT AIRCRAFT SUBSYSTEMS
C. Pearlman, and R. W. Simpson
M.I.T. Flight Transportation Laboratory
Dept. of Aeronautics and Astronautics
FT-66-2, November 1966

This report describes two detailed studies of actual maintenance costs for present transport aircraft. The first part describes maintenance costs for jet transport aircraft broken down into subsystem costs according to an ATA classification. Multiple regression techniques were then used to demonstrate the construction of cost estimating formulae for both subsystems and a total aircraft system. The short-coming of the 1960 ATA formula that forecasts maintenance cost is its failure to include some parameters such as route structure, traffic schedule, utilization, type of maintenance scheme, and fleet size, which also have a direct bearing on the size of the labor force and hence maintenance cost. However, in the improved multiple regression formulae, these parameters are all introduced. These parameters could be sorted into three classes: those which characterize the airline e.g. fleet size, utilization, the reporting year that accounts for the upsurge of labor rates, time since first delivery, airline productivity measure and a defined dummy parameter; those which describe the aircraft characteristics e.g. age of type of aircraft, vehicle components, fuselage length, number of seats, tires and engines, engine TBO, cost of aircraft, engine, propeller, rotor and hot air mass flow and fuel flow; and those which illustrate the manner of operation, e.g. landings per hour, and geography and climate. The results indicate that there is high correlation with actual data supplied by the six airlines. In fact the standard error measures 13.66 compared to that of the ATA formula which measures 31.15.

The second part of this report briefly describes the results of an extremely detailed study of actual maintenance costs for the rotor and transmission systems of present commercial helicopters. The background information concerning each item of maintenance costs was examined to determine if it would be avoidable in the context of a mature airline operation with a full scale modification program for vehicle deficiencies. The results show that if only 'normal' maintenance on rotor and transmission systems were performed, the potential maintenance costs for present helicopters are roughly 1.3 times the standard ATA estimate for fixed wing aircraft.

It is emphasized that the particular results presented here cannot be considered rigorous in the sense that there is not a sufficient statistical information input. They are presented only to exercise the technique to ascertain the data requirements, to show the problems in using the technique, and to indicate the type of results which can be obtained. Further study using more extensive data over a period of years and studying the accuracy over a wider sample is recommended by the authors in order to validate this type of conclusion.
The paper illustrates some of the similarities between the development of highway and air transportation systems, in aspects such as growth, expenditures and investment. The conditions facing the air industry are similar today to those conditions facing the highway system in 1955-56. An example is in airport planning where land acquisition poses similar problems as in the early years when acquisition of right-of-way had to be accomplished at high cost to meet construction schedules. From the size and similarity of the problems it appears that the air community could look profitably to the Federal Highway Acts for guidance in solving current airport and airway growth problems.

OVERALL ANALYSIS OF COMMERCIAL V/STOL SYSTEMS
L. E. Howard
AIAA Paper No. 67-969

The paper describes an economic analysis of the short-haul transportation system using computer techniques. The objectives of this paper, besides evaluating the economic potential are, to investigate the extent of public and private investment required to support V/STOL and to identify its role in the nation's transportation system. The primary groups concerned are the carrier, the federal and local government, the traveller and manufacturer. The simulation model is adopted from Lockheed and is explained in the paper "V/STOL Airline System Simulation" AIAA paper 67-841 by J. F. Kahn. This paper will discuss how the views of these five decision-making groups fit together to form a complete system analysis and how this analysis will aid in development of improved future intra-urban and short haul transportation systems.

The only useful information elicited from this paper is the 'value of time' concept. Actually all these figures are from the reference "A Value of Time Analysis of the Airport Shuttle Market" (Systems Research Dept. Lockheed-California Co. CASA/67-023, 14th April 1967). The conclusion reached is that the value of time concept is a very good indication of the

preference of air travellers as observed from comparing the theoretical and the surveyed value. Other than this the report is just a summary of the overall views of commercial V/STOL systems.

FEASIBILITY AND COST OF EXPANDED INTER-CITY AIR SERVICE IN THE WASHINGTON-BOSTON CORRIDOR
Systems Analysis and Research Corporation
PB 166-883, 1963

The study in this paper is concerned with air transport service in the Northeast Corridor. It investigates the additional improvements to airports, airway systems, and aircraft which will best meet the needs of the intercity air passenger market by 1980. The study does not undertake the evaluation of the comparative costs and benefits of accomplishing the goals of an overall transportation plan by all of the means available; rather it presents alternative aviation possibilities that appear to warrant further considerations. The social environment for air travel in the Corridor is first reviewed, and the role and developing problems of short haul air transportation are also discussed. Next the demand for air transport services and facilities through 1980 is projected. The final sections of this report evaluate possibilities for additional and improved services and set forth recommendations for further consideration.

Since the principal findings in this report are a set of statistical figures of the Northeast Corridor, they will not be summarized as they will not be of interest to the "CTC STOL Study". For the Corridor, it is concluded that V/STOL service will be a long term solution to short haul transport. Because of the lack of necessary detail and the problems of anticipating the cost aspects of new technology, the analysis is more qualitative than quantitative, the focus being on the screening of promising possibilities for further study rather than the searching for an optimum.

ACCESS AND EGRESS PROBLEMS

A SYSTEM APPROACH TO AIRPORT ACCESSIBILITY
R. W. Theriault and G. N. Sarames
AIAA 68-1048

The problem of airport accessibility cannot be solved by using one mode of transport alone. Analysis of alternate modes of transport to an airport
requires a tremendous body of data, and usually for a thorough solution to the airport accessibility problem computer techniques are required. This paper aims to give some insight into this problem, and for this study the technical aspects of alternate vehicle systems are assumed.

The key factors affecting the potential demand of transportation systems linking the metro and airport are outlined. They are:

- The total airport population consisting of air passengers, ground employees and visitors.
- Traffic flow patterns such as the directional flow, (to and from airport), geographic distribution of passengers within the city, and distribution of passengers by time.
- Value of time for each potential user under varying conditions.
- Effect of terminal locations and frequency of service for the commuter transit.

The significance of these factors to the demand for an airport access transport service are discussed.

The allocation of passengers by mode could proceed if the above key factors are known. This modal assignment is based on one criteria: the traveller will choose the mode if the cost per hour saved is less than the value of the hour to him. Waiting time was omitted for all modes of transport and no highway congestion was included in the calculation. Based on this method theoretical values are derived which indicate the percent distribution of public transit, limousine, and taxi are 12%, 24%, 64%, respectively. When compared with the overall average values for the four major hub airports in U.S. (1964), it validates the calculations and assumptions. The actual values are 10% for public transit, 20% for limousine, 70% for taxi.

Several important conclusions have been reached. The automobile will be the predominant mode for all travellers who have access to the auto. For those who do not, the taxi is preferred. VTOL service in a suburban area must be capable of generating enough traffic to support frequent service in order to compete with the auto. However, VTOL could play a leading role if the highway access to airport continues to worsen, especially for non-residents. However, rail transit to the airport could drive out VTOL completely, depending on the fare level and trip time of this mode.

The paper gives a concise view of the nature of the airport accessibility problem. The methodology or approach to the analysis is believed to be over-conservative. The biggest deterrent to a realistic appraisal of alternate systems does not come from the technique but from the lack of adequate demand data.

Note: references 2, 4, 7 and 8 numbered in this paper are believed to be of high value.

GROUND ACCESS TO MAJOR AIRPORTS IN THE UNITED STATES
A. J. Munds
M.I.T. Flight Transportation Laboratory
FTL-R68-7, 1968

The report reviews the problem of ground access to the airport with further recommendations as to alternatives that might alleviate the future situation.

The present distribution of air passengers for major U.S. cities tends to be an individual function for each city, but the decline of CBD and expansion of the metropolitan area of cities tends to disperse the passengers' O & D. A very general survey of the air passenger characteristics for eight of the major U.S. cities is presented, and listed below are some of the findings: the average proportion of CBD passengers is 30% or less except in New York where CBD passengers constitute 60%. Nearly all passengers traveling from the CBD are non residents whereas the ratio of non residents to resident passengers for the city as a whole is about 1:1. The automobile is always the principal means of transport to and from airport. The use of taxi declines as distance increases from CBD to airport and in such cases the patronage of coaches or limousines increases. The characteristics and ground origins of airport staff and other airport users are not suited to mass transit operations and reliance should not be placed on their use of any system provided to serve air passengers. Projections of future air passenger ground trips show that the movements between CBD and airport by themselves are unlikely to justify exclusive mass transit systems. Suburban terminals, located on the CBD/airport route wherever possible, could increase passenger usage to a level where the system might be financially viable. To make the system attractive to air passengers, it must have the following characteristics:
It appears that automobiles are incentives to air passengers for reasons (2) and (4). Therefore whatever system adopted, (1) and (3) must be strongly emphasized. After reviewing all the potential systems, a mode which involves buses operating on exclusive routes is recommended as the most feasible. VTOL aircraft operating shuttle services between suburbs and CBD is listed as a promising means. Quote: 'The level of service and time savings offered by VTOL aircraft is such that their popularity is bound to increase given the right operating framework'. But unfortunately this right framework is not defined. No matter what system is going to be introduced, the key to success lies in its ability to provide door-to-door transport.

AIRPORT ACCESS - 1980, A VTOL APPROACH
Chaim Pearlman
AIAA Paper 68-1046

At the current rates of air passenger growth, congestion at airports in the air and on the ground is growing steadily worse. This problem is especially acute at the major airports during the peak hours. For a city like Los Angeles, which has developed with the automobile as its central transportation system, the burden is placed on ground access to the airport. To build a rapid ground transit link from the central business district to the airport is not justified. Because of the large amount of capital involved, the number of passengers required to break even is usually large, and may in some cases surpass that of the airport capacity. An exception is found in Cleveland, where economic feasibility is possible due to a low capital investment of $14 million.

The paper suggests that a VTOL network that includes terminals at city centres as well as airports could alleviate both aspects of the problem. The reason why this VTOL service from the central business district to the airport must integrate into the city centre to city centre VTOL service is apparent. Despite the inherent high DOC in 10-15 mile hops, cross subsidization from the lower cost longer haul routes would keep the fare level low. Using VTOL transportation for access can give lower block time from central business district to airport, and can also give access to long-haul CTOL service to communities otherwise served by intercity VTOL alone.

AIR PASSENGER TRIP CHARACTERISTICS
EFFECT AIRPORT ACCESSIBILITY PLANNING
John Brown
October 21-24, 1968
AIAA Paper No. 68-1070

The use to be made of air transportation at an existing or potential airport is a function of the total ground plus air trip to be made by the passenger.

The passenger's residence must be considered when calculating the effect of airport accessibility on the realization of potential trips. Simultaneously, consideration must be given to the quality of service that is available at the airport nearest to the passenger versus that which is available at a competing airport because there is an interrelation of ground miles between residence and airport and the effect of the relative quality of services available at the individual airports. There are substitutes for air travel and among them is the very practical one of making fewer trips and making them of longer duration, as substantiated by recent Los Angeles air passenger surveys.

The paper cautions the airport planner to integrate airport accessibility as one of the elements when considering a new airport site. But it makes no recommendation how this accessibility problem could be overcome by various means of transport.

REGULATIONS AND SAFETY

PORTS FOR STOL - SOME OBSERVATIONS
R. D. Hiscocks and R. J. Taborek
Society of Automotive Engineers 68-0274
Air Transportation Meeting
New York, April 29 - May 2, 1968

The paper covers STOL system costs, STOL aircraft operating costs as well as STOL-port design requirements. This particular review concentrates on the safety and air regulations of STOL aircraft operation, with focus on a small transport, namely the de Havilland Twin Otter.

The maximum STOL performance and the current regulations are examined. It is found that in neither case is there a specific consideration given to the
consequence of an engine failure during take-off. A modified procedure is proposed which would eliminate the deficiencies and also permit operations at a higher standard of safety in essentially the same field defined by current civil regulations. This recommended takeoff procedure is shown below:

- Approach speed 1.22 $V_S$/72 Knot
- Flap 100%
- Approach 14%/8 degree
- Gradient
- Aiming point 180 ft. from runway threshold
- Braking All devices
- Average Landing Distance from Threshold 1000 ft.
- Margin 700 ft.
- Landing Field Length 1700 ft.

Two engine distance to 50 ft. or accelerate-stop distance determines the takeoff field length. One engine climb gradient determines the clearway.

As far as safety is concerned, statistics show that landing accidents are roughly proportional to the square of landing speeds in civil aircraft. Since the landing speed of STOL is about a half of jet transport, statistics predict that STOL will be four times as safe as jets in the landing phase.

This issue of the tentative standards is the result of recommendations received from the Aerospace Industries Association, and subsequent discussion of an FAA draft at a public conference April 2-5, 1968. The FAA plans to pursue studies aimed at more definitive tentative standards. Accordingly, this document will be revised from time to time and will be fully coordinated with interested parties. The second of these conferences was held in April 1970.

APPENDIX II

Cost Study of STOL System

OPERATION METROFLIGHT
John Seekings
Flight International, 16 April 1970

FUTURE TRANSPORT SYSTEMS
Flight International
10 July 1969

SOME FLEET ROUTING AND SCHEDULING PROBLEMS FOR AIR TRANSPORTATION SYSTEMS
Amos Levine
Flight Transportation Laboratory
M.I.T. R-68-5, Jan. 1969
Clearinghouse Call No. PB 183 014

DYNAMIC SCHEDULING IN AIRLINE OPERATIONS
O. J. Akel
Flight Transportation Laboratory, M.I.T.
R-67-1 December 1968
RELATION BETWEEN CARRIER CAPACITY AND MEAN PASSENGER WAITING TIME
K. R. Groninger
Dept. of Civil Engineering, M.I.T.
September 1967 R-67-74
Clearinghouse call No. PB 176 919

COMPUTERIZED SCHEDULE CONSTRUCTION FOR AN AIRLINE TRANSPORTATION SYSTEM
R. W. Simpson
Flight Transportation Laboratory, M.I.T.
FT-66-3, November 1966

APPLICATION OF THE CALCULUS OF VARIATIONS IN DETERMINING OPTIMUM FLIGHT PROFILES FOR COMMERCIAL SHORT HAUL AIRCRAFT
R. Gallant
FT-66-5, November 1966
Flight Transportation Laboratory, M.I.T.

OPTIMAL DISPATCHING POLICIES BY DYNAMIC PROGRAMMING
D. E. Ward
Dept. of Civil Engineering, M.I.T.
November 1966, R66-55
Clearinghouse call No. PB 173-636

Airport Access and Egress

EVALUATION OF VTOLPORTS FOR IMPROVED AIRPORT ACCESS
E. S. Wright and S. Hall
AIAA Paper 69-804
AIAA Aircraft Design and Operations Meeting July 14-16, 1969

GROUND ACCESS TO AIRPORTS
D. N. Miller
AIAA Paper 68-1071

STOL Aircraft Economy

THE ROLE OF AIRCRAFT IN FUTURE TRANSPORT SYSTEMS
E. E. Marshall
Aircraft Engineering May 1969

DESIGN CONCEPT FOR A V/STOL JET
Peter G. Kappus
AIAA Paper 69-200
AIAA/AHS VTOL Research, Design and Operations Meeting February 17-19, 1969

GENERAL AVIATION AIRCRAFT OPERATING COSTS
Federal Aviation Administration
Washington, D. C.
Clearinghouse No. AD 683 306
February 1969

ECONOMICS OF CIVIL AVIATION
National Academy of Engineering
Washington, D. C. Dec. 1968
Clearinghouse No. N69-31295

RESEARCH ABOUT THE USE OF STOL AIRCRAFT IN CIVIL TRANSPORT AVIATION
Ing. A. Salvetti, Univ. of Pisa, Italy
The Sixth Congress of the International Council of the Aeronautical Sciences
Clearinghouse No. N69-12985

SUPPLEMENT TO FEASIBILITY OF V/STOL CONCEPTS FOR SHORT-HAUL TRANSPORT AIRCRAFT
Bernard L. Fry
Prepared by the Boeing Co.
NASA Contractor Report NASA CR-743 (1)
September 1968

VTOL AIRCRAFT - COMPETITOR OR ASSISTANT
P. A. Colman, G. N. Sarames and W. C. Messecar
Society of Automotive Engineers 68-0326
April 29 - May 2, 1968

BREAKING THE GROUND BARRIER FOR FUTURE TRANSPORT AIRCRAFT
W. E. Parsons and W. F. Pieper
Society of Automotive Engineers 68-0306
April 19 - May 2, 1968

COST AND OPERATIONAL PROBLEMS OF A SCHEDULED HELICOPTER AIRLINE
Lloyd S. MacDonald
Society of Automotive Engineers 68-0285
April 29 - May 2, 1968

OPERATIONAL PROBLEMS WITH CURRENT COMMERCIAL V/STOL AIRCRAFT
J. W. Clyne
Society of Automotive Engineers 68-0283
April 29 - May 2, 1968

STUDY OF AIRCRAFT IN SHORT HAUL TRANSPORTATION SYSTEMS
Prepared by Boeing Co.
NASA Contractor report NASA CR-986
January 1968

ADDITIONAL STUDIES ON THE FEASIBILITY OF V/STOL CONCEPTS FOR SHORT HAUL TRANSPORT AIRCRAFT
K. R. Marsh
Prepared by LTV Aerospace Corporation
December 1967
NASA Contractor Report NASA CR-670(1)

OPERATING CHARACTERISTICS OF A COMMERCIAL V/STOL IN THE NORTHEAST CORRIDOR
W. J. Hesse and G. B. Pearson
AIAA Paper 67-769

THE SHORT HAUL COMPOUND TRANSPORT AND ITS PLACE IN INTERURBAN TRANSPORTATION
N. E. Nelson
Society of Automotive Engineering 67-0830
October 2 - 6, 1967

II.24
V/STOL AND SHORT HAUL COMMERCIAL REQUIREMENTS
Clifton V. von Kann
Society of Automotive Engineers, 67-0826
October 2 - 6, 1967

STUDY ON THE FEASIBILITY OF V/STOL CONCEPTS FOR SHORT HAUL TRANSPORT AIRCRAFT
Prepared by Lockheed - California Co.
NASA Contractor Report NASA CR - 902
October 1967

THE IMPACT OF FLIGHT OPERATING TECHNIQUES UPON ENGINE MAINTENANCE COSTS
S. L. Higginbottom and R. S. Tahr
Society of Automotive Engineers, 65-0212
April 12 - 15, 1965

STOL - V/STOL CITY CENTRE TRANSPORT AIRCRAFT STUDY
McDonnell Aircraft Corporation
ADS - 26
Contract No. FA64WA - 5012
Clearinghouse No. AD 614 585
October 1964
III. NAVIGATION, GUIDANCE, AIR TRAFFIC CONTROL

INTRODUCTION

This summary relates to papers, articles or documents summarized and/or reviewed under the CTC STOL study contract. The summary is divided into Communications - air to ground, ground-to-air, Navigation - enroute, terminal area, Approach and Landings, Air Traffic Control - procedures and equipment peculiar to STOL operations. It is intended to give the reader an appreciation of the state of the available literature. It was impossible to review all the papers and articles presently available, but a good cross-section in the areas noted above has been presented. The interested reader should be able to augment his review of specific areas by consulting the additional references listed in the papers reviewed. Because of their importance, a number of papers were read relating to Cockpit Instrumentation as it affects the approach phase under IFR conditions.

Communications

There appear to be very few papers dealing specifically with communications problems. The exceptions to this are a paper by Pan American World Airways describing their experiences with digital communications (Digital Communications, B. F. McLeod, FAA, RTCA Paper Washington, D. C., Sept. 1968) and one on data link systems which appeared in Flying Review International; an allusion is made in one or two papers to ‘discrete channel frequency’ to avoid channel changes in the cockpit. The problems of channel crowding, and spectrum utilization are not laid on the STOL door-step alone. They are world-wide and have not been dealt with as intensively as the navigation problems.

Generally the communication spectrum situation, while crowded, is not hazardous and the dearth of literature in this area would seem to reflect the degree of concern with which the present situation is viewed. It is apparent that some of the new procedures and equipment such as the Advanced Radar Traffic Control System (ARTS) will reduce much of the pilot-controller communication that presently takes place.

Navigation

There is a wealth of papers relating to STOL navigation systems - present, under development or test, and future. Most of the papers concern either area navigation for the terminal area or special approach aids for final approach and landing. A considerable percentage of the literature reviewed relates to area navigation systems (R NAV). The Butler VAC system and Decca Omnitrac are covered by a number of good papers. Both the Eastern Airlines and American Airlines STOL Demonstration reports describe the degree of success of these two R NAV systems. R NAV is gaining wider acceptance and its usefulness in STOL operations, particularly metropolitan and intracity is well established. The papers on R NAV generally cover the enroute as well as terminal area navigation. Since the use of STOL does not generally involve distances greater than 500 nm, R NAV is more than adequate for the purpose. There were at least ten papers reviewed which were related directly to R NAV.

There are not many papers available specifically for enroute STOL navigation. A possible exception to this is an AGARD document, Hybrid Navigation Systems - AGARD Conference Proceedings No. 54, Sept. 1969. This contains a large quantity of papers on Long Range Navigation using satellites, Loran etc. The reader concerned with navigation systems not covered by the papers in the bibliography would be advised to read this document. There are a number of technical papers available on inertial navigation systems and VOR/DME, some of which have been reviewed. The subject of enroute navigation, however, has not been given as close attention as terminal area navigation and R NAV systems.

Approach and Landing

The final approach phase for STOL and VTOL aircraft has been well covered in the literature. The obvious importance of maintaining the STOL glide path angle under instrument approach conditions has been given considerable attention. There were at least 11 papers or articles on approach aids directed to STOL operations which were considered worth summarizing in the bibliography. Some papers were reviewed but not summarized (see Appendix III). The papers cover experience with or performance of GPL-TALAR, AILS, SALT and other systems to replace the standard ILS. There are two excellent papers of a general nature which the reader, if he is not familiar with the problems peculiar to the final approach phase, will find very informative. These are Parts I and II of G. B. Litchford’s paper on Low Visibility Landing, Astronautics and Aeronautics Nov-Dec. 1968. The general state of the literature covering approach aids shows considerable attention has been paid by the scientific community to this phase of STOL operations. Papers generally report new methods, rather than attempts to modify the existing equipment. In one or two papers, the use of precision R NAV (Butler or Decca) as a final approach aid to category I limits is mentioned. (American Airlines STOL Report is one). There does seem to be a long way to go
between safe Cat II and III landings and the present system of Cat. I. There were surprisingly few papers dealing with this specific subject.

Air Traffic Control

The ATC phase of STOL operations has been fairly well documented. The papers read centre around the use of area navigation to put the routing control back in the cockpit. It is apparent that, as yet, not a great deal of attention has been paid to ATC operations with specific relevance to STOL aircraft. The American Airlines report (noted previously) makes mention of the simplicity of R NAV routings from an ATC clearance standpoint.

An Airport Surface Traffic System covered in AIAA Conference paper 69-1086, Oct. 1969 gives views of an improved surface control and collision avoidance system at JFK Airport, NYC. Such a system would reduce the ground controllers workload. What is needed, apparently, is the operational use of STOL services at large metropolitan centres to locate the problem areas and loop-holes in the present ATC system. When this is in operation, it will probably produce an increase in the available literature in this area. Some work has been done on dynamic simulation in the Los Angeles Airport complex and reported in the literature (STOL/VTOL Aircraft Characteristics, Terminal Navigation and Air Traffic Control - Barriage & Brandewie. SAE Paper 680666, Oct. 1968.) but the literature is far from saturated with papers on the ATC environment.

Cockpit Instrumentation Including CAS

Instrumentation and cockpit layout have been given moderate attention. The literature tends toward discussions of multi-readout, single unit pictorial or flight director systems. A comment noted in a number of papers is the lack of a suitable presentation of visual cues equivalent to those seen under VFR. About four papers and articles are specifically directed toward cockpit instrumentation. A number of others were reviewed but not summarized. Also included in the area of cockpit instrumentation and displays are collision avoidance systems (CAS). The IEEE Professional Group on Aerospace and Electronic Systems has an excellent collection of technical papers on this subject in the Transactions AES - 4, No. 2 March 1968. The subject has been given considerable treatment in the literature and a number of papers are noted in the Bibliography. The importance of CAS has been apparent for some time, and the considerable effort expended in this area has been well reported. As STOL operations become common, there will have to be a similar application of CAS hardware to match operational growth.

Conclusions

The literature on STOL Navigation is fairly complete. This is not the case in the fields of ATC and Communication Systems. This is probably because STOL system concepts are quite new, in fact the STOL system is virtually in its infancy in the U.S. There were almost no papers relating to STOL operations authored by Canadians. As the use of STOL becomes more general, the literature will no doubt be enhanced by papers dealing with ATC and communications problems.

GENERAL PERSPECTIVE

R-1

FINAL REPORT - AMERICAN AIRLINES INTER-METROPOLITAN STOL EVALUATION (PHASE X)
American Airlines, January 1970

This is a comprehensive, detailed and very readable report of a test program conducted by American Airlines using a Breguet 941 (MDC 188) STOL transport aircraft. The purpose of the investigation was multifold.

1. To gain practical experience with a 4 engined, full STOL passenger-type a/c.
2. To evaluate three dimensional area navigation equipment (3 D R NAV)
3. To determine the interface with CTOL and normal ATC operations.
4. To evaluate a portable microwave ILS system.
5. To evaluate the potential for STOL in inter-city use.

The report covers all facets of the operation - aircraft handling and performance, R NAV systems, approach aids, operating costs, public acceptance (postulated). A detailed coverage of the navigation equipment is provided. This consisted of

(a) Butler - National - Vector Analog Computer (VAC) Ascent/Descent Director (ADD)
(b) Decca - Omnitrac including Hyperbolic Area Coverage (HARCO) and Vertical Navigation
(c) Litton - Inertial Navigation System (INS) with
Of these, the first three were compared for their ability to perform as a 3-D RNAV systems. TALAR was used to perform a number of simulated CAT I approaches.

The report indicates a favouring of the Decca System, particularly in the New York City area, where HARCO gave excellent and repeatable results. The systems were cross-checked with optical devices such as a handheld TV camera, a vertically oriented 70 mm still camera, a Radar Theodolite using a high-precision automatic tracking radar and a photo-theodolite. In addition a photorecorder was used to provide instrument data for subsequent reduction and computer operations.

A quantity of RNAV charts and routings for operations in the Chicago and New York City areas are shown. It is apparent that the success of the program was dependent almost entirely on the ability to use RNAV, make rapid departures from the ramp area at the airports under evaluation, and clear the terminal area with a minimum of conflict with other aircraft.

The TALAR approach aid gave good results for a limited number of approaches carried out at proposed STOL port sites in the downtown St. Louis area and at Oakbrook Airport.

The report is an excellent summary of a well-organized, thoroughly documented and professionally executed STOL test program.

NAVIGATION/TRAFFIC CONTROL STUDY
FOR V/STOL AIRCRAFT
VOLUME 1: SUMMARY (N69-36352)
VOLUME 2: TECHNICAL (N69-36353)
VOLUME 3: APPENDICES (N69-36354)
Polhemus Navigation Sciences, Incorporated Burlington, Vt., March 1969

The Navigation Traffic Control Study for V/STOL aircraft (NAVTRACS) develops recommendations for the further research and development of air traffic control/navigation related technology. The desired performance characteristics of an advanced navigation/air traffic control system for the 1975-1985 domestic air transportation environment are developed from the cockpit viewpoint. V/STOL, CTOL jet, SST, and general aviation aircraft are considered. The advanced system embodies two new concepts: a Flight Reference System and Limit Logic. The concepts assume the availability of area navigation aids. Five candidate systems are evaluated: Navigation Satellite (NAVSAT), ground based hyperbolic (Decca, Loran C and Omega) and rho theta (VOR/DME) integrated with course line computer.

Enroute, terminal area and approach and landing requirements are considered. Area navigation, in this context, provides two capabilities: required horizontal position information for the pilot, and ATC system - required surveillance information. To generate the precision required for approach and landing of carrier aircraft, a differential NAVSAT and/or ground based hyperbolic capability must be incorporated into the system if individual runway instrumentation is not to be used.

Acceptability of each area navaid is evaluated through use of comparative pilot workload analysis. For purposes of this study, the pilot workload approach is used to determine desired system level(s) of automation. Detailed event sequence diagrams which cover both VFR and IFR operations define the pilot's tasks of navigation, communication, aircraft control, and systems monitoring,...and show the interface between airborne system and ATC. To insure a broadly based workload assessment, several configurations of general aviation and air carrier-type avionics systems are included in the tradeoff analyses.

Volume I of the report contains an overall summary of the results of the study. Volume II (Technical) discusses the technical approach used in the study and describes the results of various tradeoff analyses which lead to the reported conclusions and recommendations. Volume III (Appendices) documents the background technical data generated to support the analyses and system definition.

STOL DEMONSTRATION PROGRAM
A. S. Crossfield, Eastern Airlines Inc.
SAE Paper 690420, March 1969

This paper describes the joint Eastern/McDonnell Douglas STOL demonstration program in the Northeast Corridor of the U.S.A. (Boston-New York-Washington) using the MDC 188 (Breguet 941 S) STOL demonstration aircraft.

The following four basic objectives were defined for the demonstration program:
- establish air carrier STOL flight operating procedures
- determine the feasibility of operating from existing airports without interfering with existing conventional traffic
- evaluate advanced navigation and guidance systems for enroute, approach, and departure operations independent of existing routes and traffic patterns
- evaluate the approximate time and cost savings permitted by the system

A detailed description of the following program equipment and environmental aspects was presented.

- aircraft configuration
- guidance and control system
- radio navigation aids
- airports and runways
- routes and patterns
- radar coverage
- data link

Program results were divided into 3 subsections: aircraft operations, navigation and guidance, air shuttle operation comparison.

It was pointed out that the aircraft had been designed as a military STOL assault transport and had several shortcomings for commercial carrier operations. The navigation and guidance equipment on board generally functioned well. The Decca Omnitrac system was well suited to the type of operation conducted and functioned reliably with the required flexibility for defining routes and patterns required by a STOL - type operation. A very detailed description of the different navigation systems installed (HARCO, VOR/DME, PVOR, LORAN C) in both the enroute and terminal area operations is given in the report.

A simulated shuttle operation was conducted with the Brequet 941S aircraft paralleling either the normally scheduled DC-9 or the backup Electra Air Shuttle aircraft. Due to lack of realistic STOLport facilities direct comparison of the raw data for the 21 demonstration flights are not meaningful and would be misleading. However, comparable travel times could be achieved with proper facilities. The program resulted in quantitative authentication that a STOL transportation system can significantly reduce city-to-city block time. This can be effected by improved STOL aircraft with integrated airborne precision navigation systems capitalizing on unique STOL characteristics to substantially reduce non-productive time, utilizing presently unused airspace, and operating from near city centre landing fields.

Eastern Airlines indicated that no additional improvements could be extracted from the present short-haul Northeast Corridor operations with conventional jet aircraft as they were highly refined resulting from years of experience and effort by the entire air carrier industry. However, the STOL concept possesses tremendous potential for bettering short-haul transportation and will reduce overall air congestion.

Further development efforts in STOL aircraft and airborne avionics are required with emphasis placed on total system integration. Refinement of the existing airborne navigation equipment and development of a reliable, all-weather terminal guidance system is necessary to free STOL aircraft from existing terminal area guidance/runway availability limitations.

RELIABILITY WITH STOL
Spero A. Kondoleon,
Fairchild Hiller Corp.
Journal of Aircraft, Vol. 5, September-October 1968, p.443
The low speed, high-lift characteristics that make the STOL aircraft uniquely suited for short-haul transportation within relatively confined areas and on short runways introduce a requirement for increased pilot skill and proficiency in the takeoff, transition, and landing phases of operation.

A high degree of reliability in the man-machine systems and their supporting systems must therefore be available to insure confidence and maximum safety of the STOL transportation mode.

To provide the pilot with the capability of attaining this precision, many new and improved aids must be provided the STOL pilot in order to achieve safe, daily operation. The necessity for a very rapid and precise response of the STOL aircraft in the low-speed regimes during landing and takeoff requires control system augmentation to develop high control power and rapid response.

In order to utilize the peculiar capabilities of the STOL airplanes to their...
fullest extent and thus increase their reliability of operational service, certain changes in air traffic control and airport operational control must be made. Different methods of using the presently installed navigational aids and/or specially designed aids (new approach and landing aids), as well as associated cockpit instrumentation (mechanical or electronic attitude director indicator) will be required.

VTOL INSTRUMENT OPERATION STUDY- PROBLEMS OF PILOTS AND ATC’S FOR VTOL COMMERCIAL FLIGHTS
A. M. Stave,
Sikorsky Aircraft
Proceedings Vol. 2-Transport Systems and Vehicle Control IEEE Conference
Records No. 69C58-MMS, 1969

This paper describes some of the findings and recommendations of a Sikorsky Study Group looking into the problem of IFR Commercial Metropolitan and City-Center to City-Center transportation. The general purpose of this study was to devise an Air Traffic Control/Vehicle system which would operate with little degradation due to weather and without the traffic delays usually experienced by present IFR traffic.

Inputs to the study were obtained through conversation with:
- Pilots and management of all U.S. commercial VTOL operators
- ATC instructors and controllers
- FAA planners and tower operators
- FAA research personnel
- Equipment manufacturers
- Sikorsky vehicle designers

Some of the system features to be described in the paper are as follows:

1. An IFR landing system featuring an automatic approach to helipad high intensity lighting. Landings are made manually after visual contact with the lights. (Experience shows that high intensity lighting can penetrate about 200 feet under Cat III conditions).

2. A highly accurate area navigation system, to permit high density vehicle operations with a new concept in airway configuration, (high and low speed lanes).

3. Separation through time and speed control rather than position.

4. Ground controller’s role as one of computer aided monitor with inputs required only in non-normal situations.

5. Communication and ground direction through computer operated data link.

6. Airways made up of computer monitored, time oriented cube of moving air space.

7. Approach time issued prior to takeoff.

The system can be put into effect using either existing or breadboard equipment. Presently existing technology is sufficient. The specific effort described in this paper is the determination of requirements for the total system and translation of these requirements into control display interfaces for ground controllers and pilots.

Although not directly relevant to STOL operations, this paper has been included in the bibliography as it deals with many areas which are equally important to STOL operations.

THE IMPACT OF STRUCTURES AT AIRPORTS ON FLIGHT OPERATIONS
Arvin O. Basnight,
FAA, Los Angeles, Calif.
AIAA Paper 69-809,
July 1969

This paper reviews the effects on aircraft navigation and guidance systems (VOR/DME, ILS, ASR, ASDE, PAR) caused by structures at airports and surroundings.

Due to the ever increasing air travel, larger structures for office buildings, airport passenger terminals, hotels, and aircraft servicing facilities are required. Proponents of structures near airports are required to submit proposals to the FAA in accordance with part 77 of the Federal Aviation Regulations. These proposals are evaluated from the standpoint of obstructions, air traffic control tower visibility, and their effects upon existing and proposed future navigational aids because of their reflecting surfaces. The effects on radar coverage can be predicted
with reasonable accuracy; the effects on VOR, and ILS systems cannot be predicted with any degree of confidence. Work is continuing on use of higher frequencies. New systems, less sensitive to the structural environment, are being researched. Solutions that will increase rather than limit air traffic capabilities due to structural proliferation near airports must be found.

The present problems at Los Angeles International Airport are discussed in detail. Tall buildings which have been built in close vicinity of the airport have resulted in non-radar coverage in certain airspace and spotty coverage in critical areas where previously radar effectiveness had been good. Already restrictions exist on the radar monitoring approach to runway 25 and any additional structures will force the FAA to increase separation and eliminate simultaneous approaches to runways 24 and 25, resulting in a reduction of the capacity of the Los Angeles International Airport from one-third to one-fourth of its present volume.

This example shows that the situation is fairly critical at certain locations and similar problems could be expected at downtown STOLports shielded by high-rise buildings. The FAA has developed screening techniques which have been applied successfully to solve ILS problems. However, considerable improvements cannot be expected from this approach and research into new ILS systems operating at much higher frequencies must continue. Finally some legislative action may be required to properly protect a critical element of the air transportation system.

LANDING AIDS TO TRIPLE UNDER 10 YEAR PLAN
Aviation Week and Space Technology 2 March 1970, p. 29

This article, while not directly applicable to Canadian STOL development, has an indirect bearing as it points out the FAA plan for the period 1970 - 1980. Salient features are:

- Increase of ILS at airports from 224 to 487
- Increase secondary runways with ILS from 43 to 243
- General Aviation Airports with ILS to increase from 15 to 145
- VOR/DME to increase by 146
- Surveillance Radars up by 29 and replacement of the 90 existing
- Improvement of tower display for transponder equipped a/c by Automated Radar Terminal System
- Increase airway enroute sectors by about 700
- Use of discrete channel frequency will obviate multi channel changing in cockpit. Testing is likely in the mid 70's
- Modification of 129 VORs to Doppler VORs (DVOR) where terrain and man-made obstructions exist. Half of these modified stations are to have precision VORs (PVOR) to give a 3 - 5 times increase in accuracy.
AN AIRPORT SURFACE TRAFFIC SYSTEM
Walter S. Luffsey and T. B. Wendel
AIAA Paper 69-1086.
AIAA 6th Annual Meeting
October 1969

This paper describes the work proposed for JFK Airport by the FAA and Port of New York Authority to improve the airport ground control to locate, direct, expedite and control surface traffic from aircraft to towing mules. The number of large buildings being erected on airports (terminals etc.) plus the size of the jumbo jets obstructs the controller’s view even with radar and some other methods are needed. The paper further defines the sub-elements of any new system viz: detection, visual signalling, alarm, processing and reduced visibility guidance. A series of sensors along the runway and taxiway provide inputs to a computer which automatically signals caution and warning (stop) signals to the pilot should his aircraft be in danger if he proceeds further. A continuous display is presented to the ground controller who can now expedite traffic even in reduced visibility conditions.

EASTERN’S STOL EXPERIENCE
A. Scott Crossfield
Eastern Airlines Inc.
Flight International, July 17, 1969, p.97

This article discusses the experiences Eastern Airlines Inc. gained with its STOL demonstration program. The high costs of the air traffic congestion in the eastern USA to the airlines prompted Eastern Airlines to find their own solution to the ever increasing air traffic congestion. Their aim was to find use

(a) for the large amount of unused runway space that exists even at the most congested airports today

(b) for the large amount of unused airspace in the approach and departure corridors

(c) for the unused airway space enroute caused by the present VOR/DME navigation

and lastly find means of getting airborne information to the ground in the fastest and most efficient manner.

Eastern looked at these four elements and identified a system that would utilize all four. A STOL transportation system with area navigation and a data link to the ground would fit the description of such a system very well.

A short description of the Eastern Airlines STOL demonstration program with the MDC 188/Brequet 941S and the Decca Data Link is then presented.

EVALUATION OF MDC/EAL STOL DEMONSTRATION: DOT (FAA)
Flight Standards Service
Washington, D. C., May 1969

This report contains primarily Decca Omnitrack chart reproductions, showing arrival and departure routings, which resulted from a period of experimentation with a Brequet 941 STOL Demonstrator aircraft.

The report draws the following conclusions:

(a) turning radius,

$$ R = \frac{v^2}{g \tan \theta} $$

of 0.4 NM is acceptable with 15° angle of bank, 80 K IAS (for the Brequet 941 at least),

(b) the longest route segment in the terminal area should be that from the initial to the final approach fix

(c) sufficient spacing between waypoints should be allowed adjacent to a sharp course change.

The report is worth reading, although it gives little detailed information, other than the charts which must be individually interpreted.

AN AIRPORT SURFACE TRAFFIC CONTROL SYSTEM (STRACS)
Louis Achitoff, Port of New York Authority (PONYA), Paper presented at RTCA 1968 Annual Assembly Meeting

This paper deals with the proposed test installation of a surface traffic control system (STRACS) at JFK airport in New York to aid the airport ground controller in detecting, identifying, directing and controlling aircraft and vehicle surface traffic.

The size of new terminal buildings and high apron fingers for B-747 type aircraft is resulting in a loss of direct line of sight of the controller and ASDE radar and other means for ground control are needed.
The paper then defines the subelements of the new system as follows:

- detection equipment
- visual signalling equipment
- alarm and priority logic
- processing and display equipment

A series of sensors (loop detectors) along runways and taxiways provide inputs to a computer which automatically provides directing and warning (stop) signals to the pilot to expedite the aircraft from runway to gate. Alarm and priority logic will detect potential collisions and take appropriate action with regard to signalling lights and instructions; the priority logic allows preferred routings for certain aircraft and situations. The ground controller is presented with a continuous display and is able to expedite traffic safely without having visual contact with the vehicle (aircraft) concerned.

**COMMUNICATIONS**

DATA LINK IN ACTION
Flying Review International
December 1968, p. 67

This paper describes the Decca Data Link installed in 1968 for the Eastern Airlines/MDC 188 STOL Demonstrator program. One of the main features of this system is a newly developed monitor unit that incorporates its own air route map for showing present position of aircraft and indicators to denote its status when on the ground. The map is electronically generated and the operator has the choice of any one of five. In the Eastern installation, their aspects of operations were covered by the following maps:

- A blow-up of the New York area for the STOL operation
- A long-range map of the Washington/New York/Boston routes for the Shuttle Service DC-9's and other fixed-wing aircraft that may come into system
- A medium scale giving coverage between Washington and New York
- A medium scale for the New York to Boston route
- A blow-up of the La Guardia/New York route for the DC-9

Up to eight aircraft can be accommodated by the system as it now stands each one being shown as a pulsating dot on the electronically generated display. Also shown are reporting points and airports.

Advantages of the data link are listed as

- automatic provision of
  (a) identity
  (b) flight level
  (c) position of aircraft
- economy of message time and radio frequency requirements
- two way communication reduces voice communication and cockpit work-load
- aircraft can be interrogated in any order of priority required by the controller
- pilot and controller can work within a common reference by using navigational data from the same source
- the digital message format favours use of the system with computerized ATC systems

On a single frequency channel, 40 aircraft can be interrogated in 10 seconds to obtain identity, flight level and position. A special system is used to prevent the absence of a "1" in a binary coded message resulting in a "0" at the receiver, or in noise producing a spurious "1".

The spare capacity of the data link makes it possible to pass ATC messages and instructions from ground to aircraft in digital form, and for acknowledgement by the pilot to be made without the need for voice communications.

Eastern is planning to eventually fit their complete DC-9 fleet with this equipment.

DIGITAL COMMUNICATIONS
B. F. McLeod,
Pan American World Airways Inc.
September 1968

This paper is concerned with digital data communications from an aircraft to the ground. Several attempts have been made in the past to employ an air/ground data link but none were successful with the possible exception of the
Selcal system introduced by Pan American in the South Pacific in the early fifties and later accepted by ICAO.

Nowadays ATC requirements alone, or company operational requirements alone, are great enough to justify automated communications on both long range and short range routes. In Pan American's planning for a "Flight Information System", digital communications is a fundamental element of the total system.

The function of the Flight Information System will be to collect, analyze, transmit, store, receive and present information required by:

1. Air Traffic Control and Advisory Services
2. The Flight Crew
3. Company Offices

The above functions are described in some detail with a main point being that Pan Am proposes to use on-board processing, transmitting only important parameters or trends to the ground.

Pan American has made a start toward implementation of a Flight Information System by placing a limited "Digicom" system in operation on the New York - San Juan run using a Boeing B707 aircraft. The present system transmits from the aircraft to ground only. A second phase of this program calls for five or more participating aircraft with two-way equipment automatically interrogated from the ground.

The paper reviews the advantages of area navigation which may be briefly stated as

(a) a reduction in controller workload
(b) guidance along any flight path
(c) reduced cockpit work loads and errors
(d) programmed descent paths

The author points out that from his experience (he is a Pan Am employee) the ILS capture phase requires the greatest degree of pilot effort and often disrupts what initially started out as a smooth and relaxed approach. Pictorial displays are offered as an enhancement to area navigation.

The paper further describes the work done to date in getting area navigation "off the ground". Pan Am intend to explore the area navigation possibility with their B747 a/c. This is an inertial navigation system with area navigation potential, not just long range navigation. The author feels that an impediment to the implementation of area navigation has been the lack of sufficient DME stations co-located with VORs.

He goes on to describe arrival and departure routings for a STOL service into an elevated STOLport located in downtown Manhattan. Service is to Hartford and Washington. It is shown that adequate vertical and horizontal separation can be provided between STOL and CTOL a/c in a dense terminal area. This can only be safely and efficiently done with area navigation.

The author closes with a description of a Pan Am data link aboard a B707 transmitting maintenance data on the New York - San Juan route. It is implied that the successful outcome of this test points the way for an expansion into the ATC regime with data links.

The authors describe an area navigation system in use on United Air Lines B-727 aircraft. The system, developed by Hughes Aircraft and the Jeppesen Company, consists of a digital computer receiving inputs of magnetic heading, TAS, altitude, range and bearing from a VOR/DME receiver, a moving optically projected aircraft symbol on a moving map display. There are 256 map segments which can be selected by the pilot, and variations of scale accommodate high altitude (30 nm/in), low altitude (15 nm/in) and terminal area (5 nm/in). These are stored on 35 mm film strips, and the pilot has manual slew controls on the selector panel to permit placing the centre of the display at any point on the chart. A route segment indicator, crosstrack error bar and a command heading index are part of the display.

Operational usage has been extensive and rewarding. UAL report an
enthusiastic reception by crews using the navigation director for the most part. They have used it for area navigation, instrument approaches to non-instrument runways, lateral separation positioning and direct, non-vectored clearance as well as ILS capture and back-up. They found throughout the 240 flight hours that the system was used a reduction in workload and RT, reduced delays in holding and transition and an overall improvement in their own confidence in their aircraft's position.

AN AIRBORNE COMPUTER SYSTEM FOR NAVIGATION AND TRAFFIC CONTROL
Glen A. Gilbert
Paper presented at IFATCA Conference, Montreal, May 11-14, 1970

This paper presented by Glen A. Gilbert who is a consultant to Butler-National is essentially a description of the various versions of area navigation and some additions. Several papers discussing area navigation have been reviewed in this bibliography so no attempt is made here to review the basics of area navigation. Mr. Gilbert discusses area navigation systems based on VOR/DME inputs. Adding a vertical gradient computer to a 2-D R NAV system, a 3-D R NAV system is created. As an example of such a system, the Butler-National VAC and ADD are listed. A short discussion of the following topics is presented:

- R NAV approaches
- R NAV enroute operations
- R NAV terminal area application
- R NAV and mid-air collisions

Adding the time factor to the above mentioned 3-D R NAV system, one arrives at a 4-D R NAV system. Examples for application of 4-D R NAV are given which should be of substantial assistance in eliminating the air traffic congestion problems.

Combination of area navigation with an automatic data link can provide ground facilities with position data to provide redundancy to the radar system and be used for traffic situation displays to provide proximity warning indication.

An example of data link use for ATC information is presented in this paper where a R NAV clearance is given for an entire flight and air/ground communication is reduced to a minimum. In his concluding remarks the author states that "the capacity of the ATC system must be expanded on a continuing, evolutionary basis to meet overall air transportation demands. This involves unloading the system by providing the pilot with area navigation capability in four dimensions, at the same time elevating the controller's function to that of traffic flow management and surveillance. Data link transfer of aircraft position information and ATC instructions also will form an essential part in the further unloading of the system."


EVALUATION OF AREA NAVIGATION IN THE NORTHEAST CORRIDOR
Bernhart V. Dinerman,
FAA (NAFEC) Report No. NA-70-3
AD 699183, January 1970

The Federal Aviation Administration, Eastern Airlines, and two area navigation equipment manufacturers participated in an area navigation evaluation in the Northeast Corridor. Area navigation equipment was installed in two Eastern Airlines DC-9 aircraft (the installation consisted of a Collins Model 560F-3 Course Line Computer in one aircraft and a Decca Omnitrac 2A in the second aircraft) assigned to commercial shuttle flights between La Guardia Airport, New York, National Airport, Washington, and Logan Airport, Boston. Special area navigation routes, operational procedures, and an evaluation plan were developed.

To support operational conclusions, aircraft space position data were collected during flights over area navigation routes and conventional victor airways. The prime measurement source was the New York Air Route Traffic Control Center surveillance radar and secondary beacon radar with a beacon video digitizer output to a specially developed magnetic tape recorder. The final format of the measurement data analysis consisted of statistical computations of the lateral deviations of the aircraft from the desired course. Measurements were made during a total of 223 flights on 8 area navigation routes and a total of 117 flights on four conventional routes. The measurements of the conventional navigation flights on the preferred victor airways were made for comparison purposes.

Based on the evaluation of the data collected, it was determined that:
1. the total navigation errors from area navigation and conventional navigation flights over the test routes were similar.

2. the total navigation errors from the area navigation flights over the test routes were essentially well within the amount of airspace normally protected for the corresponding conventional routes.

AREA NAVIGATION CONTROL CITED AS AIR SAFETY NEED FOR 1970'S
Aviation Week and Space Technology, 1 December 1969, p. 29

Stresses the limitations of VOR/DME for the 1970's and subsequent. Points to the choice of VOR over Decca, made by ICAO Feb. 1959, has severe flight safety implications. Ground based radar requires a grossly overworked ATC system to supplement cockpit presentations; and lack of navigation information in the cockpit limits the pilot's capability to control the aircraft. Three dimensional area navigation presentation considered a necessity to safely integrate sonic and subsonic a/c.

Supplementary reading - Report by Capt. Laurie Taylor, British Airline Pilots Association to Symposium of World Airline Pilots.

NAVIGATION AND FLIGHT CONTROL
Henry E. Prew,
Grumman Aerospace Corp.
Space/Aeronautics, Vol. 52,
July 1969, p. 66

This is one of several papers reviewed discussing new developments in aircraft navigation and control. The advantages of area navigation (R-Nav) are discussed stressing that ATC must be relieved of its present navigation function in the terminal area and restricted to its proper job -- conflict monitoring and resolution as well as computerized, real-time coarse flow control through route assignment and the like. Thus independent navigation capability must be provided in the cockpit.

A description of area navigation based on angle and range data received from a VOR/DME is given and four flight tested R-Nav systems are listed.

Various problems of STOL flight control are discussed but only in general terms and not in detail.

AREA NAVIGATION AND THE AIR TRAFFIC CONTROLLER
L. Heide
Computing Devices of Canada Ltd.
Presented at CATCA Conference, May 7, 1969

This paper points out the need for area navigation to solve some of the congestion problems caused by

(a) the point source VOR/DME system resulting in a funneling of air traffic over the beacons

(b) the use of ATC radar controllers to navigate the aircraft by radar vectoring in the terminal area

(c) the limited number of aircraft the ATC controller can handle at any time.

The use of airborne computers and pictorial displays to convert the existing VOR/DME network into an area coverage system is advocated by many airlines as a solution to the problem.

CDC has been manufacturing navigation systems for the military for many years and a pilot's Projected Map System (PMS) and its associated computer produced now for the military are being adopted for area navigation.

Two versions of the R Nav system are discussed:

(1) A system designed to accept VOR, DME and Air Data inputs and display the aircraft position on a projected map display. The system consists of a card reader, a special-purpose digital computer, a control unit and the map display. This system would be applicable in the absence of any other sensors in the aircraft.

(2) A PMS system for use with a modified ARINC-561 system. As many future aircraft will be equipped with an inertial navigation system conforming to ARINC-561, this system consisting of an interface unit and map display will provide the aircraft with R Nav capability taking its inputs from the digital computer of the ARINC-561 inertial system.

Both systems will be of benefit to both the pilot and air traffic controller by placing the navigation job back into the cockpit and freeing the controller for his surveillance work.
To evaluate area navigation (R Nav) techniques in the air traffic control system, a series of test programs have been undertaken by American Airlines. Operations have been conducted in BAC-111 and B-727 jet transports during the course of regular airline service. Systems used were based mainly on VOR/DME signals, but some tests involved use of an Inertial Navigation System. Two area navigation concepts are discussed, one the course line computer system (Butler-National VAC), the second the pictorial display systems (Decca Omnitrac) which are usually more costly both in initial purchase costs and in extra operational costs of the specialized charts.

Test programs were run both in the New York City-Boston area and Chicago-New York City area. For the latter evaluation, two Boeing 727-223 were fitted with a fully integrated advanced Butler-National VAC system. The results were so promising that permanent adoption of the R NAV routing was recommended. When this paper was written further trials were in progress as part of the airline’s STOL evaluation project in which a number of additional systems were being examined. This evaluation was completed some time ago and a review of American Airlines’ report on the STOL demonstration program is given elsewhere in this bibliography.

The author states that although the area navigation concept has shown considerable benefits, it will not overnight change and improve the air traffic control problems and will not bring about immediate scrapping of designated airways and jet routes.

Much additional testing and evaluating must be undertaken by airlines and authorities before area navigation can be adopted throughout the whole U.S.A.
answers to some very important questions are still needed.

- is this system good enough to commit national aviation planning in the USA in this direction?
- is this system economically feasible for the aviation industry?
- can we safely implement this system?

It must be noted that this paper was presented 1 1/2 years ago and some answers to the above questions may be available at this time.

STEERING A COURSE TO SAFER AIR TRAVEL

E. M. Drogin, ATL
Electronics, 27 November 1967.

This article describes (in some detail) a system developed by Airborne Instruments Laboratory to give a bearing resolution of 0.01° in an improved VOR using digital techniques. The best analog receiver presently gives ± 0.25°. The FAA, under its Signal Evaluation Airborne Laboratory wished to use the improved receiver to measure ground station performance, and determine why bearing errors occur.

The ATL System uses phase-lock techniques to provide a measure of phase angle between the reference and variable sine waves produced by the VOR station. Double integration is used in an entirely digital system to provide a frequency and phase comparison of the two signals while having a number of significant advantages over the single integrator loop.

(a) very narrowband filtering is used which does not introduce phase shift errors

(b) no phase lag errors are present during a/c manoeuvring

(c) frequency deviation from 30 Hz (the basic frequency of the VOR transmitter) is automatically provided.

The author describes the system in terms of the complex frequency S and shows how the digital system is set-up to provide a very close approximation to the transfer function required, with vastly improved accuracy.

APPROACH AND LANDING

SIMPLIFIED AIRCRAFT INSTRUMENT LANDING SYSTEM (SAILS)

E. W. Rupp, Bell Aerosystems

Jour. of Amer. Helicopter Soc. Vol 14 No.4

October 1969 p. 53

Sails employs a helicopter - (or aircraft-) borne radar which tracks a beacon at or near the desired touchdown point. Position data generates cross pointer information of glide slope and azimuth. Range and range rate are provided. The pilot can select his approach path and angle, and provide for touchdown offset 2 miles north and east and 1000 ft. vertically from the beacon position, presumably from the cockpit.

The equipment operates in the 9GHz band. Ground station transmitter power is 20 watts peak, and the station is contained in a 15 pound package, complete with a transponder and antenna. The airborne unit weighs 25 lbs and has a 1 Kw pulse power transmitter output. A computer and servo unit, in a separate package, accepts inputs from the pilot-selected parameters, and attitude inputs. The RT unit is gimbaled for 360° rotation and + 15° to -85° elevation viewing angle.

Having acquired the beacon transponder, the angular error signals in 2 axes are fed to the computer to provide automatic angle tracking. An input of range voltage is combined with the resolver outputs on the pitch and yaw gimbals to provide outputs of an X, Y, Z coordinate system, stabilized with respect to the horizontal and a/c heading. The comparison of selected course and glide slope with the stabilized position voltages generate lateral and vertical error signals which are displayed on a cross pointer instrument. Lateral and vertical offsets can be introduced as system biases.

Reviewer's Comment

There may be advantages to such a system particularly for terminal area navigation. However, the chances of introducing a 'dialed in' mistake would seem to be real. The system is fairly complex and it would seem that the reliability could be a problem. Insufficient information is given in the article to substantiate this, however.
This paper describes General Precision Systems approach to a lightweight portable approach aid, providing localizer and glide slope information in a standard ILS cross pointer cockpit presentation. GPLs designation for this system is TALAR (Tactical Landing Approach Radar). It is in effect a microwave ILS operating in the 15.5 GHz band. The transmitter, weighing about 40 pounds, can operate from a variety of power sources. The receiver is located in the aircraft and consists of two boxes weighing a total of 7 pounds.

There are 4 antennae in the transmitter each of which receives 15.5 GHz energy modulated at a unique repetition rate. One pair of antennae provides an on-course glide slope signal when the outputs are equal; the other pair handle localizer information. Special attention has been given to beam shaping to provide high linearity on the on-course line, reduction of false courses on high-angle glide slopes and minimum ground illumination. Glide slope angles are available from +20° to +10°. Adjustment is made from the ground.

In summary, the salient features are:

1. lightweight
2. readily portable
3. thoroughly tested
4. environmentally rugged
5. 5 minute set up time
6. ground adjusted-no possibility of false glide slope selection from cockpit
7. simplified shop maintenance
8. ±2.5° localizer ±1° glide slope widths
9. acquisition 6 miles either side of centre-line, 6000' high at 10 nautical mi.
10. close to production status

The author points out that variable glide slope course width with glide slope angle is a necessary feature for STOL a/c approaches. He also identified the lack of VFR 'cues', that are so important in STOL approaches and absent during the IFR approach as a problem for cockpit displays. Synthesizing these cues could be an important feature of safe STOL IFR approaches at high glide slope angles.

This paper describes the basic design philosophies of approach aids for STOL/VTOL a/c

1. Scanning Beam System (generic title)
2. Shorscan
3. A-Scan, C-Scan, AILS

The author points out that there are no systems presently in use which couple all the required features of a steep angle precision approach aid in one unit. The standards presently in use are ILS for civil and GCA for military. The system designer must resort to flexibility and simplicity in any new system in the absence of a consensus as to the optimum configuration.

Under the general heading of FLARESCAN systems, AIL has developed a number of Advanced Instrument Landing Systems (AILS). These are AILS, C-Scan and A-Scan. In all of these a narrow Ku-band Beam sweeps out extended azimuth and elevation coverage. A varying pulse spacing is used to convey the angular information to the receiving a/c. Coordinated angle conveying codes permit a number of aircraft receivers to use all the various types of ground facilities. A-Scan for example provides high-angle, C and AILS progressively lower angles. The U.S. Army A-Scan system provides 3 'lanes' (in azimuth) each up to a maximum of 40° wide, for a total of ±60°. A +5 to +40° glide path is available with selectable angle and sensitivity. Adjustable sensitivity is also a feature of the azimuth coverage. DME can be added. The system is designed for portable field use.

Shorescan is a continuation of A- and C-Scan provided by two units. Elevation coverage is from the horizon to +200°, selectable, with variable sensitivity. Azimuth is ±10° with variable sensitivity. This sort of equipment appears to have good potential for use with STOL a/c. No figures on cost are available at the moment.

Presentation in the cockpit is generally a standard cross-pointer glide slope/
This paper describes a new ILS under test at RAE Farnborough. It is called a Correlation Protected ILS (CP ILS) as there are two signals generated by two signal sources for both the localizer signal, and glide path. The localizer signal, for example, is generated by two microwave sources on either side of the runway. A pulse modulated 5 GHz signal is transmitted from one antenna. The second transmitter has a pulse modulated carrier frequency which differs from the first by (say) 110 MHz. In fact the difference in carrier frequencies will be the present VHF ILS Channel frequencies, discrete and selectable with only slightly modified equipment in the aircraft.

Because standard VHF ILS is subject to beam bending, reflections, absorption, the signals received by the aircraft are not always the true representation of the localizer/glide path beam. With CPILS, the signals from the two microwave sources must be received within a specific time slot, or the read out equipment (cross pointer as per normal ILS presentation) will not be influenced by them. The signals therefore are time 'correlated'. The system is 'protected' because it will not respond to false information.

Standard demodulating equipment can be used, as the 90 Hz and 150 Hz modulating signals already common to VHF ILS for magnitude and direction of error are superimposed on the pulse train from one of the microwave sources.

The article also describes some of the test work carried out using a Varsity aircraft and the ability of the system to provide operation even when the antenna patterns are disrupted by objects and aircraft manoeuvring in their vicinity.

Supplementary reading: An ILS for the Future? S.S.D. Jones, RAE, Farnborough

This is one of the best articles on this subject that the reviewer has read for some time. Rather than giving answers to problems, the writer reviews the difficulties in low visibility (Cat I-III) landings and suggests approaches to overcome them, in general terms. He poses the problems from the pilots viewpoint - literally, how can we combine electronic aids to navigation with advanced cockpit instrumentation to provide a VFR 'feeling' in the cockpit during an instrument approach. He states that most of the electronic equipment presently in use is sufficiently error prone, that safe CAT II B landings are still some time off. While the paper was written over a year ago, the points are timely and the suggestions are those for this decade. Some of these are:

(a) farfield ILS monitoring
(b) microwave ILS to improve beam characteristics
(c) elimination of false visual cues at decision height, and installation of systems to improve VFR type cues under IFR conditions
(d) more knowledge is needed about how the pilot judges VFR approaches. This is then to be applied to IFR situations
(e) total system integration - with the electronic systems and civil engineers combining together with the pilot to solve the dense traffic and lowering landing minima problems of the 70s.

This paper (part 1 of a 2-part article) is a first-class presentation of the author's concern about category II landings (CAT II). He states clearly and concisely that there simply is not enough information to prove that CAT II B (100 ft decision height and 1200 ft RVR) will in fact allow more aircraft movements per hour at a suitably equipped airport.

The paper first traces the development of low visibility landing systems from the early part of World War II and how these have been developed to the limit
of their (and the pilot's) capability. There is some doubt that the present ILS can be extended to CAT II B. The problem of accomplishing a missed approach at an altitude of 100 ft, including the decision time, levelling-off and power application and the response time make this a hazardous task at best for any pilot. A normally executed approach is not a straight line in the vertical, but a flared-almost exponential approach to the runway touch-down point. The author suggests the straight line approach is unrealistic.

A great deal of testing is needed to determine the acceptability of CAT II B or the modifications of systems to make it acceptable. That this testing is done by performing landings under these conditions as a trial and error approach is not acceptable and is far too high a risk. The errors in the system are known. The unknown is how the pilot and aircraft operate as a human operator-machine system.
references available and in the final stages with RVR's simulated from 700 ft. decreasing to zero. Very good performance was achieved with pilots manually controlling the aircraft (by sole reference to the head-up display) to a landing with minimum lateral and longitudinal dispersion of an average touchdown rate of less than 2 ft. per second. Although this program is not directly relevant to STOL transport operations, the test results were very encouraging and would certainly be useful for the design of STOL aircraft flight control systems.

ALL WEATHER LANDING
O. B. St. John,
RAE Bedford
Shell Aviation News, No. 364, 1968, p. 2

This paper written by the Superintendent of the Blind Landing Experimental Unit (BLEU), RAE Bedford examines the current situation in all-weather landing capability for airlines, and forecasts possible trends. The potential benefits of all-weather operation to the air carrier, the manufacturer and the travelling public are reviewed.

The Blind Landing Experimental Unit was established in 1945 and is responsible for research and development of all types of landing aids. The paper deals with basic issues of all-weather operation such as safety, automatic landing and reliability. The two concepts used by BEA and BOAC in their automatic landing systems, namely the triplex system on the Trident and the duplex system with comparison monitors on the VC 10 are described and their merits discussed.

While the views of the leading countries (U.K. and U.S.A.) in all-weather operation techniques differ for Cat II operations (U.K. favours fully automatic landing systems while the U.S.A. has tended to less complex automatic equipment with more pilot participation and the use of flight directors), there is virtually full agreement that for Cat III operations fully automatic landing systems are essential.

Head-Up display applications are discussed. Here the author does not favour HUD for Cat III operations but seems to consider them useful for Cat II and I operations.

Future developments are discussed but the author points out that much work is required on ground installations as presently large numbers of commercial jets are certificated for Cat II operations but only a handful of airports worldwide have the necessary ground installations to perform Cat II landings.

SETAC - A NEW APPROACH AND LANDING SYSTEM
K. D. Eckert, H. J. Rooper,
SEL Stuttgart

This article deals with a new approach and landing system which is based on the Tactical Air Navigation (TACAN) system which has been in use for several years. A prime user of this system would be the military services for tactical operations but it could be used for civil aviation.

The SETAC (Sector Tacan) system supplies high accuracy on-board information on bearing, aircraft-to-ground slant range and elevation, as well as analog signals or digital signals for computer input. SETAC is made up of two components, SETAC - A providing azimuth and distance and SETAC - E providing elevation. The azimuth signal of SETAC - A is made up as TACAN except only 36 degrees are used. The distance information is provided by a transponder system similar to DME but with much higher accuracy (±30 feet). No details were provided on the SETAC-E operation except that it employs the Doppler effect.

The authors state that this system can be used by civil aviation for approach and landing. The existing DME onboard units would require the addition of bearing and elevation computers.

SALT-SELF-CONTAINED ALL-WEATHER LANDING AND TAXIING
R. S. Duggan Jr.
Lockheed,
AIAA Paper 69-1053, October 1969

The author describes an on-board radar system tested in a C-5 A which provides many of the desirable features of an all-weather approach system. The elements of the approach procedure are

1. Airport location by ground-mapping radar
2. On-board radar tracking of a corner reflector on the runway to establish horizontal track at 10 NM
3. Glide slope automatically initiated at 5 NM (approx. 30°)
4. Final approach at 1/4 mi.
In the last stage the tracking antenna is switched to a far reflector at a predetermined depression angle. The airport taxing mode has not yet been fully developed and the paper does not report on it.

The heart of the system is a high resolution track-while-scan radar, which tracks large area corner or luneberg lens reflectors placed along the runway at strategic points. There are advantages to this system, provided that the size and weight contributed by the on-board radar can be reduced. One, all the active equipment is on the aircraft. Ground facilities consist only of the reflectors. Two, the degree of flexibility in runway location, runway changes and the variety of instrument runways available at any airport is a significant operational and economic factor.

The paper does not describe the system in great detail, and its suitability for STOL, at this time, is doubtful. Development of systems along these lines could have interesting future possibilities.

REALISTIC LOW VISIBILITY LANDING CRITERIA FOR V/STOL AIRCRAFT
J. E. Gallagher, G. B. Litchford
Journ. Amer. Helicopter Society July 1969 p. 27

The authors describe various approach path configurations for CTOL and V/STOL (helicopter) aircraft, operating under CAT II conditions. It is seen that for the helicopter pilot, the steep angle approach for STOL (above 3° - 5°) allows the landing area to be seen. The CTOL 1200' RVR condition does not allow the runway aiming point to be seen at the 100' decision height, under a 2.5° glide slope.

The paper is of interest in that it points out some of the problems in CTOL CATII operations, shows the possible layouts for approach paths for VTOL for safe operation and discusses the necessity for wider path angles in azimuth as glide slope is increased.

V/STOL ALL-WEATHER GUIDANCE
Alexander B. Winick, FAA

This paper is one of several reviewed discussing the requirements for V/STOL operations in this decade.

The author feels that the present VORTAC facilities will be sufficient for enroute navigation but in the terminal area, precision VOR (PVOR) or doppler VOR (DVOR) would give better airspace utilization.

The totally new components of any V/STOL guidance system are those associated with approach and landing. Military developments are now under way and many of these may be useful for V/STOL transportation. A brief description of the following developments is given:

1. STATE (simplified tactical and terminal equipment)
2. TALAR (tactical landing approach radar)
3. AILS (advanced integrated landing system)
4. SAILS (simplified aircraft instrument landing system)
5. VAPS (V/STOL approach and landing system)

Some tests with the last system have been conducted at NAPEC in Atlantic City. Knowledge derived from these tests will be appropriately incorporated into design requirements for future equipment.

KLM STUDIES ON THE LANDING OF AIRCRAFT WITH LOW WEATHER MINIMA
C. H. Reede
RAE Translation No. 1250, 1965

This report describes work done by KLM to determine the flight path of a DC-8 under an ILS approach, using a Smiths PVD (Para Visual Director) as a head up display for control in the vertical plane. The company wished to obtain an insight into the way a pilot lands a large transport jet aircraft. The PVD was used to give guidance information to the flare-point and about 25 landings were conducted and data recorded, data reduction performed and the results analysed. The paper describes some interesting phenomena and comments on them at some length. Most significant of these is the fact that the pilot does not conform to the glide path during the latter stages of the approach, actually flying below it.

The paper is worth reading as it gives a good description of some of the human operator performance characteristics in this role, although it is not directly related to STOL.
BENDIX MICROVISION, A NEW ALL-WEATHER LANDING AID
Interavia, Vol. XIX, No. 10
October 1964, p. 1534

This article describes a new all-weather landing aid that pictorially displays a simulation of the runway lights as they would appear to the pilot on a normal clear-weather night landing. The system uses microwave beacon-transmitters stationed along each side of the runway. Their signals are received by an airborne receiver and form an image on a cockpit head-up display that provides the pilot with an outline of the runway. The head-up display could be used for display of other information such as airspeed, heading, horizon and flight director data. In an operational system, eight transmitters, four per side, are proposed for each 10,000 ft. of runway.

AIR TRAFFIC CONTROL

INTERFACE OF VTOL, STOL, AND CTOL TRAFFIC IN BUSY TERMINAL AREAS
Robert B. Meyersburg, FAA
SAE Paper 690422, presented at National Air Transportation Meeting
New York, April 1969

This paper treats methods of interfacing CTOL and V/STOL terminal traffic. Airport congestion, combined with the rapid and continuing growth of corridor air traffic, has spurred the development of potentially viable VTOL and STOL systems. As these systems grow, they will introduce new close-in airports in metropolitan areas, as well as increase the efficiency of existing airports for medium and long haul transportation.

New and more efficient methods of utilizing the terminal airspace must be developed to control the mix of conventional and V/STOL aircraft to minimize traffic delays, and to support in every way the maintenance of a safe, fast, reliable all-weather intercity air transport system.

The major objective is to keep both CTOL and V/STOL traffic moving safely in and out of their respective landing sites without degrading the frequency of either service, even under adverse weather conditions. A basic principle of interfacing traffic is maintaining positive control over all vehicles in the airspace involved. To maintain positive control, the following factors are of important consideration:

- accurate navigation system
- means of accurately defining aircraft geographical positions
- means of continually transmitting these position data to a ground centre (computer plus pictorial situation display)
- means of evaluating mixes of aircraft position data and computing optimum corrections for course, speed, and heights of each aircraft to maintain minimum safe separation
- means of sending these corrections, in the form of command signals, to the aircraft involved.

A description of several system improvements planned for CTOL is given which includes speed class sequencing, computer aided approach spacing and reduced separation and their impact on V/STOL operations.

A new concept is discussed for simultaneous parallel instrument approaches with lateral separation of only 2500 feet where CTOL and V/STOL aircraft conduct parallel approaches into an airport.

The concluding remark indicates that the technological capability to control a mix of V/STOL and conventional traffic safely and efficiently is at hand.

QUALITATIVE V/STOL AIR TRAFFIC CONTROL REQUIREMENTS
Robert P. Hudock, William D. Leonard
The Mitre Corp.
AIAA Paper 69-211, February 1969

This report attempts to provide some insight into the important V/STOL ATC problems and to define the qualitative airborne and ground requirements of a safe, economical, and efficient V/STOL ATC system.

A summary of the more pertinent characteristics of V/STOL operation with implications on air traffic control includes:

- a potentially dramatic increase in the number and density of terminals in a metropolitan area
- substantially more complex airspace in high density terminal areas

III.19
- materially higher load, especially in terms of number of take-offs and landings within high density metropolitan areas
- substantially increased number of routes especially within high density metropolitan terminal areas
- materially increased numbers of general aviation aircraft and mixing of commercial aircraft with general aviation in traditionally general aviation airspace
- the requirements of V/STOL operation under adverse weather conditions
- the requirement for noise control in densely populated areas

The report then describes in more detail the V/STOL ATC function which include
- control functions
- traffic separation
- traffic flow control

The implementation functions of surveillance, automation aids and airspace restrictions are described. A detailed description is given of the V/STOL ATC requirements, V/STOL ATC data requirements (ground data, airborne data), V/STOL ATC procedure requirements (altitude assignments, route assignments, segregation of vehicles), ATC structure/jurisdiction, V/STOL ATC equipment requirements (ground equipment, airborne equipment) and V/STOL ATC interfaces (avionics implications, navigation, landing/takeoff, identification, communications, CAS/PWI, vehicle implications, operational implications)

STOL AND VTOL OPERATIONS IN THE NATIONAL AIRSPACE SYSTEM
J. B. Barriage, L. N. Douglass, and R. C. Conway, FAA
AIAA Paper 68-1099, October 1968

This paper describes FAA efforts in developing flight characteristics data and planning for operations near or within metropolitan areas. Various ATC studies are being conducted by the FAA and several approach conditions, various glide slope angles and separation criteria were investigated during a simulation study at the National Aviation Facilities Experimental Center (NAFEC) in Atlantic City.

Some comments are made on the accuracy of the VOR/DME navigation system indicating that present airway width is 8 miles within 51 miles of the VOR. Present airway width could be reduced to 1/3 of the present 8 miles or 2.5 miles for route segments up to 100 miles through the use of Precision VOR/DME. However, much research and improved equipment is necessary to operate with these tolerances. A detailed description is provided on the VTOL and STOL simulation study of the Los Angeles terminal area conducted at NAFEC.

Test results indicated that the control of V/STOL aircraft required a higher degree of controller skill and judgement in order to provide proper longitudinal spacing between successive aircraft in the late stages of the final approach.

The mix of V/STOL and CTOL aircraft in relatively the same final approach airspace caused rather difficult control conditions for the Los Angeles area simulation.

Some discussion is presented on Instrument Approach aids for V/STOL aircraft describing some of the preliminary evaluations conducted at NAFEC. The paper closes with the remarks that a common landing system for all users (CTOL, V/STOL and Military) would be very desirable, but the operational functions must be satisfied for each kind of terminal and respective aircraft type.

Supplementary reading: STOL and VTOL air transportation - from the ground up, Joan B. Barriage, FAA, Astronautics and Aeronautics, Vol. 6, Sept. 1968, p. 44.

AIR TRAFFIC CONTROL - A HISTORICAL PERSPECTIVE AND FUTURE CHALLENGE
Lee Warren, FAA, AIAA Conference Paper 69-1051
Anaheim Calif., October 1969

The author traces the development of the American ATC under the CAA to the present wide area network controlled by the FAA. The paper is an excellent summary of how the system got to where it is today, and the troubles it has brought with it in its growth.

He points out the increasing role and need for automation in the system, the importance of area navigation and, most of all, the need for long range planning and adequate funding. He predicts economic and transportation chaos if such planning and funding is not adequately served.
Development of an improved beacon system is discussed. The concept is intended to increase system capacity, reduce interference problems, improve accuracy (more by multiplicity than by intrinsic accuracy) and provide data limits capability. Present 2.35 degree beacon interrogates all aircraft with transponders falling within this beam width. Transmission and interrogation delays cause overlapping and interference.

The FAA Air Traffic Control Advisory Committee recommended a system of Intermittent Positive Control which provides automatic alerting when a potential collision threat existed. Coupled to a ground computer, a modified transponder in the aircraft, interrogated in sequence instead of randomly, would provide position information from which the computer can provide potential collision data. A cockpit display would provide a simple command presentation advising left, right, up, down or straight and level action on the part of the pilot. A computer model study of VFR and controlled (under IFR) operating in the Los Angeles Basin within a 60 x 120 nm area up to 10,000 feet shows that the concept is feasible. 145 a/c under IFR and 1220 under VFR were used in the model.

The new beacon would be compatible with existing transponders and designed to work with modified units to include the selective calling feature. To obtain rapid response, standard rotating antenna systems would have to be replaced with phased arrays with electronic switching. There is considerable resistance from ALPA, General Aviation and operators who might have to modify existing equipment. The improvement in flight safety and positive control is sufficient to make this system a replacement for the existing Broadcast-type interrogation systems in use.

Supplementary Reading - Proceedings of Eascon, 1969. Presentation by Kenneth Willis of Lambda Corp.

Most airliner collisions involve a light aircraft. Yet the Time-Frequency Collision Avoidance System (T/F CAS) would be priced out of the reach of general aviation for years to come. Pilot Warning Instruments (PWI) seem to be one solution. This paper deals with the problems of the Time-Frequency CAS, describes the research being done on Pilot Warning Instruments and discusses another brand-new system by RCA, Secant-B that links a low-cost warning indicator and a full-blown collision avoidance system.

One of the major shortcomings of the T/F CAS is the fact that it will cost at least $4,000 for some years to come which excludes participation by general aviation, the category most involved in collisions. In addition, this system suffers from a high false alarm rate in dense terminal areas where most midair collisions have occurred in the past. Originally proposed by Collins, its principal proponents now are Bendix, McDonnell Douglas and Sierra/Wilcox.

Among pilot warning instruments the majority of designs use a pulsed Xenon flash lamp mounted on the tail of the aircraft and on optical detection system which will decode the flashes emitted by the Xenon lamp.

RCA’s system for collision avoidance is called Secant-B, an acronym for Separation Control of Aircraft by Nonsynchronous Techniques. As the name suggests, the principle difference between it and the T/F CAS is that it functions without synchronization of all participants. The major part of the system is a transponder and interrogating transmitter. The message transmitted includes a coded ‘message start’ header, aircraft serial number, altitude and climb/dive rate (if available), ATC designation and a special search-and-rescue identifier. Intruding aircraft replies will be processed by the interrogating aircraft according to a priority scheme, the closest intruder having the highest priority. Secant-B provides an automatic data link to the local ATC facility, alerting it to the hazard (if applicable), identifying the aircraft involved and requesting an advisory. Only when the time to respond is appreciably narrowed will the system offer an evasive manoeuvre.
RCA envisions three separate versions of the equipment. The cheapest version would be a PWI with a retail price of about $500 and therefore would be within reach of the light-aircraft owner. It will transmit the full message to other interrogators, but will only alert the pilot to the presence of an intruder. The second, more expensive version will be called a collision avoidance system at a price in the region of $10,000 to $20,000. It will have all the features mentioned previously.

The third and most elaborate version is called a Traffic Monitoring System (TMS). It adds a CRT display to the RCA collision avoidance system (the second version) on which a visual indication of surrounding A/C is presented.

The RCA system exists presently only on paper, in computer programs and in breadboards. However, it appears to be the most promising of any collision avoidance systems proposed today.

EADI LEADS SURGE INTO NEW PHASE
Aviation Week and Space Technology
March 23, 1970, p. 46

This article discusses some of the new Electronic Attitude Director Indicators (EADI) offered by U.S. and Canadian companies and new programs designed to present more (or more useful) information electronically to the pilot. Brief discussions of the G.E. Norden, Sanders EADIs and the CDC moving map display are included.

Presentations range from television-type data to CRT line scan or caligraphic (stroke writing) displays. A horizontal situation display (HSI) by Cestronautics Corporation designed for the F-111B replaces the present HSI on RMI instruments. It combines a projected map and CRT symbology.

The article points to the gradual acceptance of CRT - electronic displays on the instrument panel, and the possibility of an excess of data which could lead to a confusing display if it is not carefully controlled. There still appears to be no consensus on what should be presented, how much, and in what format.

SOME THOUGHTS ON V/STOL DISPLAYS AND APPROACH TECHNIQUES
R. W. Millward
AGARD, Problems of the Cockpit Environment
November 1969

This paper describes the authors views on cockpit instrumentation and approach techniques for use in V/STOL aircraft. He feels the current minima of 200 ft., and 1/2 mile are probably sufficient to tax the present instrumentation techniques in the V/STOL mode. He does not discount the zero/zero landing capability for STOL; however, he suggests that automatic landing techniques are generally more reliable than pilot controlled IFR approaches.

A significant point raised in the paper is the configuration of the flight director. The writer suggests a head-down system is preferable over a head-up display. (This is possibly influenced by his military experience.) Multiple information directors tend to become complex and hard to follow, and once information is lost, the pilot finds it hard to regain all the information presented.

He also suggests a 'stepped approach' technique where only one or two changes in aircraft speed or altitude are required at one time.

THE APPLICATION OF TIME/FREQUENCY TECHNOLOGY IN THE AIR TRAFFIC CONTROL ENVIRONMENT
A. Browde (MDC)
AIAA Paper No. 69-795,
Los Angeles Calif. July 1969

The writer describes in fundamental terms the McDonnell Douglas (MDC) collision Avoidance System (CAS) known as EROS (Eliminate Range Zero System). The EROS system has been thoroughly tested in the St. Louis area over a period of 5 years. During this time, it has provided CAS information in accordance with ATA specifications.

Basically the system consists of an extremely accurate clock which continuously resynchronizes up to 2000 members (a/c) every 3 seconds. Everyone of the 2000 has the correct 'time' to 1000 nanoseconds. Each member has a time 'slot' of 2000 microseconds during which time he can transmit up to 150 bits of data - ATC information, systems performance, etc. - plus an altitude pulse. Every member in the system transmits sequentially in his own allotted 'slot' period, listening for data from others the remainder of the period. The propagation delay in the reception of a pulse from another
aircraft nearby is a measure of the range to that a/c, the modulation frequency change during the message is a measure of range rate. By assigning buffer zones in altitude and distance between aircraft, a cockpit warning can be initiated when the ratio of range over range rate becomes less than a significantly safe value.

The paper shows how ground controllers, by using the data presented by the system (which operates in the 1600-1615 MHz band) can locate in XY coordinates the position and altitude of any of the members within range of the ground station.

It seems that time/frequency technology can be turned to good use to simplify the location and identification of a large number of a/c operating in a terminal area, without the ground clutter and precipitation returns which affect normal ATC radars.

AVIONICS DISPLAY GAINS ACCEPTANCE
Aviation Week and Space Technology
March 30, 1969, p. 48

A continuing series of articles on cockpit displays. This one discusses the CRT and fibre optics type which are under development by Norden, Singer-GPL/Librascope, Bendix, TI etc.

Kaiser Aerospace / Electronics have developed an electronic display on a TV-type presentation which appears to have much promise, Librascope have an above-average brightness system with an HUD under evaluation by Delta airlines; NASA Ames is evaluating a less sophisticated Librascope system in a DHC-5 Buffalo.

All of these systems are answers to the pilot's requirement for a cockpit presentation of what is actually happening as he approaches the runway threshold -- on instruments. The preference seems to be for HUD.

ELEMENTS OF THE ATA COLLISION AVOIDANCE SYSTEM
W. G. Shear, Bendix Corp.

This paper describes the components of the Air Transport Association Collision Avoidance System (CAS). The system is quite complex, but the author has broken it down into its essential elements. The system works on time-frequency domains to establish a threat to an aircraft by another within a specified range (about 40 nm).

Cockpit presentation is a fly up or fly down indicator. The transmitted frequencies in sequence are on 1575, 1580, 1585 and 1590 MHz. A frequency synthesizer, master clock and modulator system provide outputs in the form of a 200 microsecond transmitted pulse train plus an altitude pulse. Implicit in the system is sequential coding or hierarchy identification on an aircraft by aircraft basis.

The carrier must have a level of at least 1500 watts of pulse power, to allow for cable losses and provide the necessary S/N ratio. A minimum system is described which requires only 125 w of carrier.

The method of operation is rather involved and the paper should be read in conjunction with others describing the operation of the individual elements. In essence, all aircraft equipped with the CAS transmit, sequentially, pulse modulated information and coded altitude data. All other aircraft receive this information if in range and process the Doppler shift information, compute range and range rate and signal a warning if there is a co-altitude signal indicating a threat.

FLIGHT EVALUATION OF WINDSHIELD DISPLAYS FOR ALL-WEATHER LANDING
Theodore Gold, Sperry Rand Corp.

This paper describes the flight evaluation of a windshield display installed in a Douglas DC-3 aircraft. The utility of the display was evaluated in flight tests in which slant visual range from the cockpit was severely restricted.

Three windshield display configurations were evaluated,

- configuration for final approach
- in landing flare mode
- in go-around mode.

The test consisted of generation of unusual flight conditions and evaluation of pilot response to these conditions when

(a) using conventional cockpit panel instruments
(b) using windshield display with director
(c) using windshield display
without director.

The types of unusual flight conditions generated were:

- localizer standoff (left and right)
- glide slope standoff (left and right)
- induced roll rate (left and right)
- induced pitch rate (up and down)

On the basis of the flight evaluation, the following conclusions were drawn:

- Pilots can descend to considerably lower altitudes with steady localizer and glide slope standoffs, and recover safely from these situations when using the windshield displays compared with panel instruments.
- Pilots can recover from lateral offsets using substantially smaller manoeuvring distances with a windshield display as compared with panel instruments.
- Difference in performance of pilots using windshield displays with and without flight directors are smaller than any differences in which a panel display is involved.
- Where differences exist, a windshield display with a flight director is superior to the same display without a flight director.
- Behaviour of pilots during the low weather approach is more comparable to VFR conditions with the windshield display than with panel instruments.
- The windshield display images can be made to overlay the real world with sufficient accuracy for low weather approach and landing using state-of-the-art equipment.

STATUS-AIRBORNE COLLISION AVOIDANCE SYSTEM PROGRAM
J. L. Brennan, FAA

This paper is essentially a status report of the airborne collision avoidance system program of the FAA. The following elements are part of the total program:

(a) visual capability
(b) conspicuity enhancement
(c) pilot warning instruments (PWI)
(d) collision avoidance systems (CAS)

This paper deals only with the fourth element, collision avoidance systems.

The four CAS functions (Detection, Evaluation, Manoeuvre Determination, and Manoeuvre Indication at the proper time) must be performed within at least the following system performance requirements:

(1) Must accommodate a large number of aircraft within communication range
(2) Must have the capability of resolving multi-aircraft conflict situations
(3) Must process hazards in essentially real time
(4) Must operate in manoeuvring environments consisting of aircraft with varying performance characteristics.

A detailed description of collision avoidance criteria is given and the FAA's past hardware efforts are reviewed. An analysis/computer simulation effort with Collins Radio Co. is described in more detail involving the T/F (time-frequency) concept which appears very promising at this moment. The T/F concept is explained in some detail pointing out that this technique appears to extend to other uses far beyond the CAS function.

APPENDIX III

THE IMPACT OF AIR TRAFFIC CONTROL ON AVIATION GROWTH
J. D. Smith, United Airlines Inc.
AIAA Paper 69-1052, Anaheim, Calif.
October 1969

THE AIRPORT PROBLEM
N. R. Montanus
IN: World Airports, The Way Ahead
Proceedings, Institute of Civil Engineers Conference, London, England
September 23-25, 1969
A simulation study to determine the effect on air traffic control when both Vertical and Short Takeoff and Landing aircraft are introduced into a terminal air traffic control environment was conducted using the Model B Dynamic Air Traffic Control Simulator. Several approach conditions, various glide slope angles, and separation criteria were investigated to determine the effect on the terminal environment. It was concluded that Vertical and Short Takeoff and Landing aircraft could be accommodated in the terminal area using present operational procedures. However, when Vertical and Short Takeoff and Landing aircraft reduced from terminal area speed to a slow final approach speed, difficulties were encountered in providing not only the desired spacing between these aircraft but between these aircraft and conventional aircraft in the sequence to and on the final approach course.
INFLUENCE OF ANGLE OF GLIDE SLOPE ON THE ACCURACY OF PERFORMING INSTRUMENT APPROACHES IN A SIMULATOR
Lindsay J. Lina, George C. Canavos
NASA Langley Research Center, NASA TN D-4835, November 1968

AREA NAVIGATION - A MAJOR CAPABILITY IMPROVEMENT FOR AIR TRAFFIC CONTROL
Glen A. Gilbert

COMPUTER RECOMMENDATIONS FOR AN AUTOMATIC APPROACH AND LANDING SYSTEM FOR V/STOL AIRCRAFT
Harry T. Gaines et al
NASA CR-86173, June 1968

NATIONAL AIRSPACE SYSTEM ENROUTE
F. Kimber Seward, IBM
IEEE International Convention, New York, N.Y., March 20-23, 1967

NAVIGATION OF V/STOL AIRCRAFT IN HIGH-DENSITY URBAN AREAS
Tirey K. Vickers

V/STOL APPROACH AND LANDING SYSTEMS
AGARD Report No. 560
AD 672580, 1967

A THREE DIMENSIONAL NAVIGATION AND GUIDANCE SYSTEM FOR TRANSPORT AIRCRAFT

Description of an existing three dimensional navigation and guidance system for transport aircraft, many elements of which were designed specifically to alleviate an acute operational problem that exists primarily on the eastern seaboard in the United States. The operational requirements of this system are outlined, a brief description of the equipment is presented, and flight test results are quoted. The system has mostly been applied to aircraft having STOL characteristics operating in a terminal area environment. It combines accurate position fixing in the horizontal plane with a vertical guidance facility linked with the aircraft flight system.

MINIMUM OPERATIONAL CHARACTERISTICS FOR AIRBORNE AREA NAVIGATION SYSTEMS
Radio Technical Commission for Aeronautics (RTCA), Washington, D. C.
Document No. DO-141, August 1969

Discussion of the minimum operational characteristics (MOC's) for airborne area navigation systems, and outline of criteria for VOR-DME area navigation accuracy. System characteristics are examined and the reasons for compliance with the MOC's presented are stated. Aspects of system installation and performance are considered. An assessment of the error elements is given, and criteria are presented for vertical guidance in airborne area navigation.

MODILS - A NEW MICROWAVE ILS
M. A. Meyer

Description of a versatile high-precision instrument landing system developed to facilitate landings in difficult sites or under difficult conditions and to provide a new capability in instrument landing systems consistent with the expanded needs. The system is defined as a continuous measurement system in both the azimuth plane and in the vertical plane. The outstanding features are enumerated, including all weather operation, multiple course capability, multiple glide slope capability, small size, site insensitivity, convenient modular design, high reliability, flexible signal format, lightweight design for tactical operations, and capability of potential growth by adding additional features as desired. A detailed description of the principles of operation is given, and the ground station and airborne block diagrams are explained and discussed.

FAA STOL APPROACH, LANDING, AND TAKEOFF OPERATIONAL EVALUATION TESTS
J. Clay Stapes, FAA
Paper presented at SAE Meeting, Los Angeles, Calif., October 7-11, 1968
SAE Paper No. 680667

An operational evaluation of two aircraft which are candidates for metropolitan area STOLport operation is made in the approach, landing, and takeoff regimes of flight. Information is obtained on such characteristics as instrument approach angle, beam width or softness, deviations from approach course, approach obstacle clearing planes, threshold crossing heights, landing distance, takeoff distance, and offset approach angles.

III.26
V/STOL NAVIGATION IN THE TERMINAL AREA
E. N. Baur, New York Airways Inc.

Brief analysis of V/STOL navigation in the New York City area. Some of the navigational and communications equipment used in the New York Airways Boeing V-107 helicopters is considered, with emphasis on the use of the Decca Navigator System. Problems arising from the interaction of V/STOL and fixed-wing aircraft flight patterns over the New York area are briefly discussed.

OMEGA - A WORLD-WIDE NAVIGATIONAL SYSTEM - SYSTEM SPECIFICATION AND IMPLEMENTATION - Second Revision
J. A. Pierce, et al
Pickard and Burns Electronics
Waltham, Mass., May 1, 1966
AD 630900

This report presents a design plan for a radio-locating facility providing a world-wide position fixing of moderate (one-mile) accuracy by phase comparison of VLF (10-14 KHz) continuous wave radio signals from only eight strategically located transmitting stations usable by aircraft, ships, and land vehicles, and by submarines at moderate (40-50 feet) antenna depths.

Air Traffic Control

AUTOMATION IN AIR TRAFFIC CONTROL - ITS BENEFITS AND PITFALLS
J. Paul Locher III, The Mitre Corp.
AIAA Paper 69-1057 Anaheim, Calif.
October 1969

V/STOL CONSIDERATIONS IN AIR TRAFFIC CONTROL
J. T. Stutlz, R. W. Dorozewski
Sikorsky Aircraft
October 1969

RADAR DIGITAL PROCESSING AND DISPLAY SYSTEM FOR AIR TRAFFIC CONTROL
J. Rennie, Dept. of Transport
A. H. Hamilton, J. Moffett, AII
Information Display, Vol. 6,
July - August 1969 p. 29

APPLICATION OF AUTOMATION IN TERMINAL AREA AIR TRAFFIC CONTROL
John C. Mercer, FAA
AIAA Paper 68-1100

TRAFFIC CONTROL
C. S. Draper, J. W. Hursh,
R. B. Trueblood, J. H. Flanders, MIT
New York Academy of Sciences,
International Congress on Subsonic Aeronautics, New York, N.Y.,April 3-6, 1967
New York Academy of Sciences, Annals,
While the abundant literature pertaining to aircraft noise dates back to at least the early 1930's, it was recognized only recently that noise considerations are to play a significant, if indeed not crucial, role in the ultimate success or failure of contemplated STOL systems. During the last several years activities of the American Federal Aviation Agency, ultimately leading to the formulation of noise certification regulations for jet aircraft, generated a tremendous flood of research on all aspects of aircraft noise, STOL and its special problems were not neglected.

The past several years have also witnessed a remarkable awakening of public concern with the deterioration of the environment. Progressive stiffening of public resistance to noise and air pollution is inevitable. This bibliography reviews the most recent literature dealing with noise, pollution, and other factors relevant to the eventual acceptance (or rejection) of STOL aircraft by the non-passenger public.

The choice of papers to be reviewed was considerably simplified by the existence of several comprehensive bibliographical compilations of the literature published prior to 1968. In addition, a number of excellent review papers summarizing earlier work have since appeared. Accordingly, this bibliography concentrates on papers appearing in 1968 or later. A few earlier papers are included for completeness.

It is evident that the special problems to be encountered by STOL aircraft can only be assessed in the context of the wide perspective of the relationship of the aviation industry in general with the non-passenger segment of the community. The papers reviewed herein were selected with a view to introducing the non-specialist to the factors influencing community response to aircraft noise and to point out the unique features of STOL in this overall context. The papers reviewed in detail tend to be shorter descriptive ones; summarizing general concepts, de-emphasizing mathematical theories or detailed descriptions of particular devices. Nevertheless, the bibliography was intended to be sufficiently complete to serve as a starting point for in-depth study of all relevant aspects.

The bulk of the reviewed material pertains to noise related topics, reflecting their importance to non-passenger public acceptance. Many of the papers concentrate on the special problems of STOL.

Air Pollution emitted by aircraft exhausts, although potentially a nuisance locally, contributes only an insignificant amount to overall levels. No papers were found dealing specifically with the air pollution caused by STOL aircraft. Since, however, engine cycles of STOL powerplants are not expected to be greatly different to those of conventional aircraft, STOL exhaust pollution levels can be readily inferred from the reviewed papers dealing with conventional aircraft.

Any safety hazards imposed on the non-passenger public will naturally figure prominently in its attitude towards a nearby airport. Conventional aircraft accidents involve non-passengers outside of the airport boundaries very rarely indeed. Perhaps this is why no papers dealing specifically with non-passenger public aspects of safety were located. Fear of crashes, however, is an important indirect factor in subjective reactions to aircraft noise and is also reflected in property values near airports. The reviewed papers dealing with these subjects reflect safety considerations to a certain extent.

The papers are arranged in the following categories:

- General Perspective
- Noise Exposure Forecasting/Noise Rating Scales
- Subjective Response
- Community Response/Compatible Land Use
- Economic and Legal Aspects
- Operational Procedures
- Regulation and Certification
- Aircraft and Hardware
- Pollution
- Mathematical Theories of Aircraft Noise

An Appendix listing other bibliographies, relevant textbooks, and headlines from news articles is also included.

**GENERAL PERSPECTIVE**

**CARRIERS URGED TO ACT ON SOCIAL PROBLEMS**

R. G. O'Lore,
Aviation Week & Space Technology, Vol 91 No. 6, August 11, 1969, p. 53

This thought provoking article reports on an International Air Transportation Symposium held at Stanford University. The general theme of the symposium concerned social problems, mainly noise:
a number of speakers were severely critical of the airline industry. C. A. Moore, general manager of Los Angeles Department of Airports, accused the airlines of greatly underestimating the noise problem stating that 'industry efforts (at alleviating noise) are far short of what is required'. In one scathing attack William Baxter, professor of law at Stanford, expressed the opinion that 'the airline's enjoy a substantial subsidy from the public' as a result of being 'allowed to dispose noise on airport neighbours'. As warning to the airlines he pointed to the railroads who eventually experienced great hostility from the public as a result of early lack of social concern and reliance on 'political muscle'.

Due to noise restrictions Kennedy International Airport's capacity is less at the present time than when it originally opened. The planners of STOL systems would be well advised to carefully consider the experiences of the conventional air transport industry.

CONFERENCE ON STOL TRANSPORT AIRCRAFT NOISE CERTIFICATION
held in Washington, D. C. January 30, 1969
FAA No-69-1 (also N69-21726)

These are the proceedings of a conference organized by the FAA's office of noise abatement in order to initiate discussion of the criteria which would form a basis for STOL aircraft noise certification. A number of presentations were delivered by FAA and NASA administrators and researchers to an audience of over 100 representatives of industry and government organizations.

The technical papers (referenced individually in this bibliography) represent an excellent overview of STOL aircraft noise: source, transmission, reception. The papers are written texts of the oral presentations and as such are concise and suitable for the non-specialist reader. A disadvantage, however, is the absence of references. The open comments and discussion which took place at the end of the meeting were, unfortunately, not recorded.

The list of attendees might be helpful in indicating who is concerned with STOL noise in various organizations: American, Canadian, and other.

In his concluding remarks the director of FAA Office of Noise Abatement reviews noise certification criteria for CTOL and differences to be considered in similar criteria for STOL. He notes that the proposed noise ceilings for CTOL are greater than any 'acceptable' level. In view of the recognized social and economic benefits of air commerce to the whole of society, it was felt necessary that some reasonable cost be imposed on a minority living close to airports. It is stressed, however, that this same minority must be reimbursed in some way. (Tax reduction proportional to noise exposure?)

STOL operations, on the other hand, are considered less essential to general well being of the public: accordingly, they will not be allowed to impose a noise cost on the STOLport environment. Optimism is expressed about eventual development of STOL vehicles with acceptable noise characteristics.

Two distinct possible concepts for noise certification of STOL aircraft are reviewed. The first is a modification of the three-point measurement method being used for conventional transport aircraft. The second involves only validation of an aircraft's noise characteristics followed by operational restrictions adjusted to land usage around each particular STOLport.

A SYSTEM SOLUTION TO THE AIRCRAFT NOISE PROBLEM
I. H. Hoover
Aero, J. of the Royal Aero. Soc.
Vol. 72, No. 688, April 1968, pp 299-301

This is the text of a short paper presented at the Tenth Anglo-American Aeronautical Conference held in Los Angeles, Oct. 20, 1967. The author was then director of the FAA Office of Noise Abatement.

It is pointed out that the air transport industry is essential to economic and social welfare. To avoid stangulation of the whole industry, it is felt that new airport development is essential. The noise problem is designated as a serious impediment to such development.

It is suggested that the problem can only be tackled on a system basis to achieve the most cost effective solution using all available options: technical, operational, airport, compatible land use. The remarks on the various options are applicable to STOL as well.

An interesting opinion is that 'the noise which cannot be eliminated should be condensed to the immediate airport area'. That is, it is felt that people living near airports enjoy economic benefits as result of this proximity so that they 'should pay the price of noise exposure if, in fact, someone must pay'. This point is also very
apropos to proposed STOL operations. Since it is possible to trade off lessened noise over a widespread area against relatively localized intense noise a philosophy will have to evolve, perhaps dependent on the particular application.

HOW SHOULD CIVIL AVIATION DEVELOP TO SERVE OUR SOCIETY BEST?
AIAA President's Forum
Astronautics & Aeronautics Vol. 7, No. 2
February 1969, pp. 28-55

In an attempt to answer the title question a panel of prominent figures were convened for a forum discussion. In the keynote address H. G. Stever, president of Carnegie - Mellon University, former head of MIT engineering department, chairman of numerous advisory boards, designated noise as a research and development area of critical importance to the continued viability of civil aviation: rating it second only to ground support facilities but ahead of air traffic control. He cites the noise problem as a major obstacle to growth and development of STOL.

Any solution to the noise problem, Stever claims, must include development of quieter aircraft; establishment of federal noise regulations; development of consistent land use practices around airports; and development of better building and sound proofing methods to reduce noise in buildings already close to airports.

The forum panel included P. W. Cherington, Professor of Transportation at the Harvard Business School; James Ferguson, leader of (U.S.) Air Force Systems Command; N. E. Halaby, head of Pan American Airways, former FAA Administrator; D. S. Lewis, president of McDonnell Douglas; W. F. McKee, former FAA Administrator and former Assistant Administrator at NASA; R. C. Seamans Jr., then Air Force Secretary, current AIAA President; and J. R. Wiley director of the aviation department of the Port of New York Authority. Noise and non-passenger public acceptance was the subject of a large portion of the free-wheeling discussion. The comments were well punctuated with references to STOL.

As an illustration of the impact of public acceptance or non-acceptance consider Wiley's remark noting that were it not for noise abatement procedures, Kennedy Airport's capacity could be immediately increased by 35%.

Some relevant quotations:

Wiley:
"The proposed solution (of airplanes being unable to meet noise requirements) to shift the measuring point...is putting one's head in the sand."
"Those who benefit from air transportation must....deal with the added cost of supressing noise at the source."

Seamans:
"I think we must take the point of view that increases in noise and pollution will not be allowed, and then see how much performance can be improved."
"...the country is fed up with noise and air pollution."

Lewis:
"I do not think we're making progress ...it is unlikely we will unless a big fire is built under the social structure."

L. A. GIRDS FOR JET-NOISE SHOWDOWN
R. L. Parrish
American Aviation,
January 6, 1969, pp. 23-24

Some indication of the growing spirit of revolt against noise may be obtained by noting that noise suits and claims aggregating to nearly 2.5 billion (U,S.) dollars are presently pending against airports, manufacturers, and operators in Southern California. Since this article was written a California Superior court has issued a pre-trial ruling upholding liability of airlines and manufacturers for damage from jet noise and fumes (see Aviation Week, May 11, 1970, p.44).

It is interesting to note that suits against Los Angeles International have been initiated by groups situated as far as 18 miles from it. Of more significance to STOL is the case of Santa Monica Airport, a facility not used by the airlines but by business jets and propeller aircraft. Local families have brought suit against the city of Santa Monica alleging maintenance of a public nuisance, improper zoning, and personal and property damage.

SOCIAL CHANGE TO AFFECT EQUIPMENT DESIGN
Aviation Week & Space Technology
Mid December 1968, pp. 24-26

This unhilined article, dealing with market prospects for the next generation of aircraft, stresses the emergence of sociological environments as a major factor in public acceptance of new technologies. The next generation of adults are anticipated to have a marked 'man before the machine'
outlook: consequently, even stiffer public resistance to noise and air pollution is forthcoming. It is expected that VSTOL aircraft operating in metropolitan areas will be especially affected. The Boeing Company, for example, considers noise to be the chief obstacle in producing acceptable future designs.

PROGRESS OF NASA RESEARCH RELATING TO NOISE ALLEVIATION OF JET AIRCRAFT NASA SP-189
Conference held at Langley Research Center, Hampton, Va., October 8-10, 1968

A series of papers describing NASA sponsored research into the evaluation/alleviation of the noise of large jet aircraft. No direct references are made to STOL but many of the papers are relevant.

The first two sections 'Nacelle Acoustic Treatment Technology' and 'Nacelle Acoustic Treatment Application', although primarily applicable to conventional jets, are also relevant to STOL aircraft using lift jets. The fourteen papers in these sections review all aspects of nacelle acoustic treatment and contain numerous up-to-date references.

The section entitled 'Noise Generation and Reduction at the Source' is comprised of six papers reviewing recent research into quietening turbofan engines. The discussions are aimed directly at subsonic jet transports and application to STOL vehicles is very indirect.

The final two sections 'Operational and Environmental Considerations' and 'Subjective Reaction' are generally the most relevant to STOL. They deal with calculation or measurement of aircraft noise reaching a particular point and the prediction of subjective response to this noise. The results could be applied to STOL in obvious ways even though the actual STOL vehicle noise characteristics would normally be quite different from the jet noise discussed. Some of the most pertinent papers are reviewed individually.

NOISE EXPOSURE FORECASTING/NOISE RATING SCALES

AIRCRAFT NOISE EVALUATION
W. C. Sperry
U.S. Federal Aviation Administration, FAA-No 68-34, September 1968

At the time of writing of this report, the American Federal Aviation Agency was in the process of drafting regulations for certification of aircraft for noise. Basic to such regulations is the concept of a single number evaluator to rate the subjective reaction of humans to a particular noise. The evaluator which has since been adopted is the effective perceived noise level or EPNL. At that time considerable controversy, still not completely resolved, raged within the aviation community over the suitability of EPNL as a basic unit for certification requirements.

The EPNL is open to criticism both in general concept and in particular details in the calculation procedure. This report represents a well reasoned and moderate rebuttal of these criticisms. Towards this end, the history of how the EPNL concept emerged as the FAA's favoured method is first outlined; particular criticisms are then examined in detail.

The most valid criticisms seem to be centred around the corrections for duration and pure tone content. To meet the criticisms the original investigations into these factors are reviewed. It is concluded that the preponderance of evidence definitely indicates the necessity for accounting for duration and tones. Admittedly, the actual details of calculating corrections may need revision. The best available calculation method is outlined. It is stressed that the method is flexible and changes can and will be incorporated as soon as justified by the state-of-the-art.

This well reasoned, moderate, and clearly written report is a welcome aid in clarification of the controversial aspects of the EPNL concept. This concept has since been incorporated into FAA noise certification procedures for conventional jet aircraft and will undoubtedly be basic to the coming STOL regulations. The fact that simplifications may be (and usually are) introduced in calculation of particular noise contours must not be allowed to obscure questions regarding general validity of the basic concept.
These procedures were developed by Bolt Beranek and Newen Inc. (BBN) for a study of the noise environment of JFK, O'Hare, and Los Angeles International Airports. They evolved out of predecessor procedures described in various FAA, BBN, and SAE publications predating this report.

The basic procedure is supposed to be applicable to any airport situation - including STOLports. In the applications considered large jet aircraft dominate the noise output, so that these were the only type needed to be taken into account.

Since this report was issued, the FAA has incorporated some minor modifications into its recommended procedures. These changes are mainly to simplify the estimation of noise characteristics of the aircraft and are not necessarily useful to Canadian STOL application (see below). The basic procedure may be considered the most up to date available and despite various shortcomings is generally accepted as the best practical method at the present time. The Canadian Department of Transport currently bases its noise forecasting on the method of this report.

The aim of the procedure is to calculate contours of Noise Exposure Forecast (NEF) around an airport from knowledge of the types of aircraft and their operations. To find the NEF at a given point, the contribution of each aircraft type using each runway is calculated in turn. (Landings and takeoffs are considered separately.) The contribution from each type is weighed for a number of operations and the total contribution is then obtained by appropriate summation. This is done for enough points surrounding the airport to allow construction of the contours.

The contribution from a particular aircraft depends mainly on the maximum noise heard during the flypast. Because of the directional properties of aircraft noise, the loudest noise does not necessarily occur when the aircraft is directly opposite. For most jet aircraft for example, the loudest noise during takeoff is radiated backwards at about 45° to the flight path: this property has to be taken into account. (Considerable differences can exist in the directionality of the noise from different STOL types.)

Knowing the position of the aircraft at the instant when the loudest noise is heard the distance between aircraft and observer is calculated from geometrical considerations. Based on this distance and the temperature and humidity the attenuation of sound pressure level in the different frequency bands is calculated. Corrections for ground attenuation, downwind effects, focussing, etc. are also introduced at this stage.

The attenuated sound pressure levels are then combined into perceived noise level (i.e. - weighing high frequencies more than low frequencies). Finally corrections are made for duration and discrete tones to get the 'effective perceived noise level' in EPNdB. Some of the literature pertinent to these calculations is reviewed elsewhere in this bibliography.

The complete calculation outlined has to be carried out for each aircraft type using each runway at every point of interest: clearly a job for electronic computing equipment. Simplifications subsequently introduced (alluded to above) consist of presentation of the basic aircraft noise data directly as EPNdB vs distance. This reduces computation but destroys the flexibility needed to account for non-standard climatic conditions, focussing effects, and the like. Thus the simplifications might not be applicable to the STOL situation.

The EPNdB values are converted to NEF by summation on an energy basis with weights for number of operations and time of day. The final NEF values are related to land use compatibility through information from sociological surveys.

It is neither necessary nor recommended to wade through this report for general understanding of the procedure: some of the shorter popularized articles (reviewed in this bibliography) being entirely adequate for that purpose. However, for someone contemplating actual calculations, this report will provide a framework for a detailed computation procedure. Familiarity with the main references of this bibliography will be prerequisite for adaptation to STOL applications.
RELATIONS AMONG THE VARIOUS SINGLE-NUMBER RATINGS FOR ENVIRONMENTAL NOISE
T. J. Schutz
Paper presented at 79th Meeting of the Acoustical Society of America
Atlantic City, N.J., April 21-24, 1970

Fifteen different rating scales currently used for evaluating noise in terms of subjective response are reviewed. Despite apparently great differences in formulation, the ratings show high correlation among themselves. The relationships among the ratings are discussed and reasons are suggested for the correlations.

ASSESSMENT OF AIRCRAFT NOISE DISTURBANCE
C. G. Van Neikerk, J. L. Muller
Vol. 73, p. 383, May 1969

The need for a standardized procedure to describe the noise environment of airports is generally recognized. One such procedure, discussed in great detail in a number of references reviewed in this bibliography, is the Noise Exposure Forecast or NEF methodology. Although recommended by the International Organization for Standardization, the NEF procedure is by no means universally accepted. The South African authorities, for example, 'balked at the extent of measurements and laborious computations required'. Accordingly, they devised the alternate methodology described in this paper.

This reference is mentioned merely to emphasize the existence of alternate methods. The preponderance of opinion favours adoption of the NEF procedure for both conventional and STOL operations.

VARIABILITY IN AIRPLANE NOISE MEASUREMENTS
D. A. Hilton, H. R. Henderson
Paper 24 in NASA SP-189, pp. 359-367
Conference held at Langley Research Center, Hampton, Va.
October 9-10, 1968

In noise exposure forecasting it is necessary to use the measured noise characteristics and typical flight profiles of a particular aircraft type. This short paper describes some experimental measurements of flyover noise of jet aircraft under carefully controlled conditions. Some of the conclusions seem applicable to STOL operations.

MATHEMATICAL FORMULATION OF THE NOY TABLES
R. A. Pinker

The accepted standard for determining a subjective rating of aircraft noise is based on the perceived noise level (PNL) with corrections for discrete tones and duration producing the effective PNL (EPNL). Fundamental to the calculation of PNL is conversion of 1/3 or full octave band sound pressure levels to NOY values; that is, multiplication by weighing factors depending on level and frequency to relate to actual annoyance. The weighing factors were originally presented as bulky tables or graphs. This paper gives an efficient computer method for calculating the PNL (based on linear fits to various portions of the table of weights). This method represents the best available for computation at the present time.

ON ESTIMATING NOISINESS OF AIRCRAFT SOUNDS
R. W. Young, A. Peterson
J. Acoust. Soc. Am., Vol. 45 No. 1
January 1968, pp. 106-115

A number of different physical measurements have been used to estimate the subjective noisiness of aircraft sounds. The measure currently adopted in airport noise studies is the 'effective' perceived noise level (expressed in EPNdB) which adds corrections for pure tones and duration to the older perceived noise level (expressed in PNdB). Alternate
measures are the various weighted scales: Sound Levels A, B, C, and D.

In this paper published results of subjective judgement tests of noise have been collected and analyzed collectively. Statistical procedures revealed that differences between calculated perceived noise level and Sound Levels A and D are not statistically significant. Sound Levels B and C, however, are clearly inferior as predictors of subjective noisiness. Since Sound Level A (which is conveniently measured by a single meter reading) predicted noisiness as well as calculated perceived noise level, it may well be applied as a quick check on STOL aircraft noise. It seems that if the various corrections are kept in mind, this level could also be used as a basis for certification standards.

THE PROPAGATION OF SOUND FROM AIRPORT GROUND OPERATIONS
P. A. Franken, D. E. Bishop
NASA CR-767, 1967

The report presents the results of some experiments to determine the absorption (or enhancement) of sound due to "miscellaneous meteorological and ground effects" including downwind propagation. The results of previous work of this nature are summarized. A procedure is suggested for estimation of this "excess attenuation".

By way of explanation of some difficulties encountered in evaluating the experimental data it is suggested that the standard attenuation values (ARP 866) are too large by about a factor of two for frequencies of 2,000 cps or above. This reviewer cannot agree with this conclusion as the standard values are in substantial agreement with the results of some very carefully controlled experiments (Harris, NASA CR-647, 1967).

Since STOLports will be located in built up areas with surface characteristics considerably different than the experimental ones, the conclusions/procedures of this report are judged inapplicable to STOL studies.

ABSORPTION OF SOUND IN AIR VERSUS HUMIDITY AND TEMPERATURE
C. M. Harris
NASA CR-647, 1967

Complete charts and tables for calculation of the attenuation of sound energy propagated through (still) air. Results are based on measurements made in a spherical test chamber under controlled conditions.

Data covers a temperature range of -10°C to 30°C, relative humidity from 5 to 100 percent (slightly extrapolated for low temperatures). The standard values (ARP 866) based on flyover measurements taken under less controllable conditions are largely corroborated.

STANDARD VALUES OF ATMOSPHERIC ABSORPTION AS A FUNCTION OF TEMPERATURE AND HUMIDITY FOR USE IN EVALUATING AIRCRAFT FLYOVER NOISE
Soc. of Automotive Engineers
ARP 866, 1964

Charts for calculating the absorption of sound energy by the atmosphere as a function of the temperature and humidity are presented. A brief description of the relevant theory is also included.

The data was extracted from measurements of aircraft flyover noise; it is in substantial agreement with test chamber data (Harris, NASA CR-647, 1967).

Since the absorption has very complex dependence on temperature and frequency standard curves of perceived noise level vs distance may require correction. A limitation with respect to possible Canadian applications is that the temperature data is not given for below 0°F.

SUBJECTIVE RESPONSE

PREDICTION OF EFFECTS OF NOISE ON MAN
K. D. Kryter,
Conference held at Langley Research Center Hampton, Va., Oct. 8-10, 1968
Paper 34 in NASA SP-189, pp. 547-560

This paper represents an excellent brief general introduction to prediction of the deliterious effects of noise on man. These include masking of wanted sounds, damage to hearing, general 'unwantedness'. Distinction is drawn between sound that is unwanted (i.e. noise) because it carries information having unpleasant connotation and sound unwanted because of its actual physical characteristics.

Various possible ways of defining a 'Composite Noise Rating' to describe general nuisance of particular combinations of noises are described. It is thought that a Composite Noise Rating will find beneficial practical application as a guide for design, for
forecasting noise environments, and as a guide for setting acoustic standards.

JUDGMENTS OF THE ACCEPTABILITY OF AIRCRAFT NOISE IN THE PRESENCE OF SPEECH
C. E. Williams, K. N. Stevens, M. Klatt

In usual tests for evaluating subjective response to flyover noise the listeners' only task is evaluation of the noise. For acceptability in the home, however, the aircraft noise has also to be judged when its occurrence coincides with listening to radio or TV, speaking on the telephone, etc.

In this paper experiments obtaining subjective ratings under carefully selected conditions simulating the home environment are described. It was found that listener ratings corresponded very well with duration corrected PNL's. Moreover, little difference was observed between ratings obtained with and without a comfortable level of masking speech.

A conclusion with particular relevance to the STOL study is that listeners largely judge aircraft noise in terms of potential interference with speech communication. If so, there exists an absolute standard for acceptability of noise which will not change due to acclimatization. This refutes arguments sometimes advanced in connection with proposed STOL (and other) operations.

STUDIES RELATING THE INDIVIDUAL CHARACTERISTICS OF PEOPLE WITH THEIR RESPONSES TO NOISE
R. G. Pearson, F. D. Hart
Paper No. 35 in NASA SP 189, pp. 561-572
1968

This paper describes preliminary research aimed at isolating the influence of individual personality traits on subjective response to aircraft noise.

One hundred and sixty-six adults varying in age, sex, and background were used to subjectively evaluate a variety of recorded noises (aircraft, trucks, factory machinery, and others). Two different settings were used, a 'soft' one furnished fairly luxuriously and a 'hard' one with austere furnishings.

It was found that the setting had little effect on judged noisiness but individual psychological factors (personality traits, acquired attitudes) were extremely important. For example, subjects identified as having general antiaviation attitudes, anxiety, or health complaints showed greater sensitivity to noise.

The results of this study point to the possible necessity of adjusting noise exposure forecast contours for special psychological factors predominant in a particular STOLport environment.

CONCEPTS OF PERCEIVED NOISINESS, THEIR IMPLEMENTATION AND APPLICATION
K. D. Kryter

This polished, scholarly article presents the rationale leading to the proposal of Effective Perceived Noise
Level (EPNL) as a measure of the total sound environment. Interrelationships between this measure and previously proposed measures (CNR in the United States, NNI in Great Britain, Q in Germany) are discussed. The paper includes detailed review of the assumptions and practical limitations inherent in concepts of perceived noisiness and suggestions of the tolerable limits for noise before annoyance or hearing damage becomes probable. The 55 references in the footnotes will provide ample material for an historical perspective.

Arguments concerning the relative merits of various measures of perceived noisiness often become quite heated; indeed, it can be argued that, due to the great variety of sounds existing in the world, no single unit is capable of meaningfully comparing all noise environments. In this very readable paper the author provides detailed background which could be a great help in sorting out the considerable conflicting 'evidence' on the still controversial title subject.

SUBJECTIVE RESPONSE TO SYNTHESIZED FLIGHT NOISE SIGNATURES OF SEVERAL TYPES OF V/STOL AIRCRAFT
E. G. Hinterkeuser, H. Sternfeld, Jr.
NASA CR-1118, 1968

Subjective response to the noise characteristics of several V/STOL aircraft types are evaluated. The aircraft are all sized for 60 passengers and 500 mile range; the types are lift fan VTOL, jet lift VTOL, tilt wing VTOL, turbofan STOL, rigid single rotor composite, and tandem rotor helicopter. The first three types emerged from previous NASA studies as the most promising concepts for commercial short haul operations. The last two are added to provide good coverage of the disk loading spectrum. The sound frequency spectra associated with each type was estimated in a way appropriate to that particular type. Tapes of the predicted sound were then synthesized; generally starting from recordings of aircraft of the same general configuration and recordings of specific components. It seems that the precautions taken to ensure reproduction of subjective aural effects were very good. Variation of amplitude with time and doppler shift, for example, were obtained by re-recording the sound as it was broadcast from a passing vehicle.

The final recordings were compared to a jet aircraft through standard subjective testing (using a test group of 82 college students). Subsequent analysis revealed good correlation between the subjective test results and calculated effective perceived noise.

Although the general noise levels were less than for the comparison jet, it was concluded that substantial distances between the aircraft and public will be required to retain noise levels at present limits without control at the source (i.e. modification of aircraft). Each aircraft type was examined to determine the noise reduction required to allow the aircraft to operate at 500 (or 200) feet from the terminal or to fly at 1000 (or 500) feet altitude in cruise. The predominant noise contributing components are identified for each type. Several components are exposed as consistent noise contributors: engine intakes and exhausts, propellers, rotors.

This report will contribute valuable data to assess potential noise problems in any proposed V/STOL study. The data presented will provide valuable estimates to likely noise levels (and/or reductions required). Further, the calculation methods are presented in enough detail to allow modifications for V/STOL aircraft differing from the actual study types.

THE EFFECTS OF BACKGROUND NOISE UPON PERCEIVED NOISINESS
D. C. Nagel, J. E. Parnell, H. J. Parry

Since STOLports may be located in downtown areas where considerable background noise (e.g. from surface traffic) may exist it is useful to know how continuous background levels can affect the perceived noisiness of an intruding sound. It is believed that a moderate or high continuous background noise makes a more intense intruding noise less objectionable. This paper describes some experiments to determine the masking effect of background noise and suggests a calculation procedure for its estimation.

The calculations procedure is based on a band by band comparison of the frequency spectra of the background and intrusive noise. It is unlikely that such a procedure would be necessary in a preliminary consideration of the noise around STOLports. Some useful general conclusions might be noted

(i) For signal to background noise ratios greater than about 65 dB no correction is warranted

(ii) For signal to background ratio of
40 dB the masking is of order 3 dB.

The bibliography of this report lists some of the fundamental papers on this topic.

EFFECTS OF TEMPORAL AND SPECTRAL COMBINATIONS ON JUDGED NOISINESS OF AIRCRAFT SOUNDS
K. S. Pearsons, R. L. Bennett

Subjective tests on the effect of duration and pure tone content of various noise signals showed the superiority of the corrected (EPNL) over the uncorrected (PNL) perceived noise level. As an example, in one test 75% of data was within 4 dB of the standard for EPNL as compared to 11 dB for PNL.

This represents additional evidence in support of the (sometimes disputed) claims that EPNL is also a good indicator of subjective response to STOL aircraft noise.

SOUND DURATION AND ITS EFFECT ON JUDGED ANNOYANCE
J. W. Little, J. E. Mobray
J. Sound Vib., Vol. 9, No. 2, March 1969 pp. 247-262

This report describes experiments wherein a group of 94 people subjectively rated both random noise and the noise of a fan jet. The results, using noise of various amplitudes and durations confirm the generally accepted increase in annoyance with increased duration. The amount of increase (roughly 2 dB for doubling of duration) determined in these tests is somewhat lower, however, than has been observed in other experiments.

An interesting side result was yet another demonstration of the fact that the results of judgement tests are extremely sensitive to the wording of the instructions. When the subjects were reminded to take into account varying duration higher annoyances were recorded.

A REVIEW OF HEARING DAMAGE RISK CRITERIA
W. I. Acton

No contemplated STOL operation would generate noise intense enough to produce appreciable risk of hearing damage to non-passenger public. If the question should ever arise, this reference will provide the best available information. The literature on hearing damage risk associated with exposure to continuous, intermittent, or impulsive noise is reviewed.

COMMUNITY RESPONSE/COMPATIBLE LAND USE

COMMUNITY RESPONSE TO AIRCRAFT NOISE
R. C. Casperson

A short account, for the general reader, of psychoacoustic and sociological research aimed at establishing acceptable noise standards - with particular reference to the special problems of aircraft noise.

The sensitivity of the human ear to acoustic signals and the subjective character of the response to noise is discussed. The historical evolution of subjective measures and the emergence of Effective Perceived Noise Level (EPNL) as a not altogether satisfactory compromise between conflicting data is reviewed. Sociological surveys establishing the relevance of subjective scales to community response are also discussed.

A well written short paper which could serve as a good introduction to the general topic of subjective response to aircraft noise.

AIRPORT NOISE: AN ENVIRONMENTAL PROBLEM
J. O. Powers,

A short non-technical discussion of airport noise from the point of view of a federal regulating agency.

In the introductory remarks on growing environmental degradation due to airport noise it is estimated that about 14 million Americans could significantly benefit from application of current acoustic technology. An abbreviated account of the Noise Exposure Forecast technique follows. Due recognition is given to the fundamental importance of acoustic environment in STOLport location.

The main areas of noise control are delineated as control at the source, control of the transmission path, and received control. Control at the source involves use of jet suppressors, nacelle
linings, and the like in order to comply with (existing or future) noise certification criteria. Noise transmission path can be controlled by noise abatement regulations, while receiver control results from community land use planning.

Economic aspects of airport noise are briefly taken up. The costs are identified as psychic costs, litigation, property devaluation, physical damage, and the like in order to comply with (existing or future) noise certification criteria. Noise transmission path can be controlled by noise abatement regulations, while receiver control results from community land use planning.

A STUDY OF THE OPTIMUM USE OF LAND EXPOSED TO AIRCRAFT LANDING AND TAKEOFF NOISE
Anon.
NASA CR-410, 1966

The study examines the alleviation of aircraft noise from the point of view of the receiver; that is, through community planning and interception of the sound by structures. Considerable discussion centres around administrative and legal aspects pertinent to the United States. The indicated conflicts between many government agencies with various levels of authority is not, however, restricted to that country.

Interior sound levels acceptable for various activities are suggested. Detailed tables listing the sound transmission characteristics of different building materials are included. Ways of modifying the acoustic properties of buildings and relative cost of such modifications are discussed. Categories of land use most compatible with high noise levels are suggested. Finally, the suggested noise control techniques are applied to a hypothetical community as illustration of a comprehensive attack on a particular airport noise situation.

A number of useful generalizations can be extracted. For instance, it is suggested that in areas exposed to less than 100 PNdB the interior noise level can be reduced by up to 10 dB through structural modifications; in areas exposed to noise greater than 110 PNdB major reconstruction would be required to produce a bearable interior environment. A figure of one percent of the cost of the basic structure per dB is the suggested price of noise reduction in buildings.

The section on acoustical control in structures (with associated tables) is particularly relevant to airports in Canada; insulation against cold also being insulation against noise. As an example, with use of effective storm windows the outside noise level can be approximately 2 dB higher for the same interior annoyance.

On the whole this report represents a very comprehensive discussion of the title subject. Some of the details such as dollar values of building materials or the suggested method of calculating noise exposure contours naturally need updating.

THE STOLPORT AND ITS ENVIRONMENT
G. L. Buley
Conference on STOL Transport Aircraft Noise Certification, held in Washington, D. C. January 30, 1969
FAA-No-69-1 (also N69-21726) pp. 73-81

The author, representing FAA Airport Service, states that 'the importance of aircraft noise in relation to the siting of a STOLport cannot be over-emphasized', stressing the relationship of the STOLport to its total environment.

In the context of the present study, the chief point emerging from this paper is the faith implicitly expressed in NEF (Noise Exposure Forecast) Methodology.

AERONAUTICS AND THE COMMUNITY
W. E. Downes, Jr.
AIAA Paper No. 69-1090, 1969

This short paper gives a brief account of the decline of Chicago's Midway Airport from the world's busiest prior to 1959 to a 'ghost airport' by 1967. Since then the airport has been re-activated and is currently on the way to becoming a major airport once more.

The story is an interesting one offering some insight into the role of public relations in the airport noise controversy. The eventual complete transfer of service from Midway to O'Hare airport resulted from the inability of the then newly introduced 707's and DC8's to operate from Midway's short runways. When in 1962 the City of Chicago announced a program to re-activate Midway great public debate flared up. On one hand, business and industry favoured re-activation; on the other, organizations of home owners were vocally against it. Eventually it seems that the majority of the community came around to be in favour of re-activation.

The conclusion of the author (Commissioner of Aviation, City of Chicago Department of Aviation) is worth quoting in full:
"In conclusion our observation regarding similar situations in other areas is that giving the people the right to complain and reasoning with them why remedial steps are necessary they become more reasonable to deal with. As a result and despite their previous objections to jet operations at Midway Airport, the Department has not received a single complaint during the eighteen months it has been in operation."

LAND USE PLANNING RELATING TO AIRCRAFT NOISE
Bolt Beranek and Newman, Incorporated
AD 615015, 1964

This was an interim report: much of the technical information and many procedural details have been superseded by the more recent material presented elsewhere in this bibliography.

ECONOMIC AND LEGAL ASPECTS

SOME ECONOMIC ASPECTS OF THE AIRCRAFT NOISE PROBLEM
G. P. Hunter
Conference on STOL Transport Aircraft Noise Certification, held in Washington D. C., January 30, 1969
FAA-No.69-1 (also N69-21726) pp. 144-155

In this unusual and well developed paper the senior economist of the FAA office of Noise Abatement comes to grips with the economic realities of the airport noise debate. He presents, in a general way, his (and presumably FAA's) views on the economic nature of this serious problem; economic objectives of government intervention; economic criteria for establishing levels of regulation; the rationale which should be used to determine who pays for noise alleviation.

If the prices of some goods do not reflect their actual production costs more resources are devoted to their production than would otherwise be the case; economic efficiency is not achieved. That is, 'the Nation's scarce resources are not allocated to their most productive use'. Airport noise is described as an 'external' cost which, in the interest of economic efficiency, should be reflected in the service provided by the air transport industry.

A conflict between the air transport industry and residents near airports arises as a result of the external cost of noise. Hunter feels that government intervention is warranted when the cost is in some sense serious and the groups in conflict are incapable of reaching agreement. 'The equitable approach for government is to consider both sets of costs...and to choose courses of remedial and preventative action to equate the marginal costs and reduce the total costs to a minimum'.

It is possible to base noise standards (or goals for noise reduction) on classical economic analysis. This involves finding the noise exposure level at which the marginal cost of control just balances the marginal cost of the noise. That is, where every dollar spent on noise control reduces the cost created by the noise by an equal amount. Admittedly, the cost of the noise, which is largely indirect, is very tricky to estimate. Nevertheless, Hunter feels that the attempt should be made. If nothing else, a clarification of issues will result from an effort to identify and quantify the noise costs.

In the interest of both economic efficiency and equity Hunter concludes that the net costs of alleviating aircraft noise should be borne ultimately by air travellers and shippers.

ALLOCATING THE COSTS OF ALLEVIATING SUBSONIC JET AIRCRAFT NOISE
P. K. Dygert
U.S. Defense Documentation Center
AD 698-748, February 1967

This paper explores the subtle economic relationships and public policy issues affecting the allocation of costs of the alleviation of conventional aircraft noise. (The word 'jet' in the title serves as a reminder that noise around airports emerged as a serious problem as this type of aircraft came into widespread use). The discussion provides background essential to an appreciation of the complex social and economic trade-offs, conflicts between public and private goals, and conflicting interests of different segments of the public having relevance to the problem of airport noise cost allocation.

In transferring the discussion to STOL operations it must be recognized that the overall social benefit of air transport, a generally accepted truism, does not necessarily extend to new forms such as STOL. Despite differences in government structure, the main arguments advanced apply also in Canadian context.
LAND VALUES NEAR AIRPORTS
H. O. Walther

An airport's influence on the value of nearby real estate exerts considerable influence on the attitude of local residents towards that airport. In one view noise and fear of crashes tend to depress property values near airports. An opposing view has it that property values tend, in fact, to rise more rapidly near airports than elsewhere in an urban community. This paper reports on studies of real estate transactions showing conclusively that in a large number of American cities airports had no adverse effects on the market values of surrounding real estate during the past two decades.

The conclusion represents valuable factual evidence even though the author's condescending manner ('They will accept the annoyance caused by noise and fear as a part of our way of life, and part of the price of progress') is considered by this reviewer to be hopelessly out of touch with present trends.

OPERATIONAL PROCEDURES

NOISE AND THE DESIGN OF AIRPORTS
E. J. Richards

Official regulations controlling aircraft noise dates back to the introduction of the Boeing 707 at Kennedy Airport (then Idlewild). To quell the outcry from a small community, Jamaica Bay, about 4 miles past the lift-off point, a rule was passed restricting the noise at a particular monitoring point at the edge of town. Since the aircraft flew over the sea immediately after passing by, the noise requirement could be met by throttling back the engines just before overflying the monitoring point. Similar noise abatement techniques were subsequently introduced at other airports without regard for differences in surrounding population patterns. It is now realized that the loss of climb rate resulting from the power cut back can greatly extend the total nuisance through exposing a greater total number of people to the lessened noise.

How can the noise nuisance be quantized? In this very readable paper Prof. Richards discusses methods of estimating total community annoyance. He points out that the proportion of population expressing a stated level of annoyance correlates well with the computed Noise Number Index or NNI. (It is similar to the Noise Exposure Forecast (NEF) favoured on this continent, with somewhat greater weighing attached to number of exposures.) A relationship between NNI and proportion of people annoyed can be extracted from sociological surveys; thus the total number of people annoyed by a particular pattern of flights can be estimated using NNI (or NEF) contours and demographic data. Examples showing how reorientation of runways and change in flight paths can alter the total annoyance are given, with reference to specific airports in Britain.

Richards estimates an average noise reduction of 1 dB/aircraft will be necessary each year to compensate for increased traffic if present annoyance levels are not to be exceeded. He cites encouraging trends in engine design but mentions a tendency to work up to prescribed limits (which he considers generous) if these are set once and for all. Airport planners are urged to accept the need for noise regulations just as aircraft manufacturers have already.

The discussion centres around conventional airports in England with high surrounding population densities. The relevance to proposed STOLports in this country is obvious.

TECHNIQUE FOR CALCULATING OPTIMUM TAKEOFF AND CLIMBOUT TRAJECTORIES FOR NOISE ABATEMENT
H. Eizberger, H. Q. Lee
NASA TN D-5182, May 1969

An analytic procedure to determine optimum noise abatement takeoff trajectories is described. A dynamic programming algorithm is used to find the control settings (and hence trajectories) to minimize some preselected criterion of noisiness (i.e. average perceived noise level over the ground track).

Essentially, the computation determines the trade-offs between thrust, altitude, airspeed, and duration for least noise annoyance. These trade-offs are discussed by means of example computations for a typical large jet transport. It is shown, for example, that maximum altitude at the beginning of the noise sensitive area is not necessarily optimum. Optimum trajectories may trade lower altitude for steeper climb or greater thrust reduction.
The importance of this paper to the STOL study lies in the new application of optimum control theory. The actual noise criteria associated with particular aircraft or trajectories can be adjusted in obvious ways to encompass V/STOL applications.

(A shorter version of this paper may be found as Paper No. 27 in NASA SP-189, 1968.)

TWO METHODS OF EVALUATING CLIMBOUT NOISE
W. L. Copeland
NASA SP-189, Paper No. 25
PP. 369-376, 1968

This paper briefly describes some experiments showing how noise levels associated with various departure techniques can be established from flight test data without need for repeated takeoffs and landings.

Perceived noise levels were calculated from acoustic data measured by an array of stations on the ground track line for a jet aircraft taking off and climbing out at different rates, with and without power cut backs. Acoustic data were also obtained while the aircraft flew over the stations at various altitudes and various configurations but without landing in between. It was shown that the first set of measurements could be accurately synthesized from the second. The technique may be useful for rapidly verifying the noise characteristics of STOL aircraft.

EFFECTS OF NOISE ON COMMERCIAL V/STOL AIRCRAFT DESIGN AND OPERATION
H. Sternfeld Jr., E. G. Hinterkeuser
AIAA Paper 68-1137, October 1968

The title is misleading. This paper summarizes the results of experiments using a panel of listeners to subjectively evaluate synthesized aircraft noise. A more complete write up may be found in another paper by the same authors (NASA CR-1118, 1968) reviewed in this bibliography.

NOISE CONSIDERATIONS IN THE DESIGN AND OPERATION OF V/STOL AIRCRAFT
D. J. Maglieri, D. A. Hilton, and H. H. Hubbard
NASA TN D-736, April 1961

Noise characteristics of several V/STOL propulsion systems and configurations are indicated in a sketchy way. The data of this paper are given in PNdB; it is to be noted that subsequent developments (c.f. other papers in this bibliography) indicate that corrections should be applied for pure tones, time duration and doppler shift. Nevertheless, this paper contains valuable information to aid in preliminary assessment of STOL noise problems: for example a rough estimate of blade loading or tip Mach number effects on the noise radiated by a propeller; or the effect of climb angle on ground noise contours.

REGULATION AND CERTIFICATION

NOISE STANDARDS: AIRCRAFT TYPE CERTIFICATION
Anon.
Advance copy pending issuance of New Part 36 of U.S. Federal Aviation Regulations, November 1969

This document describes in detail the standards and procedures adopted by the U.S. Federal Aviation Agency for noise certification of subsonic transport aircraft: measurement procedures, instruments, data reduction, corrections for atmospheric conditions and flight path deviations, validation of the measurements, sample size and so on. It is noted that with respect to foreign aircraft there is no distinction between airworthiness and aircraft noise standards.

At the present time STOL aircraft would have to be certified for noise under these regulations. New regulations currently being drawn up specifically for STOL types will however follow the same pattern with different noise values and distances (this information was verified by FAA in a private communication). Previous experience indicates that the FAA regulations will almost certainly be sanctioned by ICAO; if so, Canada will follow suit according to a high ranking DOT official.

Besides the obvious implication of this document as the first official aircraft noise regulation in existance, the extensive introduction is very relevant to an appreciation of the federal role in control of aircraft noise. In this section an attempt is made to justify the rules and to meet criticisms that were leveled after the initial notice of proposed rule making.

According to American law the FAA was required to consider 'economic' reasonableness and technological practical ability' in formulating the noise regulations. Attention is drawn to this limitation time and time again in rebutting criticisms charging that the
proposed standards were not stiff enough. It is stressed that compliance with these regulations must not be construed as an endorsement of the acceptability of the aircraft from a noise standpoint. Responsibility for determining permissible noise levels for aircraft using an airport is to remain with the proprietor of that airport. Since in Canada the federal government owns all major airports, the opportunity for federally controlling aircraft noise in Canada is much greater than it is in the U.S.

NOISE EVALUATION FOR CERTIFICATION

W. C. Sperry
Conference on STOL Transport Aircraft Noise Certification, held in Washington D. C., January 30, 1969
FAA No. 69-1 (also N69-21726) pp. 86-103

Fundamental to any procedure for certification of aircraft noise is the evaluation measure upon which criteria are based. The forthcoming United States Federal Aviation Agency regulations will be based on the Noise Exposure Forecast (NEF) methodology using Effective Perceived Noise Level (EPNL) as the primary element. The steps in calculation of EPNL and NEF are reviewed in this paper.

It is recognized that EPNL is not universally accepted as the best measure of subjective reaction to the noise of STOL aircraft. In defence it is pointed out that the EPNL concept is flexible: the implication being that modifications or refinements will be incorporated in the future as experience dictates.

STOL NOISE ABATEMENT OPERATIONAL CONSIDERATIONS

A. P. Betti, P. D. Wilburn
Conference on STOL Transport Aircraft Noise Certification, held in Washington D. C., January 30, 1969
FAA No.69-1 (also N69-21726) pp 67-71

The authors, associated with the FAA Flight Standards Service, express the opinion that the success or failure of STOL operations will critically depend on public acceptance of the aircraft. As illustration of the seriousness of noise considerations, they cite the curtailment of New York Airways' schedule from the Pan Am roof as direct consequence of complaints.

In the authors' opinion, noise is best controlled through basic design rather than operational considerations. Nevertheless, recognizing the value of noise abatement procedures for all aircraft, they discuss the special advantages of STOL. Generally they feel that the increased manoeuvrability can be used to advantage in lessening or eliminating the noise in critical areas.

FAA ISSUES AIRCRAFT NOISE-REDUCTION RULE

H. Taylor
American Aviation, January 20, 1969, p.25

This short article summarizes the noise reduction standards for subsonic transport aircraft which were proposed by the U.S. Federal Aviation Agency. The intention of FAA to apply similar regulations to STOL aircraft is indicated explicitly.

The information given should satisfy most purposes: the official document is 'Noise Standards: A/C Type Certification FAA, DOT Notice of Proposed Rule Making, 14 CFR, Parts 21 and 36, Docket No. 9337; Notice 69-1, January 11, 1969.'

AMERICAN AIRLINES AND THE NOISE PROBLEM

F. W. Kolk et al
Canadian Aeronautics and Space Journal Vol.15, No. 6, June 1969, pp. 215-220

The written version of a paper presented at the 1968 Montreal Aerospace Exposition, this article describes an airline's view of the problem of alleviating the noise nuisance around airports. Consideration is given to the effect of prospective V/STOL operations.

It is suggested that many of the V/STOL concepts which are promising from the economic or operational point of view may generate unacceptable noise levels. It is recommended that priority be given to setting noise certification standards so as to avoid wasting time on unsuitable designs.

In the author's opinion 'tilt-wing turboprop and lift-jet V/STOL aircraft have noise levels much too high for city-centre operation, and will have for many years to come.' Lift fans are thought to show promise. It is felt that research should determine quickly whether acceptable noise levels can be obtained using this type of power plant; if not, effort should be concentrated on rotary wing types.

THE EFFECT OF NOISE REGULATIONS ON VTOL AIRCRAFT OF THE FUTURE

R. H. Spencer
Verti Flite Vol. 14, No. 10, October 1968

A brief 'popular' discussion of some of
the noise problems to be faced before practical VTOL short-haul systems can be realized.

A short historical review of the growth of noise regulations for first operation and then certification of fixed wing aircraft is followed by prediction of similar but more stringent regulations for VTOL. The sources of VTOL noise (powerplant, propellers, fans, blade slap) are outlined. Current thinking on noise control through design and operations are mentioned.

AIRCRAFT AND HARDWARE

AIRCRAFT AND HARDWARE

NOISE STUDY OF TRANSPORT DESIGNS
W. H. Deckert
Conference on STOL Transport Aircraft Noise Certification, held in Washington D. C., January 30, 1969
FAA No. 69-1 (also N69-21726), p. 5-23

Noise characteristics obtained during the course of several NASA sponsored STOL design studies are discussed. The aircraft types were tilt-wing turboprop, fan-in-wing V/STOL, fan-in-wing STOL, jet flap, and cruise fan STOL.

Several points illustrating the need for caution emerge. For example, the lift fan design which is noisiest at distances closer than about 1,000 feet is about 15 dB quieter than prop and rotorcraft at a distance of 8,000 feet due to preferential attenuation of its predominantly high frequency noise. Other examples concern the noise reduction of particular components. In one case a reduction of 200 feet/sec in propeller tip speed produced no appreciable noise reduction due to an accompanying increase in engine noise.

It was concluded that the best approach for noise reduction is to apply noise reducing techniques to the source.

PROPELLER RESEARCH GAINS EMPHASIS
M. L. Yaffee
Aviation Week & Space Technology
November 24, 1969, p. 56

A feature article on Hamilton Standard research on quieter propellers. The material is essentially that found in AIAA Paper 69-1038 by Rosen and Rohrbach (reviewed in this bibliography).

The opinion is expressed that it will not be economical to achieve the full noise reduction potential for commercial applications. It is thought, however, that perceived noise levels of below 90 dB at the 500 foot sideline can be achieved with reasonable economics.

NOISE REDUCTION TECHNIQUES FOR PROPELLERS AND ENGINES
D. J. Maglieri, J. L. Crigler and H. H. Hubbard
Conference on STOL Transport Aircraft Noise Certification held in Washington D. C., January 30, 1969
FAA No. 69-1 (also N69-21726) pp 120-142

A preceding paper of the same conference dealt with noise characteristics of propellers and engines. This paper concerns methods of reducing this noise.

Several types of exhaust mufflers for reciprocating engines are described and sample performance curves are given. For low frequencies (below 700 cps, say) resonator or expansion chamber types are most effective; for higher frequencies a lined duct type is suggested.

Propeller noise depends mainly on velocity (rotational and forward), geometry, and loading. Generally, reduced noise is associated with slower tip speed or more blades. The authors express the opinion that tip speeds will have to be restricted in order to ensure acceptable limits for the cruise speed noise.

Reduced noise from gas turbine engines may be achieved by increasing bypass ratio, vane-blade spacing, or inlet guide vane Mach number. Acoustic treatment inside the engine nacelles is also considered effective.

Jet mixing noise, external to the engine, is suggested to represent the base level below which reduction of other noise sources becomes unprofitable. It is pointed out that exhaust suppressors might be useful even on high bypass engines in some cases. Attention is also drawn to the noise reduction potential of jet flap configurations.

SOME DEVELOPMENTS IN NOISE REDUCTION IN DUCTED PROPELLERS AND FANS
D. H. Hickey
Conference on STOL Transport Aircraft Noise Certification, held in Washington D. C., January 30, 1969
FAA No. 69-1 (also N69-21726) pp 104-108

The characteristics of noise generated by ducted propellers and fans were discussed by the author in a preceding paper of the same conference. In this one he discusses possible methods of
reducing the noise. The initial warning about possible penalties in performance and weight should always be kept in mind.

It is suggested that if rotational noise and stage interactions were eliminated, the remaining jet and vortex noises would probably prove acceptable. The conventional techniques of varying tip speed and geometry are discussed more fully in other reports (e.g., NASA CR-1493 by Benzakein and Volk). More unusual methods such as using a serrated leading edge to simulate an owl's wing are also mentioned.

A potential noise reduction of 10-15 PNdB is believed possible using only conventional means. Such a reduction would make the ducted fan noise level comparable with that of conventional helicopters.

CHARACTERISTICS OF NOISE GENERATED BY DUCTED PROPELLERS AND FANS
D. H. Hickey
Conference on STOL Transport Aircraft Noise Certification, held in Washington, D. C. January 30, 1969
FAA No. 69-1 (also N69-21726) pp. 46-66

Ducted propellers operate at low pressure ratios, (less than 1.03, say), have few blades, and are meant for relatively low cruise speed applications. Because stators are generally not required, the dominant noise sources are rotational and vortex shedding. On the other hand, the term ducted fan usually designates many bladed configurations operating at relatively high pressure ratios (up to 1.5, say). Cruise speeds up to Mach 0.9 are possible but stators become mandatory so that rotor-stator interaction emerges as a principal noise source.

This paper illustrates the two types, showing spectra and directivities. Results from tests of a large scale lift fan model tending to validate prediction methods are also shown. As an aside, rotary wing noise sources are also mentioned.

CHARACTERISTICS OF NOISE GENERATED BY PROPELLERS AND ENGINES
H. H. Hubbard, D. J. Maglieri
Conference on STOL Transport Aircraft Noise Certification, held in Washington, D. C. January 30, 1969
FAA No. 69-1 (also N69-21726) pp. 25-43

Experience indicates that the dominant noise sources in STOL vehicles will be the propulsion units. This paper briefly describes the main characteristics of the noise from propellers and jet or reciprocating engines. Typical spectra and time histories are indicated.

The figures clearly illustrate the advantage of the gas turbine over the reciprocating engine: elimination of firing frequency noises. Another figure illustrates the very distinct difference in ground noise levels for vertical and horizontal propellers.

A good introduction to the qualitative features of the title topic.
given for ground run up, takeoff, hover, landing. Comparison with calculations is very encouraging in view of the difficulty of estimating such effects as shielding and ground reflections. The actual calculation methods are not discussed but it is implied that standard techniques were used.

Noise reductions due to improved engines incorporating mixing nozzles are estimated. It is concluded that V/STOL noise could be comparable to that of conventional aircraft of the same weight (despite the much higher installed thrust) due to more flexible flight path control.

The measured data provide useful information about a complete configuration. The general tone of this paper is perhaps overly optimistic with respect to both possible reductions and acceptable levels for this type of aircraft.

ASSessment AND DEVELOPMENT OF METHODS OF ACOUSTIC PERFORMANCE FOR JET NOISE SUPPRESSION
D. Middleton, P. J. F. Clark
University of Toronto
Institute for Aerospace Studies
TN 134, 1969

The development of jet noise suppressors has been largely ad hoc. No completely satisfactory theory exists for the prediction of noise reduction due to special exhaust nozzle configurations (i.e., corrugations, multiple tubes); however, a number of crude estimation methods based on dimensional reasoning and/or empirical relationships have emerged in the literature. These methods are reviewed in this report. Some of the shortcomings and inconsistencies are pointed out.

Based on the review of suggested methods, the most consistent method for prediction of the muffling of subsonic jets due to axi-symmetric suppressors is suggested. Both spectral density and directivity are considered. The method is applied with reasonable success to measurements reported in the literature.

This report will be more useful as an introduction to the background literature and theory than as source of a method of prediction.

LAX STUDIES HOUSE INSULATION AS WAY TO DECREASE JET NOISE
F. S. Hunter
American Aviation, September 12, 1968,p.25

This single page article draws attention to two noise abatement programs studied at Los Angeles International Airport (LAX).

With regard to noise insulation of houses a cost of U.S. $1.50 - $2.00 per square foot is mentioned for insulating new buildings; for existing ones the cost is expected to triple. The cost should be somewhat less in Canada due to the usual inclusion of insulation against cold.

It is also reported that a fiberglass shield was found to successfully muzzle engine noises during ground run up, although some problems were experienced with vibrations induced in the airframe and build up of exhaust gases. Such a device could prove beneficial in STOLport applications.
A STUDY OF PROPELLER NOISE RESEARCH
Anon.
Hamilton Standard Division,
United Aircraft, Windsor Locks Conn.,
SP 67184 Revision A, November 8, 1967

A review of literature on propeller noise: theoretical and empirical prediction methods; model and full-scale test data.

It was concluded that at the time of writing none of the known theoretical methods could accurately predict measured noise levels under all operating conditions. Deficiencies were noted in understanding the noise generating mechanisms and blade loading distributions.

Empirically based methods are said to give ± 3 dB accuracy. An empirical procedure for both near and far field noise (excluding vortex noise) is given. It is recognized that the procedure does not give the necessary insight into the nature of the noise generation to allow rational design improvements to quieten future propellers. As a remedy, the direction future research should take is suggested. It is estimated that a 10 dB reduction of current propeller noise levels will be possible on future V/STOL aircraft without compromise in aerodynamic performance.

POLLUTION

JET AIRCRAFT: A GROWING POLLUTION SOURCE
R. E. George, et al
J. of the Air Pollution Control Association, Vol. 19, No. 11
November 1969, pp. 847-855

This article presents the results of extensive tests determining the kinds and quantities of air contaminants from jet aircraft engines. The tests giving the average per flight rates of emission of each contaminant are given for the most used commercial jet engines.

In addition to being a source of very useful quantitative data, this paper includes a valuable discussion of the dimension of the aircraft pollution problem. An extremely important point (relevant to STOL operations as well) concerns the fact that peak emission rates can be dangerously high even in spite of relatively low daily averages. Comparisons of total yearly emissions with other sources (e.g., power plants, automobiles) are considered specious.

Besides the conspicuously visible smoke, adverse effects resulting in a great number of 'bitter complaints' from residents under and adjacent to flight paths include nauseating odors, soiling effects, impaired visibility, and eye irritation.

To end on a bright note the paper also describes tests showing significant reduction of contaminants due to various additives to the fuel.

REDUCING JET POLLUTION BEFORE IT BECOMES SERIOUS
R. F. Sawyer
Astronautics & Aeronautics, Vol. 8, No. 4

This article is a slightly condensed (and perhaps more accessible) version of a previous paper by the same author (AIAA Paper No. 69-1040) reviewed separately.

PROBLEMS IN URBAN AIR POLLUTION
J. F. Griffiths
AIAA Paper 70-112
AIAA 8th Aerospace Sciences Meeting
New York, N.Y., January 19-21, 1970

A short introduction to problems of atmospheric pollution in urban areas (in contradistinction to rural areas).

Some recent data on pollutants in major world cities (all non-Canadian) is presented. The modifications to climate and effect on atmospheric pollution due to urbanization are briefly discussed.

FUNDAMENTAL PROCESSES CONTROLLING THE AIR POLLUTION EMISSIONS FROM TURBOJET ENGINES
R. F. Sawyer
AIAA Paper 69-1040, 1969

At present exhaust emissions from jet aircraft make only a minor contribution to overall air pollution in the United States. Increasing number of operations coupled with control of other sources will, however, tend to emphasize this contribution. This paper reviews, in clear language suitable for the general reader, the nature and production of the pollutants in jet exhausts.

Carbon monoxide and hydrocarbons are major contributors to pollution under idle conditions while nitric oxide and smoke dominate at higher loads. Model tests to determine the mechanisms of pollution formation are described. Possible methods of control of production of the major polluting species are
discussed in qualitative terms. It is concluded that design solutions appear possible which should keep jet engine air pollution from becoming a serious problem.

In the context of STOL operations, the discussion suggests (not explicitly) that the most serious potential pollutant would be exhaust smoke. While not considered a menace to health, the carbon particles in the smoke can reduce visibility and be deposited at ground level as well as be objectionable on aesthetic grounds. The closer proximity of STOLports to heavily populated areas could well emphasize the importance of these aspects. Ordinances which are usually restricted to the immediate area in conventional airports may also be more objectionable around STOLports.

JET AIRCRAFT AIR POLLUTANT PRODUCTION
AND DISPERSION
J. B. Heywood, L. H. Linden
AIAA Paper 70-115
AIAA 8th Aerospace Sciences Meeting
New York, N.Y., January 19-21, 1970

Discusses (i) production of the two major pollutants (nitric oxide and soot) in gas turbines, (ii) dispersion of these pollutants in the atmosphere.

Applicable to all turbine engines, but models are probably too simplified to be directly useful in practical situations. The paper does give a feel for the factors involved.

MATHEMATICAL THEORIES OF AIRCRAFT NOISE

THE NOISE OF AIRCRAFT
H. S. Ribner
University of Toronto
Institute for Aerospace Studies
UTIAS Review 24, 1964

The written version of the keynote address presented at the Fourth Congress of International Council of the Aeronautical Sciences (Paris 1964), this paper is a comprehensive review of the then existing state of knowledge of the noise generation processes associated with aircraft. The discussion reviews the fundamental features of flow noise and considers the principal aspects of combustion noise, propellers and rotors, jet noise, sonic boom, boundary layer noise.

While not directed at STOL noise in particular, this paper is an excellent background to the broad picture of noise generated by and around all air

traversing vehicles.
AIRCRAFT NOISE AND SONIC BOOM,
SELECTED REFERENCES
U.S. Federal Aviation Administration
Bibliographic List No. 13, 1966
(Updated in 1969, see U.S. Dept. of
Commerce AD-699915)

NOISE REDUCTION AND CONTROL;
ANNOTATED BIBLIOGRAPHY 1958-64.
Warren Springs Laboratory,
Great Britain
Report No. 4.2.2, 1966

PROPAGATION OF SOUND IN AIR: A
BIBLIOGRAPHY WITH ABSTRACTS 1929-1963
University of Michigan
Institute of Science and Technology, 1965

AN AEROSONICS BIBLIOGRAPHY
University of California Dept. of
Engineering, Report 63-51, 1963
Report 64-20, 1964 (Supplement No. 1)
Report 65-3, 1965 (Supplement No. 2)

AIRCRAFT NOISE AND ITS PROBLEMS
U.S. Federal Aviation Administration
Selected Bibliographic List No. 6, 1962

Textbooks

AIR POLLUTION CONTROL
M. Sittig
Noyes Publications, New York, 1969

NOISE AND MAN
W. Burns
Lippincot, Philadelphia, 1969

AIR POLLUTION: A COMPREHENSIVE TREATISE
A. C. Stern, Editor

THEORETICAL ACOUSTICS
P. M. Morse, K. U. Ingard

FUNDAMENTALS OF ACOUSTICS
E. L. Kinsler, A. R. Frey
John Wiley & Sons, New York, 1967

NOISE AND ACOUSTIC FATIGUE IN
AERONAUTICS
E. J. Richards, D. J. Meade
John Wiley & Sons, New York, 1965

NOISE REDUCTION
L. L. Beranek, Editor

HANDBOOK OF NOISE CONTROL
C. M. Harris
McGraw-Hill, New York, 1957

Headlines from Aviation Week & Space
Technology, 1968 - 1970

1970

May 25, p. 98
Advanced jet engine test-cell built

IV.21
The planned expansion of major airports could lead to a new type of air pollution problem. These giant jetports will be capable of handling annually a hundred million passengers and more than a million aircraft operations. The pollutants emitted by aircraft during landing, taxiing, and takeoff

GROWTH OF NOISINESS FOR TONES AND BANDS OF NOISE AT DIFFERENT FREQUENCIES
J. E. Parnell et al.
U.S. Dept. of Commerce
AD 633-904, December 1967

TECHNIQUE FOR DEVELOPING NOISE EXPOSURE FORECASTS
SAE Research Project Committee R 2.5
U.S. Federal Aviation Administration
FAA DS-67-14, August 1967

THE SUBJECTIVE BASIS FOR AIRCRAFT NOISE LIMITATION
D. W. Robinson
J. Royal Aero. Soc., No. 678, Vol. 71
pp. 396-400, June 1967

FREQUENCY SPECTRUM AND TIME DURATION DESCRIPTIONS OF AIRCRAFT FLYOVER NOISE SIGNALS
D. E. Bishop
U.S. Federal Aviation Administration
FAA DS-67-6, May 1967

AIRCRAFT NOISE - MITIGATING THE NUISANCE
E. J. Richards
Astronautics and Aeronautics
January 1967, pp. 34-45

ALLEVIGATION OF AIRCRAFT NOISE
N. E. Golovin
Astronautics and Aeronautics
January 1967, pp. 71-75

THE CONTRAINING ORDER OF AIRPORT NOISE
E. J. Richards
U. of Southampton, I.S.A.V.
Report No. 148, July 1966

REVIEW OF RESEARCH AND METHODS FOR MEASURING THE LOUDNESS AND NOISINESS OF COMPLEX SOUNDS
K. D. Kryter
NASA CR-422, April 1966

NOISE LITIGATION AT PUBLIC AIRPORTS
Toudel L. M. in 'Alleviation of Jet Aircraft Noise Near Airports'
U.S. Office of Science and Technology
March 1966

STUDY OF THE EFFECT OF DEPARTURE PROCEDURES ON THE NOISE PRODUCED BY JET TRANSPORT AIRCRAFT
W. J. Galloway, et al.
U.S. Department of Commerce
AD 617-766, March 1965

AIR POLLUTION FROM FUTURE GIANT JETPORTS
J. A. Fray
M.I.T. Fluid Mechanics Lab. Publication
No. 70-6, May 1970

The planned expansion of major airports could lead to a new type of air pollution problem. These giant jetports will be capable of handling annually a hundred million passengers and more than a million aircraft operations. The pollutants emitted by aircraft during landing, taxiing, and takeoff
will cause higher ambient levels than is now encountered at existing airports. Because aircraft arrive and depart in a generally upwind direction, the pollutants are deposited in a narrow corridor extending downwind of the airport. Vertical mixing in the turbulent atmosphere will not dilute such a trail, since the pollutants are distributed vertically during the landing and takeoff operations. As a consequence, airport pollution may persist twenty to forty miles downwind without much attenuation. Based on this simple meteorological model, calculations of the ambient levels of nitric oxide and particulates to be expected downwind of a giant jetport show them to be about equal to those in present urban environments. These calculations are based on measured emission rates from jet engines and estimates of aircraft performance and traffic for future jetports.

FOR THE REDUCTION OF AIRCRAFT NOISE-
NOISE CERTIFICATIONS PROGRAM FOR AIRCRAFT
Hans Achtnich
International Civil Aviation Organization
Special Meeting on Aircraft Noise

Discussion of a program which intends to use the required issuance of noise certifications as a means to limit aircraft noise to acceptable levels. Noise certifications as envisaged by a tripartite draft plan (U.S., U.K., and France) are considered. Legal questions in connection with the proposed noise certifications are examined. It is discussed which aircraft types should be subjected to the noise certifications program.

BUILDING VIBRATIONS DUE TO AIRCRAFT
NOISE AND SONIC-BOOM EXCITATION
Huey D. Carden, Donald S. Findley and William H. Mayes

Results of investigations of the vibration response characteristics of residential type structures to several types of aircraft flyover noise. These results are supplemented by forced point load excitation studies on the same buildings and by laboratory tests of individual components. Modal patterns, acceleration levels, and spectra are described along with noise transmission characteristics of the house structures. Also included is a typical example of a noise-induced rattle phenomenon associated with some internal house furnishings. Aircraft noise-induced building responses are correlated with those due to other common events.

TURBINE NOISE-ITS SIGNIFICANCE IN THE CIVIL AIRCRAFT NOISE PROBLEM
M. J. T. Smith, K. W. BusheII
American Society of Mechanical Engineers

It is shown that the presence of noise from the turbine of a turbojet or turbofan engine can be a significant contributor to the overall engine noise. Currently available information from both full-scale engines and model turbines is reviewed and correlated along lines following those previously developed for fans and compressors.

LOW-NOISE PROPULSION SYSTEMS FOR SUBSONIC TRANSPORTS
James J Kramer et al.

Brief review of the preliminary design studies that led to a definition of specifications for a low-noise output turbofan engine for use on long-range subsonic transport aircraft. Data on low-speed fans, with and without acoustic treatment in the fan ducting indicate that overall noise output of four-engine long-range transport aircraft can be reduced by 20 perceived noise decibels with appropriate fan design and by the use of nacelle acoustic treatment.

AIRCRAFT ENGINE NOISE AND THE SONIC BOOM AGARD Conference Proceedings, No. 42 May 1969

The noise of modern aircraft and the sonic boom of future supersonic carriers pose important problems. Considerable effort has been devoted in recent years to studying the generation, propagation and effects of aircraft engine noise and sonic boom, with the final aim of developing means to minimise them.

Of the thirty-four programmed papers, five were review papers devoted respectively to the physics of noise, some legal problems relating to sonic boom, airport design and operation for minimising exposure to noise, the effects of aircraft noise and sonic boom on ground structures, and human response to sonic booms. The remaining papers dealt with specialized aspects.
One valid point of view characterizes STOL vehicles as ordinary aircraft with superior performance in the airport vicinity. The lengthy runways of modern airports are a direct result of having progressively sacrificed field performance for other considerations during the evolution of modern transport aircraft. There is, in fact, a lesson to be learned from the realization that the conventional aircraft - all successful aircraft - of a previous period in the history of aviation were in every instance 'STOL' by present standards; this lesson is that we may expect pressures to develop to increase STOLport runway lengths just as happened in the case of CTOL decades ago. If we are not to reinvent CTOL, we must be prepared to resist such pressures.

Although opinions may differ on this point, the present writer cannot see any essential difference in flight cruise characteristics between turboprop STOL and turboprop CTOL, or between jet STOL and jet CTOL; for this reason, one might well wonder whether such adjuncts as area navigation between New York and Washington, for example, should not be equally applicable to STOL and to CTOL aircraft without discrimination (aside, perhaps, from the inhibiting effects of institutional restraints). In any event, a good deal of existing airport technology, at least, is as applicable to STOL as to CTOL, even though perhaps worked out with only the latter in mind.

For example, it is clear that the structural design of pavements will not depend upon how the critical design aircraft performs in respect of approach and climbout speeds and angles, but only upon that aircraft's weight, tire pressure, and wheel spacing factors. While it would be hoped that STOL aircraft might carry proportionately larger and softer tires than do most CTOL craft, the chances of this difference persisting for very long at major STOLports appear a bit dim in view of proposals such as that by Boeing to develop a jet STOL Model 751 capable of cruising at 550 mph with a 707-size load of passengers.

For somewhat analogous reasons, some VTOL information has at times been found rather pertinent to the present STOL technology study.

This being in general the situation, a great deal of literature exists which may be considered to have some relevance to STOL systems, at least as far as the ground facilities (chiefly the ports) are concerned. While not a great deal has been written specifically about STOLports per se as far as has been determined in this literature survey, there is a broad range of material to be studied on many topics, which must all contribute to the sum of our knowledge of the proper appreciation and eventual successful development of STOLport networks, entities and subsystems.

This is not to say that everything written about CTOLports and related topics, about VTOLports, or even about STOLports for that matter, is worth reading. A fair number of items have been altogether omitted from the listings hereunder because they did not seem worth including, frequently from the quality and/or relevance viewpoints. For this reason, all papers reviewed in writing in this section may be considered to have at least some significant bearing on the study in hand, even when given a low rating on the relevance scale used. (A further implication is that more literature has been surveyed than is represented hereunder.)

Certain items from the literature are of highly variable relevances under varying circumstances, a situation which is quite difficult to express with but a single relevance rating digit. For example, permafrost technology is highly relevant to arctic STOLports, although not necessarily to all 'northern' area STOLports as permafrost has its geographic limits, whereas it is entirely irrelevant to metropolitan STOLports, there being no particular prospect of the latter developing soon within Canada's permafrost regions. For reasons such as this, it has been considered worthwhile in most instances to discuss the relevance question briefly within the text of most literature reviews so as to allow the reader to appreciate readily the considerations leading to the assigned ratings. In many instances, it is quite conceivable, and eminently reasonable, that the reader will want to assume different ratings than the reviewer has done. The provision of fairly complete reviews should help the reader to do this, it is hoped; it should however be noted that no review of a few pages' length can even approach doing justice to a subject which an author has considered perhaps barely outlined in possibly 20 to 100 or more pages of his own writings.

It has at times been necessary to take issue with some of the contents of the works reviewed. It has been this reviewer's belief that he should use his experience in the field as the basis of discussion and at times criticism of the works reviewed. Admittedly, there is every reason to suppose that others might in turn wish to take issue with the
written with reference mainly, or frequently exclusively, to CTOL or VTOL. As was the case for the reviewed selections preceding this appendix, numerous papers hereunder were originally written with reference mainly, or frequently exclusively, to CTOL or VTOL. As has been noted, however, the technology discussed may in many areas be quite applicable to STOL.

Not all available (and discovered) CTOL and VTOL airport-related papers have been selected for inclusion, by any means. For example it has been assumed, rightly or wrongly, that STOL is very unlikely to carry massive amounts of air cargo à la CTOL. One compelling reason is the short range of STOL unless, of course, the concept of convertible STOL craft flying CTOL during off-peak hours should eventually develop into reality. Even if STOL freight should come into being, it is thought that any major freight terminal would have to be located off the central metropolitan STOLport, at least, and that quick loading and unloading methods involving containers and pallets will be employed to cut down on freight handling requirements at the aircraft apron. On the basis of these arguments, it has been assumed that reports and articles dealing with large, on-airport, CTOL oriented freight terminals are not appropriate to the current study.

Similarly, it is assumed that Canadian metropolitan STOLports will tend to be decentralized so as to bring the only advantage of STOL, greater port accessibility, to more of the user population; this being the case, reports dealing with massive ground access systems, e.g. for Kennedy International Airport, are not listed here.

Certain facets of the complete STOLport system seem to lack due coverage in the literature, perhaps because of some lack of glamour, and also possibly because confidential industrial information may sometimes be involved. It is to be hoped that this dearth of discussion will not result in such aspects being overlooked when STOLports are to be planned as total packages.

To cite an example, little seems to have been written about maintenance and storage hangars for aircraft, and even less about maintenance garages, anti-ice sand storage buildings and the like, whereby the STOLport would be kept in operable condition. Facilities such as these will have to be considered before, for instance, a STOLport can be fully studied from the land use, ground transport planning, or aero-dynamic modelling viewpoint.

Some planners have attempted to brush aside the aircraft maintenance, fuelling and storage questions by assuming that such functions will be carried out 'elsewhere', but it must be realized that somebody or other must take the responsibility to provide such support, and in fact perhaps all STOLports will have to do their shares. Furthermore, one can hardly expect to 'pass the buck' for the maintenance and operation of one's own STOLport to some other site located elsewhere down the line. Similarly, provision must be made at each STOLport for on-site firefighting and crash rescue adjuncts.

COMPREHENSIVE PLANNING AND GENERAL DISCUSSIONS

A REVIEW AND ANALYSIS OF STOL SYSTEMS TECHNOLOGY,
Aviation Planning and Research Division Report S-70-2, Civil Aviation Branch Department of Transport
Ottawa, April 1970

This aviation-oriented report is organized in five main sections, covering 'the air vehicle', 'V/STOLports', 'air traffic control systems', 'air navigation systems' and 'certification'. It is proposed here to review chiefly the 'V/STOLports' section, as other reviewers are expected to cover most of the other parts of the
treatment. All such partial reviews should probably be read together.

The report's own abstract reads as follows:

'The report attempts to provide a summary of technological developments in the STOL V/STOL and VTOL field so that trends may be identified and future requirements may be anticipated.

'A large number of STOL and VTOL research vehicles have been built and flown throughout the world. In Europe the tendency has been towards VTOL while in North America it has been more towards STOL. Of the large number of vehicles tested only a very few have continued into the production phase.

'The period up to 1974-75 will see the introduction of STOL aircraft types using presently-available and proven powerplants, essentially turboprop. These aircraft will provide the incentive for construction of STOLports close to towns and where possible downtown. During this period the navigation aid requirements for V/STOL service will be identified and the equipment developed.

'The second generation of STOL aircraft will be introduced in the second half of the decade. These will be faster and more profitable than the previous aircraft and it is probable that during this period fan-jet engined aircraft will be introduced.

'After 1980 there will be an emphasis toward shorter and shorter runway requirements with a gradual shift toward VTOL aircraft as the lift-to-weight ratios of fan-jet engines are improved.

'The FAA has produced an Interim Design Criteria* for Metropolitan STOLports and STOL runways. They have proposed a 1500' long strip with 150' runways. There does however appear to be a reasonable argument for a minimum runway length of 2000' for initial development of STOLports.

'Navigation systems are presently available which could be used to start IFR STOL service with some limitations on performance. Further development of area navigation equipment for enroute and terminal guidance and also improved approach aids such as scanning beam microwave will be required before Category II operations can be carried out.'

From the foregoing it is evident that the historical trends involved are considered important. Such trends form the basis of the report's Introduction, which reviews the rapid growth of aviation since World War II and the development of congestion in the system. Airport operators have in recent years borne disproportionate costs as aircraft have been designed to minimize their own operating costs and to optimize their cruise performance. Relief is provided by the reappearance of STOL (normal during the 1920's) and development of VTOL. An interesting de Havilland chart shows, as is also predicted by the gravity model, the heavy concentration of passenger trips on the shorter hauls, until below about 200 miles the competition of surface transport causes the chart to drop off rapidly. (The short haul is, of course, the domain of STOL which may eventually be expected to pick up extra traffic below the 200-mile range because of the expected better access to STOLports than to CTOLports.)

The Introduction goes on to outline current airline (Eastern and American) thinking on STOL.

Skipping to the V/STOLports section, it is immediately apparent that the discussion takes into account only, or basically, the possible applications connected with large cities, as just three general types of ports are mentioned, viz. those on major airports, those 'for downtown operations', and those in suburban locations. These types are first reviewed as to current limitations, e.g. in terms of IFR guidance at major airports and in terms of cost, compatibility and dimensional questions at downtown sites.

Next, a de Havilland Canada argument in favour of longer (about 2000') STOL runways, based on minimization of aircraft direct operating costs, is quoted at length, with 3 supporting graphs (see 'The Influence of Factored Airfield Performance of Less Than 2000 Feet on STOL Systems Economics'). Extensive quotations from FAA information looks further at STOLports and at VTOLports from the aviation viewpoint, but this material is generally summarized in the appropriate FAA Advisory Circular (see 'Planning and Design Criteria for Metropolitan STOLports'). De Havilland quoted cost estimates (not verified in this review) for STOLports, and other costing information are included next, followed by a brief bibliography. Information on non-aviation aspects is minimal, and cost estimates are necessarily very generalized (not site-related).
Technical design criteria occupy this AC’s Chapter 2, following a set of definitions at the close of Chapter 1. This information seems particularly relevant as it spells out the conditions under which a very important part of the total STOL system must operate. The material covered is too detailed to review meaningfully here, but it might be mentioned that, in addition to the list of criteria governing aircraft operating surfaces and aviation safety protection (‘zoning’) surfaces, Chapter 2 also discusses microwave ILS for STOL use, runway orientation, parallel STOL runways, STOL runways at existing airports, runway capacity, and area navigation, among other subjects.

Chapter 3, ‘Metropolitan Planning’, clearly makes the point that a system of metropolitan STOLports should be planned, with the timing of development of individual sites paralleling the projected shift of the short haul market from CTOL to STOL, and starting at an early time with those near principal generating centres. FAA is currently studying the U.S. market potential for STOL. Site investigations, potential configurations, airspace protection, land use and noise exposure are also covered in this chapter.

Chapter 4 is devoted to elevated STOLport structures, and Chapter 5 to visual aids. It remains to be seen how much of these chapters will be applied in Canada (the same of course goes for the other chapters as well), but at present Chapter 5 in particular seems quite relevant. Chapter 6 devotes two pages to the terminal area, and says rather little of practical value. Chapter 7 discusses the role of government, but this material is peculiar in application to the U.S.

Appendices include a bibliography as already mentioned, and further details on STOL runway length determination.

A GUIDE TO STOL TRANSPORTATION SYSTEM PLANNING
The de Havilland Aircraft of Canada, Ltd.
Downsview, Ontario, January 1970

This document has a strong promotional flavour, first for STOL in general as a civil transport system, and second for the DHC-6 and -7 STOL aircraft. The following quotation sets the document’s tone:

‘WHAT IS STOL?
Short Takeoff and Landing (STOL) airplanes are transport airplanes designed to operate from the short runways of a downtown STOLport. A STOL
transportation system can bring the comfort and convenience of modern air travel directly to the center of today's crowded cities. STOL aircraft are QUIET; quiet enough to be accepted in the central business district or suburban dormitory community.

Discussions and illustrations relate both to STOLports and DHC aircraft. Two photos have been heavily retouched to show (1) a somewhat improbable-looking, but according to a de Havilland spokesman FAA approved, elevated STOLport plan for Houston, Texas, and (2) an at least equally improbable at-grade STOLport along the downtown Manhattan shore. Figure 1 illustrates in plan view the 'basic elevated STOLport' concept according to de Havilland - e.g. with deck length of 2000' (compared with FAA's proposal for 1800' total length and a different placement of thresholds relative to deck ends), no taxiway facilities, aircraft (DHC-7's) parked with noses about 100' to 120' from the runway edge and tails apparently overhanding the building's edge -- and relates to the above mentioned Houston concept illustration, which portrays a solid type of building construction likely to create turbulence problems over the deck (compare discussion of 'Metropolitan Airports For V/STOL Aircraft'). Arrestor cable safety barriers are indicated at both ends of the elevated STOLport deck, but there is no indication of a practical and proved system to prevent aircraft going over the lateral deck edges, which lie 75' from the edges of the proposed 100' - wide runway; mention is made of 'fixed barriers on both sides, terminating near the ends of the landing surface', the terminal apron area being placed at one end of the complex to avoid creating a break in the side restraint barrier. If necessary, these barriers are intended to incorporate turning vanes to control airflow over the deck.

The peculiarity of providing no taxiways in the scheme seems to be related to the assumed provision of only two gate positions with ten-minute turn-around times during peak hours. Theoretically, this situation would produce a landing or takeoff every 2 1/2 minutes on average, in the simplest case (no touch-and-go operations, for example, and no accommodation of STOL corporate aircraft or of any other 'extraneous' traffic). Under this assumption, taxing on the runway could probably be allowed. The STOLport's imagined DHC-7-only peak hour capacity is on this basis given as 1,150 passengers (24 operation of 48-passenger aircraft carrying full loads). In practice, of course, only a fraction of this number of passengers would actually be handled, as 100% load factors cannot be maintained; hence the de Havilland claim that the arrangement could accommodate 2.28 million passengers annually lacks credibility. This being the case, the credibility of the economic argument for the scheme is also shaken.

A STOL system fare structure based on the relationship, $\text{Fare} = 6.00 + 7\frac{1}{2}$ per mile is recommended for feasibility study purposes. This formula is based on an examination of current short-haul fares, and not on any future amortization of system costs etc. An example heavily favouring STOL over CTOL is stated, but it assumes identical flight times and costs in the two instances, with access and processing times, as well as access costs, drastically reduced for STOL. This presentation thus shows all good and no bad for STOL as compared with CTOL.

Toward the document's end it also compares STOL with VTOL, to the former's advantage.

Owing to the subject matter treated, this document is considered relevant, but misgivings as to its objectivity reduce the relevance rating to 2.

PRINCIPLES OF STOLPORT OPERATION
The de Havilland Aircraft of Canada, Ltd.
Downsview, Ontario, November 1969

The paper's introductory paragraphs are as follows:

'This report presents statements on aircraft and STOLport characteristics and on operating conditions for safe, economical air transportation from elevated STOLports.

'Alterations to the standard practices of FAR 25 and 121 are minimal and are only those indicated by the inherent differences in operating on elevated STOLports as compared to conventional runways. The guiding principle throughout is that STOLport operations shall be at least as safe as conventional air transport operations.

'This presentation of aircraft and STOLport criteria and associated operating conditions can provide a basis for a general statement of guidelines for STOLport operations. We believe such guidelines would permit the

*From the viewpoint of persons concerned with comprehensive airport system complexes, only. See text.
introduction of STOL services based on today’s technology and would be consistent with the requirements of future generations of aircraft even though the latter may require a significant restatement of certification standards.

The report deals only with differences from current practices and proposals and is not intended to be a complete statement of certification and operating standards. We do intend, however, that it should serve as a basis for agreement in principle and thereby permit aircraft manufacturers and the air transport industry to evaluate the validity of aircraft proposed for STOL systems.

As may be gathered from the foregoing, this paper does not in fact deal to any significant extent with STOLport operation, but rather with aircraft and navaid operation, at and in the vicinity of STOLports. From the STOLport viewpoint, then, the discussion’s relevance is medium at best, since only one phase (the airside) of the airside-terminal interface - groundside total airport system is considered.

On the other hand, this paper will without doubt be considered highly relevant from the points of view of aviation and guidance systems interests. It seems unfortunate that the title could not have reflected this fact so as to attract the attention of those groups.

Airside STOLport layout aspects per se are discussed in 2 1/2 pages (double spaced) with essentially only one supporting drawing. The architect, airport engineer, or systems planner will find a very limited amount of useful information here; the traffic engineer will find none.

DEVELOPING A STOLPORT POLICY FOR THE CITY-CENTER
B.F.L. Darden, and M.I. Khan,
Canadian Aeronautics and Space Institute, Ottawa, 1969

This paper outlines the approach used to develop a STOLport policy for New York City. Its purpose is to provide a guide for urban planners who wish to take advantage of this new dimension in short haul traffic.

There is no pat formula for the immediate construction of a STOLport, and this paper does not attempt to offer a comprehensive blueprint. That function is better left to engineers and architects. Rather, this is a report on the methodology of policy formation.’ -- author’s introduction.

The main portion of the paper opens with a review of the standard reasons why STOL and V/STOL technology should be put to work in the short-haul market. Next, the investigation’s ‘Policy objective’ is stated, and here it will be noted that the stated objective is not to arrive at a policy (much less at a firm proposal), but only to carry out a study:

To determine the immediate and long-range requirements for STOL, VTOL and V/STOL systems in a metropolitan city-center...(The system) must be a small consumer of land...it should also have a navigation system compatible with existing systems...It is essential that it also be revenue producing...It cannot have an adverse effect on adjacent property...rather it should act as a ‘growth pole’ for other revenue-producing activities.

Subsequently, the paper lists factors which must be examined under ‘The Planning/Policy Making Analysis’, briefly outlines ‘Activity Forecast Methodology’, gives an example of statistical information, states a number of relevant assumptions about a STOLport (concept is illustrated) and aircraft, and then lists and in some cases comments on a number of further factors to be considered.

The author’s summary is as follows:

Time in transit can be subdivided into two parts; time in the vehicle and time spent between local origin or destination and the terminal. A V/STOL system will enable urban planners to significantly reduce or eliminate access times and at least to retain today’s block speeds. Demand will depend upon value of the traveller’s time, as well as convenience, reliability and frequency.

Surface access time and tie in with ground transport systems is essential in order to realize the benefits of the V/STOL system’s time savings.

Compatible land uses adjacent to a city-center facility are an absolute necessity to ensure political and community acceptance. Of particular concern is aircraft noise exposure.

Last, but extremely significant, is the coordinative process. The efforts of the urban planner must be carefully cross checked with pertinent governmental authorities, particularly in the area of air traffic control, obstruction clearance and zoning protection.
Potential operators must be brought in at every phase of the planning effort if the project is to be economically viable and attractive to investors."

This paper may be looked upon as a skeleton outline of 'how to do it' in approaching the planning of a local component of a STOL or V/STOL air transport system. The international, national and regional aspects are not dealt with in any detail; nor are safety standards and the like drawn out. The paper seems likely to be most useful as a checklist of questions to be examined within a certain limited scope and as a guide to the procedure of calculating aircraft turnaround times and a few other factors of planning, operational and economic significance.

Owing to the number of important matters this paper does not cover, its relevance is rated at level 2.

PLANNING STOL FACILITIES
L. Schaefer, (Port of New York Authority)
SAE Paper No. 690421, Presented at National Air Transportation Meeting New York, April 21-24, 1969
Society of Automotive Engineers

Author's abstract:

'This paper assumes the development of a Short Takeoff and Landing (STOL) commercial aircraft as an aid and a competitor to the Conventional Takeoff and Landing (CTOL) aircraft. It also assumes the development of an IFR navigation system which will permit STOL operations independent of and compatible with CTOL operations.

'The city center STOLport may have to be designed into an environment which creates additional challenge to the Airport Planner. Criteria has* to be applied to sites restricted by surrounding obstructions, developed communities, congested ground access systems, and a reluctance on the part of the community to accept an aviation facility because of noise, congestion, and safety.

'STOL aircraft can help ameliorate* airport capacity problems facing the nation today while offering the major segment of the short haul market better service. Care in site selection will certainly be a major factor in the success of the new mode of air travel.'

*(sic).

Author's conclusions:

'Many of the major cities of the country and certainly those of the Northeast Corridor, Boston-Washington, are adjacent to navigable waterways and contain major rail terminals and rail yards. All have the similar characteristics of congested city centers.

'The ideal STOLport location would be as close to city center as possible. In many instances, waterfront or rail terminal areas offer the ideal air rights areas for STOLports. Because of the desire to make any new facility self supporting, it is necessary to consider facilities ancillary to or unrelated to STOL to help defray the costs of acres of expensive elevated platforms to support a STOLport. Such companion facilities may doom the STOLport to defeat.

'It may be necessary to consider STOLport sites removed from city center in order to make the facility self supporting as well as compatible with its neighborhood.'

The body of this paper begins with an unusually concise review of the problems of CTOL as the reason for considering STOL, and then very briefly defines the latter. The involvement of the Port of New York Authority (PNYA) is then outlined. In 1956 their first heliport was constructed, although present thinking regards STOL as more promising in terms of relief of congestion. The congestion itself was forecast by PNYA as early as 1959. PNYA now hopes to see STOL aircraft of up to 120 passengers capacity and with enough speed to compete with CTOL with ranges up to 250 miles.

Basic considerations discussed are as follows:

(a) compatibility and complementarity re CTOL system;

(b) improved short-haul services through use of exclusive facilities, and more room for growth of CTOL for longer haul services;

(c) required length, strength, width and other such characteristics of elevated STOLports;

(d) interaction of STOL and CTOL, especially in IFR conditions;

(e) forecast traffic demand (NY area as an example, incidentally showing that several STOLports could be supported with several million annual passengers each) with locational factors;

(f) the implications of such demands in
terms of annual and hourly movements, gates, et al;

(g) wind direction and runway alignment (crosswind runways are assumed necessary);

(h) approaches and obstructions;

(i) aircraft noise;

(j) ground accessibility;

(k) convenience and site availability

The latter point leads into a comparison of at-grade and elevated STOLport schemes in which, however, the assumption is made that crosswind orientations are essential. This assumption does not now appear valid, and consequently this paper's further conclusions may well be invalid in many instances.

Lastly there are two short paragraphs on 'terminal design'.

Because mainly of the invalid assumption re runways, this paper cannot be given an unqualified relevance rating of 1.

CONSIDERATIONS OF AIRPORT PLANNING
TIME SPAN
Department of Transport
Air Services, Construction Engineering & Architectural Branch, Development Engineering Division,
Ottawa, September 1966

This research paper begins with the following outline of the problem to be considered, and of some fundamental relevant concepts:

'One of the most basic considerations in the planning of an enterprise is the selection of the proper planning time span. The question is, how far into the future should one look? Presumably as far as one can see, but this usually means something short of eternity so far as putting down cost and gain estimates is concerned. Suppose a temporary building were constructed to take care of the present needs and the replacement date by a more permanent structure was also known. It would then be a simple matter to determine the costs and benefits for this building. If the residual value at the end of the useful life of the building is determined, the investment analysis can be made fairly accurately. However, for the permanent structure, analysis is more difficult as a major decision regarding the useful life of the building is required. During this expected life, it could well become technically obsolescent and/or just too small. For these reasons, major reconstructions could be required, themselves necessitating further decisions on economic and technological time spans. The extent to which capacity in excess of requirements is to be provided remains primarily an economic problem. McKean discusses the adoption of a 'time horizon' or cut-off date. He defines it as the length of time over which costs and gains are estimated, and beyond which one could not see well enough for estimates to be worthwhile. Thus beyond some date, the gain from preparing hazy estimates is less than the cost. There may be other limits than the time horizon, however; these may be defined as 'planning boundaries' which may occur before the 'time horizon' becomes effective. We consider these planning boundaries to be inherent in the conditions of a particular site. The purpose of this paper, then, is to consider, if possible, the factors that make up the 'time horizon' and to indicate how critical 'planning boundaries' may be determined in individual cases.'

The objectives and requirements of the organization or endeavour for which planning is to be carried out must be kept in mind. In the case in point here, such objectives and requirements include safety, commercial viability and growth, public acceptance, and public service, among others.

The paper's next consideration is to explore the 'planning boundaries' concept. Physical obstructions to expansion in the forms of topography (e.g. a watercourse, or rough terrain) and cultural development (e.g. a highway, railway, building, or area of developed urban fabric) are most obvious, but there may also be foreseeable technological changes, as have been exemplified in airport history by the elimination of most fuelling stops through the development of long-range aircraft. Planning should be carried out as efficiently as possible within the planning boundary's confines, but in order to ensure continuity of service and development beyond these it is necessary also to work on parallel projects (symbolized by new airport sites) capable of taking over after further expansion of the original facility is stopped. Planning must be balanced for all parts of the system, for the ability to expand some will be of little avail where other parts are at their ultimately constraining limits. For example, it will be of no use to plan runway capacity increases beyond what can be supported by the ground access and terminal portions of the total system.
The need to amortize investments over the useful life of the facilities involved is an obvious economic requirement. The paper indicates what may be considered as suitable amortization periods for various fixed facility categories. It also provides a proposed flow chart for planning time span investigations. A certain flexibility of approach is promoted by the study. The paper's summary includes the following passages:

'It has been shown that a great number of factors must be considered in setting a time span for the planning of future airport facilities. Because of the large number of variables involved, it would be a mistake to restrict airport planning by an arbitrarily fixed number of years.

'Clearly, individual decisions must be made and based on the merits of individual cases. Tentative guidelines have, therefore, been proposed.

'In brief, the following factors are considered to enter the process of planning time span determination:

(a) Economics (through cost/benefit considerations and amortization)
(b) Technology (through the distance for which it is possible and necessary to plan ahead)
(c) Physical conditions (through the existence of planning restraints).

The study's potential for application to STOL as well as CTOLports is obvious.

The extensive and intensive report to be surveyed here is prefaced by the following conclusions:

'(1) A short haul air transportation system for the Northeast Corridor could be developed during the 1970-80 period for a total investment of the order of 0.5 billion dollars and operating at fare levels of the order of 5 cents per passenger mile over stage lengths around 100 miles.

'(2) This system would have an improved all-weather capability which would permit operations under 99.5% of expected weather conditions and would show a trip completion factor at least as good as present ground transportation systems.

'(3) The direct operating cost differentials between VTOL, STOL, and conventional short haul aircraft are not sufficient to be decisive in the choice of any particular vehicle type.

'(4) The indirect costs are, however, a dominant factor in determining choice of vehicle type and would indicate a preference for aircraft with a complete vertical takeoff and landing capability because of the greater convenience in siting and lesser terminal costs in city centers.'
exposed to the immediate presence of aircraft. A number of findings such as that 'The direct operating costs of all VTOL vehicles are better than 1980 conventional aircraft for distances less than 100 miles' (page I-5 for example) appears questionable, at least in its application to the Canadian scene. Even some of the curves and graphs might be questioned, as in the instance of Figure I-1 where an initial block time delay of 12 minutes is shown for STOL as against only 2 minutes for VTOL which could presumably be operating under virtually identical conditions.

The foregoing points are mainly within the competence of other reviewers to evaluate and criticize further; here we should concern ourselves more with the report's Part V, Ground Facilities. It may be immediately pointed out that, as far as STOL is concerned, the study is now known to have been on shaky ground in assuming that crossed runways would be essential to STOL (see Fig. V-2 and text at top of page V-36, for example) and that runway lengths might be 750', 1000' or 1500' (see top of page V-12). The study has concluded on this basis that 'STOL stops' will each require about 22 acres of land, whereas de Havilland, with carparks admittedly in decks below their operations deck, have estimated 12.4 acres for a Houston STOLport proposal which is said to have won FAA approval (c.f. 'A Guide to STOL Transportation System Planning'). This factor is one of several which has led MIT to favour VTOL over STOL for the Northeast Corridor application. The weighing of port development costs so as to help justify VTOL in the present report is close to an exact contradiction of the approach taken in The Influence of Factored Airfield Performance of Less Than 2000 Feet on STOL System Economics, in which de Havillard also used curves to argue, in effect, that the longer the runways the better, as their costs are only marginal in the total system's economics.

It is the reviewer's opinion that the foregoing remarks should be kept in mind for a balanced appreciation of the following conclusions to Part V:

'Small VTOL Airbus stops require 2 acres and can be easily distributed at appropriate points within the corridor at a small investment cost, most of which is recoverable should service be discontinued. The STOL stops will require about 22 acres, plus clear approach areas, and have a large investment sunk into small runways. It will not be easy to locate suitable sites, nor feasible to move sites elsewhere.'

'The STOL system indirect costs will be higher than the VTOL system due to the higher terminal costs, and the predominant effect of ground facilities costs on the indirect costs of very short haul air systems such as envisaged for the Northeast Corridor.'

The conclusions of other chapters are often of equal relevance from the ground facilities viewpoint. The following excerpts are taken from the conclusions to Part VII:

'For successful operation of any short haul passenger transportation system, low costs in terminal operations must be achieved. The U.S. Intercity Bus Carrier costs demonstrate the possible levels to which these costs can be reduced.

'An air system, with its more complex vehicle and terminals can approach the bus cost levels by adopting bus type operations where multi-stop, line haul service is provided between major terminals.'

In addition, Part VIII concluded in part as follows:

'The serious air traffic problems of fixed wing traffic* will cause extremely severe delays by 1980 unless more ILS instrument runways can be placed in operation within the Northeast Corridor. The VTOL Airbus system can alleviate present airport congestion by allowing the distribution of short haul air terminals within the city center and suburban areas, thereby reducing the short haul traffic at the Corridor airports.'

All in all, this report merits a rather high relevance rating despite its sometimes questionable assumptions and conclusions, if for no other reason than the study is such an influential one. On the other hand, it is not very authoritative in terms of today's STOL technology.

* i.e., of CTOL
STOL OPERATIONS
R. H. Whitby
World Airports - The Way Ahead
The Institution of Civil Engineers
London, 1969; with discussions.

This British paper is related to 'Means of Increasing Airport Capacity' and is somewhat more informative on STOL matters, including on STOLport location questions.

There is some orientation toward the special interests of the airlines, and hence away from the comprehensive or 'systems' approach. For example it is mentioned in the paper that, on a 200 mile sector, a delay of 30 minutes waiting takeoff and/or landing clearance will increase direct (aircraft) operating costs by 30% or total (airlines) costs by nearly 20%, without consideration of what the delay may cost the passengers. To clarify the latter point, if 50 passenger-hours were to be lost at $10.00 per hour (to take a pair of arbitrary figures purely for the sake of illustration), then the cost to the passengers would be $500 as a base figure, not to mention the costs of missed connections and appointments, etc.; the paper does not look at such facets of the problem.

FAA's interim STOLport design, and also FAA's comparison of CTOL, STOL and VTOL flight profiles and noise footprints are reproduced among this paper's illustrations. On the basis of CTOLport congestion as it now exists, STOL is proposed as a means of reducing (airline) costs but it is suggested that the intended impact would only be achieved with STOL aircraft of 100 seats or more. Additional STOL applications to feeder and regional services are mentioned, possibly 'without involving an airport' -- i.e. presumably without requiring terminal facilities, at the smaller regional towns. Another possibility is to interlink the airports of a single metropolitan region by STOL, possibly as an interim measure pending the development of better VTOL vehicles.

Using the CTOL picture as a base, the paper concludes that the potential STOL market in Britain and in continental Europe is not great (Sweden, however, is recalled to have shown considerable official interest in STOL a few years ago and in the case of Britain, one should realize that distances are relatively short, e.g. London - Bristol about 100 miles, London - Manchester about 160, Manchester - Liverpool about 25 to 30, scaled from a map, city centre to city centre. In Sweden, Stockholm - Göteborg is about 250 miles, Stockholm - Malmö is about 320, and Stockholm - Luleå is about 450. It would be somewhat surprising to find British domestic CTOL flourishing greatly except on a very few routes such as London - Glasgow, about 350 miles).

The paper also assumes that '...in London, much of the time is taken in getting clear of the city traffic congestion which would still have to be got through to a STOLport.' This remark suggests the author's evident, if perhaps temporary, fixation on STOL adjuncts to existing airports only, and ignores the possibility of city centre and other metropolitan area specialized STOLports. The author does mention, however, that the U.S. view is that STOL can be made marketable through enjoyment of superior access to 'the closer-in small airfields' which presumably would still not be true STOLports, but rather borrowed General Aviation sites.

The remainder of the paper reviews the STOL strips at La Guardia and examines the possibility of STOL at London Heathrow, drawing out some aviation implications of the latter.

The author puts forth further and slightly more interesting views in the Discussion section; for instance, he points out the possibility of STOL strips in towns, but he fails to suggest any details on them. He also suggests that STOL strips be built over existing carparks at CTOL airports, but otherwise, he makes no novel contributions. His conference presentation included the showing of a film, on which the proceedings give no information.

AIRPORTS FOR FUTURE AIRCRAFT - A PLANNING GUIDE
R. H. Callahan and R. F. Birk
Eastern Air Lines Inc.
Paper presented at AIAA Aircraft Design and Operations Meeting July 14-16
Los Angeles, California
American Institute of Aeronautics and Astronautics, New York, 1969

The author's abstract is as follows:
'The basic design criteria for airport facilities (airfield and structures) that served the aircraft of the '30's, '40's, '50's and '60's and housed activities related thereto, will not be appropriate for development of facilities to serve aircraft for the '70's, '80's and '90's. An entirely new unconstrained approach to the problem areas will determine the requirements for, and ground handling characteristics of the basic types (conventional jet, STOL, JUMBO and SST) of aircraft that
will largely comprise the fleet mix for the last quarter of the 20th century. These requirements and characteristics coupled with cost effectiveness of related facilities will be determinative of basic design criteria for development of such facilities and their priority of location. Implementation of this program of criteria and order of priority will result in facilities near the airport core that are functional and that permit maximized economy in aircraft ground handling operations.

'Other activities and related facilities will be remoted from the core in descending order of priority. These activities and related facilities will be unified by appropriate transportation sub-system elements, thereby creating an overall facility system that will be functional and economically feasible.'

Chief attention is directed toward ground facilities. The paper is not 'a planning guide' in the sense of constituting an official manual, but rather states one airline's view of airport development trends and what should be done about them.

The historic development of (CTOL) passenger terminal area concepts in the U.S. is first outlined. Trends culminated, by the time of writing, in facilities and proposals bearing cost estimates in the order of $500 million to $1 billion, with traumatic effects upon those required to provide the funds. Analysis showed that three specific airport projects would increase costs by more than 1000% and, according to the author, would be related to a traffic increase of only 200%.

The latter criticism may not be entirely fair; sufficient information is not provided to be at all sure on this point, but it seems quite possible that the traffic capacity of the airports in question was also to be increased by more than 1000%, possibly making up for capacity deficiencies which had already been allowed to develop, and/or providing for continued facility use far beyond the 1975 cutoff date for the 200% forecast traffic increase. The amortization periods involved may conceivably be quite long, and cannot properly be overlooked.

While over exhuberant planning with other people's money is not an unknown phenomenon, it is still possible in the cases in point that the proposals had been or would be properly justified through benefit/cost analysis. To discuss costs without also considering benefits is misleading; it obviously costs nothing to do nothing, but the related benefits will be zero or negative in most cases.

'To remedy the situation,' the authors opine, 'study and research should start with the airplane, its operating characteristics, the economics of its activities and the nature of its ground functions. After completion of such research, design criteria should be developed to insure appropriate facilities to accommodate the functional and economic operation of the aircraft.'

'...emphasis supplied. Attention must be focussed, they say, on minimizing aircraft ground time, on minimizing the economic impact (upon the airlines) of automobile access to the heart of the airport, and on developing long-life facilities having extended amortization periods.

Such precepts, presented in this paper from the airline viewpoint (and, one might add, from that of Canadian airlines only since a policy of having them pay for the facilities they require was instituted within the last few years), state only part of what the airport planner has, or at least should have, kept in mind throughout his work from the outset.

A preferred major CTOL airport and terminal area concept is outlined in the paper. The general layout is reminiscent of Dallas-Ft. Worth International, and has been arranged to minimize aircraft taxing time, seemingly with little regard to certain other factors such as land consumption. The terminal system concept contains elements of recognizable schemes such as those of Roissy-en-France (Paris Nord), and appears to call for rather numerous, and probably expensive, tunnels under loadbearing aircraft aprons.

Although STOL is occasionally and briefly mentioned in passing, the paper's relevance to a STOL technology study is fairly low.

AIRPORTS AND FACILITATION
(‘Les Aeroports et la ‘Facilitation’)
Jacques Block
(Aeroprt de Paris)
Icare. Summer 1969, pp. 98-104

M. Block has written several (or possibly 'many') reports and articles, in French, on aspects of airport systems planning. His style is always refreshing, and he has particularly earned this reviewer's respect for having been one of the first to point out the relationship of aviation markets and demographic factors to the rational laying out of a network or system of airports designed to meet the
requirements of those markets and factors.

Early in this amusingly illustrated article he stresses the importance of balanced systems planning of airports, and in so doing effectively refutes the concluding paragraph of 'Airport Problems In Flight Operations', as quoted elsewhere in this literature survey. In effect, he says, it is useless to enlarge airports if air-space congestion will prevent their full utilization, or equally if ground constraints should prevent passengers arriving at or departing from them. Immense capital investment requirements are foreseeable for the next five years, at least.

Despite increases in aircraft productivity, indirect costs will keep fares from falling. Air commerce will nevertheless increase, owing to continuing improvements in standards of living and of education (among other things). With an unstable relation of investments to receipts, aviation is in effect forced to continue expanding in order to survive. All elements concerned are in accord in this regard, be they manufacturers, airlines, airport authorities, or the city or economy served, itself; no element can afford to become the bottleneck which may strangle the entire complex. Each element must therefore resolve its own difficulties and meet the requirements of growing traffic.

Regarding airports, M. Block leaves aside in this article the more tangible or visible questions of building concepts and the like, and considers the less concrete question of procedures which can either facilitate or block air transport, depending upon how well they are conceived to meet requirements. If air transport is to become mass transport, it must certainly be considerably simplified. Taking a plane can never be quite like taking a train, as one cannot ride a plane standing up; in addition, railway stations are not of optimal comfort. Still, passengers, baggage and freight do need to be subjected to simpler and swifter formalities. Computer reservation systems could have more terminals than at present to avoid passenger queuing. In addition, computers being much faster than men, these machines could look after pre-flight documentation and allow acceptance of passengers right up to flight time. Such changes would be easier for short- and medium-haul, and especially for domestic services, than for long haul, international services.

The increase in aircraft capacity makes it possible to discontinue baggage weight limitations. On the other hand, this simplification will be accompanied by an increase in the number of articles to be handled, as larger aircraft are placed in service. Baggage containers will not solve the entire problem.

The article continues in this vein to examine departure and arrival formalities and what may be done about them. Generally, the discussion is keyed to the Boeing 747 and to international traffic. For this reason, a relevance rating of 3 is assigned, on the assumption that international STOL services, particularly with the carriage of freight, are not on the immediate horizon. Certainly, long-range STOL is not a foreseeable development at this time.

The Aeronautical Journal, Vol. 73, p.490
The Royal Aeronautical Society
London, June 1969

This paper looks mainly at the airline problems connected with airport congestion, aircraft performance and noise output, and runway bearing strength limitations. STOL comes into the picture as a palliative for the congestion problem.

While intra - metropolitan STOL services are recognized as a good means of feeding the CTOL airport despite ground transport congestion problems, they do nothing to alleviate air transport congestion and in fact may make the problem worse, especially as small aircraft of very limited capacity are employed. Study of the success of such services has, however, suggested to the airlines that inter - metropolitan STOL services could serve the public's real short-range travel needs. A new system of STOLports distributed to meet the needs of the population's distribution is suggested as a means of taking the pressure off the existing major airports.

During the next ten years, the major airlines are expected to become involved in (a) evaluation of STOL systems, (b) the initiation of trial services, (c) the development of 100-seat quiet STOL airliners and of STOLports and navigation systems, and (d), 'The eventual, but problematical, development of VTOL aeroplanes with the
competitive en route performance capabilities, economics, comfort and noise characteristics.'

The constructive attitude now being taken by at least the vanguard of the airlines industry is illustrated by a relevant paragraph from the paper’s conclusions:

'The needs of the public and the traffic congestion at major airports bring urgency to the development of Inter-Metropolitan STOL aircraft, STOLports and auxiliary systems for trunk carrier use. Major airlines will assume a position of leadership in this development and are now seeking the first hand experience needed to ensure an orderly evolution of the needed services.'

While a positive attitude toward STOL in general is important to the successful development of a system of this type, this paper contains no useful contribution in the form of technical knowledge, whence its low relevance rating.

Toward Aviation Growth: THE AIRPORT HANGUP
Herman Lowenhar
Space/Aeronautics, Vol. 51, May 1969 p.62

This survey-type article begins by outlining in somewhat lurid terms the U.S. ‘airways - airports mess’ of delays and spiralling costs owing, in general, to capacity inadequacies in various parts of the existing CTOL - terminal-ground transport system. It then goes on to discuss approaches being taken toward the solution of the problems now in existence.

Here, a wide range of subjects is touched on, a listing of major items being as follows:

- additional CTOL runways (note: nothing is said about high speed exit and parallel taxiways as additional means of increasing system capacity);
- offshore airports;
- ILS problems and the current FAA - sponsored microwave scanning ILS proposal (mentioned to be suitable for STOL);
- PAR (precision approach radar, being phased out);
- airfield surface traffic control;
- fog dispersal;

- ground access during zero-zero weather;
- ground access vehicle systems;
- ‘mobile lounges’ and other airside transit systems;
- baggage transfer and retrieval systems;
- automated ticketing and passenger advice;
- the use of STOL aircraft, initially to transfer some traffic off the CTOL runways, and eventually to take much of this traffic (plus whatever else may be generated through the presence of highly accessible STOLports) completely away from the CTOL sites;
- area navigation;
- the 1966 Operation Metro Air Support exercise using STOL and VTOL vehicles;
- public acceptance of downtown STOL, beginning with small, quiet, and seemingly non-threatening STOL air taxis.

This article is considered to provide a useful introductory résumé of many of the questions currently at issue in the world of civil air transport. Its STOL technology coverage is minor, but it helps put at least American STOL needs into an appropriate context with CTOL’s problems. Unfortunately, though, STOL is not considered as a separate entity with its own markets; hence the full potential of STOL is not explored.

CONSIDERATIONS REGARDING THE INTEGRATION OF THE AIRPORT INTERFACE INTO TOMORROW’S AIR TRAFFIC
(Überlegungen Zur Anpassung Der Nahtstelle Flughafen an Den Luftverkehr Von Morgen)
H. Schulte
Luftfahrttechnik Raumfahrttechnik
Vol. 14, No. 12, December 1968

This paper is a well written review of existing, mainly US literature on airport planning. The stand is taken that the V/STOL aircraft may be a means to solve some of the airport access problems.

In view of the fact that the paper, although relevant, does not contain much original information, it is suggested that the original sources are more appropriate to the CTC study. These are, as far as V/STOL technology is concerned:

AIAA papers 68-1046
68-1137
AIRPORTS AND HELIPORTS: PLANNING, MANAGEMENT AND OPERATIONS SAFETY.
SELECTED REFERENCES
Bibliographic List No. 10
Office of Headquarters Operations
Library Services Division, FAA
Washington, December 1963

This somewhat outdated, partially annotated bibliography has a companion volume, Bibliographic List No. 9, 'Airports and Heliports: Design, Construction and Maintenance' which was not available at the time the present review was written. Coverage is for the period 1959 - 1963 only, and obviously would call for updating at regular intervals for maximum usefulness. In a sense, however, the place of this bibliography is more than adequately filled by such abstract series as STAR and IAA, as can be seen in any competent aerospace library.

The particular charm of the document under review is in its compactness in comparison with the abstract series mentioned above. This compactness no doubt arises mainly out of concentration upon a restricted subject area. In addition a good number of the literature references are simply cited as to title and source, and are not discussed: this appears to be the case mainly for magazine articles, whereas separate reports of major importance, e.g. 'Airport Capacity' by Airborne Instruments Laboratory (June 1963), are at least briefly described: 'A handbook for analyzing airport designs to determine practical movement rates and aircraft operating costs.' Nonetheless, in many instances periodical articles, too, have been outlined, sometimes in more detail than in the foregoing example.

Virtually all aspects of airports, as considered up to 1963, are probably covered by Bibliographic Lists 9 and 10, but rather than cite a bare list of topics, many of which may be of limited relevance in the present context, attention will be focussed here upon the results obtained from scanning the contents of Bibliographic List 10 for items clearly applicable specifically to STOL (VTOL is well covered and also in a Helicopter subsection under the general heading of Aircraft Noise).

Reference 178 (under Aircraft Noise/Helicopter) is a 1961 NASA paper entitled, 'Noise Considerations in the Design and Operation of V/STOL Aircraft.' References to low-tip-speed propellers and turbofan engines in the printed abstract make it clear that straight STOL aircraft (as opposed to V/STOL 'hybrids') probably are covered. However, little or nothing seems to be said about STOLports; only aircraft appear to be discussed.

Under the heading of Site Selection, a number of items such as References 224 and 226 on airport sites for industry might or might not have STOL implications. Reference 229, 'Airports Will Be Downtown by 1970', and 230, 'New York Harbor Airport Site Proposed', most probably do have. Other seemingly relevant items include References 232, 233 and 236 on site selection; 232 stresses airphoto interpretation, 233 does the same but in relation to arctic regions, and 236 consists of a 10-page bibliography on airport site selection.

In Reference 238, the role of helicopters in feeding major airports is covered under the Ground Transportation heading; this role could be taken over by STOL if urban STOLport developments should go ahead. This possibility seems to come out more clearly in Reference 242, 'V/STOL Aircraft Needed to Free Airport Ground Traffic Ills'. Reference 247 could apply to STOLports themselves: 'Airport Location in Relation to Urban Transport', as indeed could several other references in a similar vein.

Additional specific references to STOL under the same section heading are 251, 'Economic and Safety Aspects of Short Haul V/STOL Aircraft on High Density Routes', and 254: 'Technical and Economic Problems of Commercial Short Haul Air Transportation'.

FAA believes that aircraft arresting gear for emergency use will be mandatory on elevated STOLports. Accordingly, References 566 et seq. on such gear must be considered relevant, if possibly technologically obsolescent. Also covered under the Safety Equipment and Facilities heading are items on apron control and communications, firefighting and rescue services and the like. Somewhat curiously, a further section on Equipment begins with Reference 674, and gives additional coverage regarding firefighting and rescue gear.

Heliports are, as noted, specifically
covered in 39 references (References 694-732) at the end of the bibliography.

Miscellaneous references which may be of interest in connection with a broad STOL study include Reference 282, 'Aviation the Key to Canada's Arctic' and 192, 'Role of the Airport in the Geographical Re-distribution of Economic Activities'.

Altogether, this bibliography might be looked upon as of top relevance to a researcher if it were up to date. For a non-researcher interested in facts rather than in further literature references, the relevance would be less and, of course, the bibliography as reviewed here is rather out of date. For these combined reasons, a '3' relevance rating is assigned with some regret.

AIRPORTS AND HELIPORTS: DESIGN, CONSTRUCTION AND MAINTENANCE.
SELECTED REFERENCES
Bibliographic List No. 9
Office of Headquarters Operations
Library Services Division, FAA
Washington, July 1963

This rather outdated, partially annotated bibliography is companion to Bibliographic List No. 10, Airports and Heliports: Planning, Management and Operations, Safety; the latter has also been reviewed in this series. Coverage is again for the 1959-63 period, except that Bibliographic List No. 9 was issued in mid-1963 and therefore has missed covering half of that year. As editorial resemblances between the two bibliographies are strong, this review will focus immediately on the content of List No.9.

The following topics are listed in the Table of Contents:

AIRPORTS
General; Layout and Configuration; Runway, Taxiway and Apron Studies; Aircraft Runway Length Requirements; Visual Aids: Runway - Taxiway and Apron - Miscellaneous; Buildings: Terminal - Cargo Facilities - Maintenance - Hangars - Miscellaneous; Cargo Handling Methods and Equipment; Ground Support Equipment and Facilities: Fuel - Aircraft Servicing - Passenger Handling; Master Planning; Pavement: Design - Friction - Smoothness - Miscellaneous; Construction Methods, Equipment and Costs; Construction Materials: Concrete - Bituminous - Aggregates - Conduits and Pipes - Miscellaneous; Pavement and Foundation Soils; Maintenance: Pavement Repairs - Cleaning - Snow Removal - Miscellaneous - Drainage.

HELIPORTS
General; Layout and Configuration; Visual Aids; Lighting Equipment; Miscellaneous.

As in the case of List No. 10, the titles and abstracts have been scanned for explicit references pertinent to STOL. Among other things this search has turned up is an abstract pertaining to a 1960 bibliography (Reference 19 in List No. 9) entitled 'Bibliography on Airport Engineering'; this extends coverage of its topic back to 1938, although without specific reference to STOL per se as far as can be seen from the evidence.

STOL is mentioned in the abstract of Reference 263, 'Ground Environment Problems', a survey of such difficulties as noise and increasing CTOL terminal zone congestion; the prominence of the subject in the total paper seems minor, to judge from the abstract. With this single exception, no mention of STOL has been noticed under the entire AIRPORTS heading. A good number of basically CTOL papers would have potential STOL application, however, such as in the areas of pavement design and construction technology, slush drag, pavement friction testing, and snow and ice removal. Evidently, by 1963 STOL had not progressed to the point of opening new frontiers for the airport engineer, and hence it gave him little or nothing to write about, as a discrete topic.

STOL coverage under the HELIPORTS heading is no better; the only directly pertinent item is Reference 458, 'Preliminary Study of V/STOL Transport Aircraft and Bibliography of NASA Research in the VTOL - STOL Field. IV - Takeoff and Landing Facilities'. At least this paper may be of direct value, however; author is R.J. Tapscott. Further identification reads 'NASA TN D-624, Jan. 1961, p. 67-79.'

Generally speaking, Bibliographic List No. 9 is disappointing from the specific STOL technology viewpoint. Add to this the fact that it is out of date, and it only rates a bare '3' on the 1 to 3 relevance scale.
These two overlapping and to some extent complementary reports are considered to cover the state-of-the-art of offshore airport development very well up to their date of issue. As it happens, two important floating airport studies have been reported since that date, of which the system put forth in 'Floating Aerodromes' is considered the more viable. 'Floating Aerodromes' therefore constitutes a supplement to the present discussion.

The acquisition or development of a suitable operating site is of course essential to any airport development; the reports under review cover airports in general and not specifically STOports. These reports are therefore considered to be of moderate relevance in areas where offshore airports are a possibility. At inland locations lacking considerable bodies of water, the degree of relevance is nil. It should be borne in mind, though, that STOports on at least filled extensions to the mainland (in some cases such extensions already exist) seem a distinct possibility at several major Canadian cities including Toronto, Montreal, Vancouver, Victoria, Ottawa, Halifax and Quebec -- assuming that such developments would be both feasible and preferable to natural land alternatives.

A specifically STOL-oriented proposal reviewed in the evaluation report (pages A-59 to A-64) is the Rutgers Aquadrome circular floating V/STOLport concept. The 1,000' diameter area proposed by Rutgers would be inadequate to meet STOL requirements, but the basic concept may be of independent interest. The proposal envisioned a thick disc with a 16' clear interior height and a column-supported deck. Aircraft elevators would theoretically permit parking below decks for all unloading, servicing and loading operations. The 16' height provision, however, would be inadequate to accommodate transport category STOL aircraft. This and a number of other factors would require the facility to be thoroughly redesigned. The Parsons Co.'s final conclusion is most significant: 'Indicated cost of the redesigned structure will be prohibitive.'

Another floating airport scheme, the Armstrong Seadrome, was patented in 1924. The original flight deck dimensions were to have been 1,200' x 400' but by 1946 the length had grown to 6,000' as aircraft progressively took on the characteristics of today's CTOL. The scheme used vertical hollow cylindrical steel floats, with their maximum diameter and buoyance beneath the wave zone. Costs, steel corrosion, and the typical floating airport problems of access, anchorage, ship collisions and expansion forces, spray and contamination where seawater is a factor would make the scheme impractical except under the most unusual circumstances.

The more promising means of creating or extending airport lands are by landfill (sometimes with a wave-shedding rim dike allowing the general fill level to be reduced), by dike-and-polder development as has been extensively practiced in The Netherlands, and by pile-supported decks standing above water level, as have been used at La Guardia Airport, New York. The reports under review provide much useful information on these methods.

Costs per unit of area vary by water depth, by availability of materials, by exposure to currents, waves and storms, by construction methods, and so forth, as well as by general concept followed. While surface area is a major determinant of fill costs, dike length is more important to dike-and-polder costs. The picture is not simple; reference is therefore made to the Parsons reports for costing information.

Under favourable circumstances, land extension costs can be quite competitive with dryland purchase costs.

THE EFFECT OF JET NOISE ON THE VALUE OF REAL ESTATE

Paul T. McClure (Rand Corp.)
AIAA Paper No. 69-802, AIAA Aircraft Design and Operations Meeting
Los Angeles, July 14-16, 1969
American Institute of Aeronautics and Astronautics, New York, 1969

Real estate values as affected by jet noise are discussed with the following as indicators: (1) market value changes (2) sound insulation costs (3) easement costs, and (4) litigation. Regarding market value changes, the market survey discussed in this paper includes all sales of single-family residences during a thirteen year period in neighbourhoods near Los Angeles International Airport with noise exposures ranging up to approximately 105 PNdB. Insulation is...
defined as the required remodelling of structures that reduces the noise level (caused by jets) to a level equivalent to that where no aircraft noise is generated. The subsequent cost of insulation refers to the amount of insulation required to allow the real estate value to fluctuate normally (i.e. as if no jet noise penetrated the structures). Easement costs reflect the amount of depreciation in value of real estate caused by the activity permitted in the easement. Finally, included in litigation are not just the damage costs but also costs incurred resulting from personal injury, annoyance and other damages.

The hypothetical house model is a seven room, $24,000, stucco finished house with 1200 sq. ft. of surface area. All four examples of property value effects are applied to this hypothetical house. Four residential areas around Los Angeles are chosen for the sample study; two of these areas fall within an allowable noise contour of 90 PNdB and the other two areas exceed the allowable noise level. Extensive and fairly detailed analysis was carried out but the conclusions arrived at were, to say the least, somewhat nebulous and certainly not reflective of the amount of research done. 'It cannot be concluded that this market survey provides any meaningful conclusions about the effect of jet noise on the value of real estate'.

In parallel investigation reported within the same paper, various other studies were examined such as the Bolt, Beranek and Newman study; London, England (Heathrow Airport); and various cities in the U.S. Insulation costs and easement costs were investigated and values were attached to the hypothetical model house, described earlier. These are best summarized in the attached Table (next column). Regarding litigation in the Los Angeles area (Los Angeles International - LAX), suits brought forth by individuals, groups of individuals and organizations were examined and suitable values again were applied to the hypothetical model house.

Thus in conclusion, the market survey insulation cost, easement cost and litigation data give evidence that jet noise has a negative effect on the value of residential property, though the most credible of these four indicators is probably the cost of easements. On the other hand the least reliable information comes from claims by litigants. Hence on the basis of insulation and easement costs it is ultimately concluded that property exposed to jet noise is worth 10% to 20% less than it would be if not exposed to jet noise.

The relevance of this particular paper to STOL air transport depends upon the location of STOLports relative to private housing, as much as anything. Somewhere, sometime, STOLports are likely to invade the suburbs; a fair relevance rating is therefore assigned.

Hypothetical House: 1200 sq. ft. seven rooms $24,000 market value, stucco exterior, exposed to 100 PNdB.

<table>
<thead>
<tr>
<th>LAX Market Survey</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Insulation Costs</strong></td>
<td>Mean = $3,907</td>
</tr>
<tr>
<td>LAX Study</td>
<td>5,522</td>
</tr>
<tr>
<td>Bolt, Beranek &amp; Newman Study</td>
<td>4,080</td>
</tr>
<tr>
<td>London Experience</td>
<td>2,120</td>
</tr>
<tr>
<td><strong>Easement Costs</strong></td>
<td>Mean = $3,353</td>
</tr>
<tr>
<td>Columbus, Ohio</td>
<td>4,350</td>
</tr>
<tr>
<td>Denver, Colorado</td>
<td>1,590</td>
</tr>
<tr>
<td>Des Moines, Iowa</td>
<td>2,000</td>
</tr>
<tr>
<td>Seattle, Washington</td>
<td>4,200</td>
</tr>
<tr>
<td>Jacksonville, Florida</td>
<td>4,625</td>
</tr>
<tr>
<td><strong>LAX Litigation</strong></td>
<td>Mean = $23,206</td>
</tr>
<tr>
<td>By Individuals</td>
<td>27,500</td>
</tr>
<tr>
<td>By Groups of Individuals</td>
<td>18,837</td>
</tr>
<tr>
<td>By Organizations</td>
<td>23,280</td>
</tr>
</tbody>
</table>

TABLE 10 - Estimated effect of jet noise on value of the hypothetical house

This paper begins with a general survey of contemporary trends (including toward V/STOL) in the development of air transport, and predicts considerable impact of the new equipment (aircraft) on air travel, 'which in turn may affect the form and structure of cities and metropolitan areas'. It then goes on to view the airport from four different viewpoints, viz. as a transport facility, as a nuisance and focus of hazards, as an influence upon land use, and as an interjurisdictional concern.

As transport facilities, airports are considered first in terms of the U.S. National Airport System and other American national institutions, and
subsequently as factors 'in the local transportation system'. On the national level, reference is made chiefly to the parts played by CAB and FAA, whereas on the local level some actual, but highly generalized, quasi-technical information is provided, e.g. regarding ground access modal split. Emphasis is placed upon the ground traffic generating aspects of airports, and related problems are superficially discussed.

Under the heading, 'The Airport Nuisance Problem', noise, crash hazards, air pollution and the problems posed by neighbours of Airports (obstruction, lighting interference etc.) are reviewed. One very interesting table from this section is as follows:

<table>
<thead>
<tr>
<th>Transportation Non-occupant Fatalities, 1950-1963, by Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automobiles</td>
</tr>
<tr>
<td>Railroad Passenger Trains</td>
</tr>
<tr>
<td>Buses</td>
</tr>
<tr>
<td>Scheduled Air Carriers</td>
</tr>
<tr>
<td>121,853</td>
</tr>
<tr>
<td>12,830</td>
</tr>
<tr>
<td>4,908</td>
</tr>
<tr>
<td>41</td>
</tr>
</tbody>
</table>

Regarding airport influences upon land use, the report notes that motels and convention hotels, manufacturing plants and offices are tending to locate near airports, and that in some cases airports are incorporating 'fly-in' industrial park areas. 'Airport cities' competing with their cities' central business districts (CBD's) are envisioned, assuming of course that the airport itself will not be at the CBD (as a STOLport might). In addition, the direct consumption of large tracts of land by (CTOL) airports themselves is noted. It is held that airport isolation to prevent friction with the community does not work, and that a remote airport will either attract other development and prosper, or alternatively go underutilized.

The interjurisdictional aspects of airports have certainly proved troublesome in connection with STOLports in the past, e.g. in securing suitable land use restrictions within neighbouring municipalities not deriving tax benefits from the existence of an airport nearby. Besides the lack of horizontal integration or co-ordination of political power, there is also an inherent lack of vertical integration or co-ordination which can only be overcome through exercise of a cooperative spirit at all levels. The report briefly explores the U.S. situation on this front.

Following the foregoing survey, the report next gets down to the planning of the airport environment and, in its next major section, to an examination of the public powers (e.g. zoning restrictions, building codes, purchase and expropriation) available for the implementation of a developed plan.

It should be specially pointed out that the report is not concerned with the planning of airports, but with the planning of airport environments. Its stated planning objectives therefore are connected with (a) capitalizing on the airport's impact on land development, (b) provision of suitable access, (c) compatibility regarding noise, and (d) compatibility regarding airport restrictions owing to surrounding development. Since co-ordination and compatibility require that concern cross boundaries (including the airport's boundaries), the somewhat rambling discussion is certainly germane to the responsibilities of the airport planner; however, there is no direct discussion involving the problems of STOLports.

An appendix rather briefly outlines some implications of aircraft noise, but does not contain enough information to allow noise exposure analyses to be made.

THE RELATIONSHIP OF AIRPORT PLANNING, DEVELOPMENT AND OPERATION TO URBAN GEOGRAPHY

P. T. Hodgins,
A term paper for Urban Geography (Geography 420) course at Carleton University, Ottawa, December 1967

This paper was written as an introduction to airports for urban geographers, inasmuch as it seemed obvious to the author that the urban geography textbooks of the day were paying scant attention to the major impacts of airports on the urban environment. Such impacts go far beyond the consumption of urban land directly for the siting and protection of aviation related facilities, and include the generation of aircraft noise over large areas, the attraction of very significant flows of automotive traffic over the city's street and highway network as well as, for that matter, into the airport city from surrounding communities, the provision of employment to many urban dwellers and consequently the stimulation of the retail, real estate and other trades patronized by airport employees and their families, the facilitation of business in general through improved communications with more distant markets and sources of supply, and the requirement for zoning restrictions upon urban development to prevent or control both the erection of obstructions in aviation airspace, and the location of housing.
hospitals, schools and other noise-sensitive urban land use in noise-affected areas.

Interrelationship via air between urban communities situated at some distance from one another have been explored to some extent in 'An Application of the Gravity Model to Canadian Domestic Intercity Airline Passenger Traffic' and similar papers. The numerous types of impact by airports upon the city as briefly suggested above are too extensive for the report now under review to treat exhaustively.

The general history of airports as an important part of the air transport and aviation system is briefly outlined as a key to the understanding of airports as they exist today. Concurrent with airport growth and development has been the leapfrogging of urban development and land speculation into and beyond the vicinities of many airports which once were thought to have been remotely sited. Antagonisms have thus been set up which have been as damaging on one side as on the other.

Airport site and situation questions are discussed in general terms, 'site' being more or less synonymous with 'location' in geographic parlance, while 'situation' has reference to such questions as market access and other relationships having a bearing on an airport's viability and usefulness.

The case for 'downtown airports' (of whatever type, e.g. STOLports, VTOLports, or seaplane aerodromes within downtown harbour areas) is discussed, and possible types of such facilities are explored. Seaplane facilities are not considered practical on a year-round, all-weather basis; at least, the problems involved have not yet been solved, and the system could not extend to cities having no suitable water areas downtown. VTOL operations are costly, but the associated land requirements are minimal. STOL requires a bigger, more expensive airport than does VTOL, but may be able to pay for this through superior operating economics. It is predicted that downtown airports are an important forthcoming urban feature for the geographer to watch and, perhaps, to take part in planning.

Conclusions include the observation that costs, noise, zoning and ground access will be among the factors important to downtown airports, be they STOL or VTOL. Studies of potential downtown airport sites would be appropriately undertaken forthwith. The importance of a practical approach to site studies to the present STOL technology enquiry can scarcely be exaggerated; on the other hand, the paper under review gives little STOL-related information, and also fails to consider applications outside the urban environment. For these reasons, a moderate relevance rating is assigned.

EXPROPRIATION
P. T. Hodgins
Paper prepared for course in Land Resource Use (Geography 445) at Carleton University, Ottawa, March 1969

This layman's paper has been selected here, not for any originality of content or intrinsic merit, but by way of representing its subject area in a simple manner. Four references are cited for those whose interests and expertise may lead them to dig deeper into the subject.

Expropriation involves a statutory power to take land without the consent of the owner, and may be an important tool for the assembly of lands necessary to the carrying out of some project such as the development of an airport. From the owner's viewpoint, however, expropriation is a sword of Damocles threatening to sever him from his belongings; at one time, there was not even any assurance that reparations of any sort would be made, for as Mr. Justice Riddell has said, 'The prohibition 'thou shalt not steal' has no legal force upon the sovereign body'.

Out of consideration of 'natural justice' and of basic or assumed human rights, the former situation was intolerable, and at least statutory (unfortunately still not constitutional in Canada) protection to the individual has since been enacted, subject perhaps to some loopholes for the benefit of the Crown.

The protective measures have in fact become so complex as to make expropriation an onerous undertaking — to the benefit, however, of the individual. While land can of course still be expropriated, and this includes all things attaching to land such as buildings, steps have been taken to ensure that this will not be done arbitrarily, overly hastily, or without due compensation. 'Due compensation' covers, not merely the market value of the property expropriated, but also a factor to cover damages of assorted kinds attributable to expropriation. The aim is to leave the owner no worse off after expropriation than he was before.

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This research and development report might be relevant to STOL system requirements under two principal conditions: (1) that the local air transport market to be served should be situated in close proximity to a sizeable body of water available for airport use and (2) that a sufficient and suitable area on land for STOLport use would be unavailable at an economically competitive cost.

Despite the report's title, it contains information on several different systems for developing offshore airports. In addition to floating platform systems, the principal categories are airports on fill, in polders surrounded by dikes, and on pile-supported platforms supported above the water's surface. These alternative systems are probably best explored in 'Offshore Airport Planning'.

The chief contribution of the present study is to outline an unusually promising floating platform design concept, the significant feature of which is a multitude of concrete cells left open at the bottom, and capped on top by the structure of the load bearing deck system. Water can be displaced from the cells through internal air pressure increases, affording a convenient method of levelling and adjusting the height of the platform. At the same time, the open cell bottoms provide 'surge tanks' which can allow water to rush in and out according to wave action, without heavily loading the structure.

The proposal needs model testing, and has not yet received realistic costing, although the authors believe that unit costs would not exceed those of the concrete platforms on piles erected in 1965-67 at La Guardia Airport, New York (these costs were rather high). Means of overcoming the severe special problems of access, anchorage, floating ice action, spray with wetting and icing, and possible contamination by salt water are not developed in this study. In some circumstances at least, such questions are expected to make proposals of this sort unfeasible, and they are certain to add a good deal to total system costs.

On the other hand, the relatively small areas required for STOL operations could greatly reduce the impact of such outstanding problems. The question perhaps is whether we need offshore floating airports of any type, anywhere in Canada. This is a matter for future site studies to determine, but at the time of writing the answer appears to be 'no'.

INDIVIDUAL STOLPORT DEVELOPMENT PROPOSALS

SKYPORT DESIGNED FOR CITY-CENTER SERVICE
John A. Nammack
Airport World, March 1970 pp. 46-48

This concise article outlines a concept proposed by Grumman Aerospace Corp. of Bethpage, N.Y. for a 'total transportation complex' for the west side of Manhattan. A STOLport would occupy the upper floors of a 140-ft. high building, over a railway spur and the West Side Highway; a taxi, truck and bus terminal would be incorporated at street level. The site considered is also proposed in 'Heliport Study' and 'Proposed Combined STOL/Air Cargo Terminal for New York's West Side'.

The STOLport would have a parallel runway pair (independent information has at one point suggested that municipal constraints might put these onto quite a poor orientation relative to the prevailing wind pattern, making the project a somewhat doubtful starter*) on a rooftop channelled in the general form of a very flat 'W', the elevated edges and median area being designed to control abnormal aircraft motion and prevent over-the-edge or across-the median accidents, and also to direct noise upward and shield the neighbourhood to some degree.**

Aircraft elevators would be employed to allow unloading, servicing and loading belowdecks, the aircraft being moved from position to position there by tow cables. Eight parallel servicing channels would be provided for this purpose, and the promoters claim that 60 landings and 60 takeoffs per hour, handling nearly 100,000 passengers per day (possibly about 35,000,000 passengers per year, in the absence of severe crosswind problems) could be accommodated by the system.

*More recent information on FAA STOL technology investigations and proposed airworthiness requirements indicates that the problem will most likely be overcome.
**FAA investigations are unfavourable to this concept, particularly in terms of its aerodynamics.
Overall project cost 'might be as much as $600 million'.

No extensive aircraft repair service would be provided; disabled aircraft would be removed by barge to La Guardia.

Grumman has been making presentations with a scale model of its skyport in several cities besides New York.

It at present seems doubtful that a treatment of this sort is required in Canada.

**METROPOLITAN AIRPORTS FOR V/STOL AIRCRAFT**

Albert C. Martin,

SAE Paper 690402, Presented at National Air Transportation Meeting

New York, April 21-24, 1969

Society of Automotive Engineers

New York, 1969

This paper begins with a somewhat conventional review of the reasons for interest in metropolitan STOLports. Basically, the point is to attain an alternative to CTOL in view of the problems associated with such transport today. The U.S. federal government envisions STOL planes as the major short-haul air carriers 'in the next 15 years,' and FAA has recommended development of 25 STOLports in its 1968 National Airports Plan. Four of these STOLports are to be in the Los Angeles area, and the author's firm has been at work on the downtown Los Angeles Metroport in this context. Generalized STOLport site criteria are summarized in respect of proximity to expressways and possibly to rapid transit, to minimum land consumption, to runway length (1500' or more'), to mechanical systems (ticketing, baggage handling, passenger movement), to ingress and egress efficiency for all types of vehicles, and to adequacy and convenience of parking.

It might be noted at this point that the present paper seems to place almost as much emphasis on the ground side of the airport system as other reports such as 'Principles of STOLport Operation' sometimes do on the airside, for the foregoing list is 50% concerned with ground access aspects, and says nothing about air navigation, airspace/runway capacity and so forth. It is felt, however, that the author has concentrated somewhat on those aspects of special interest to the Society of Automotive Engineers for the purposes of this paper only, and that the facility in question has in fact been planned in a properly comprehensive manner. The relevance rating assigned to this paper would have been 1 if the STOLport proposal discussed had been at grade.

The author expected 90° approach angles. FAA seems to be leaning strongly toward 7 1/2°. There is no indication, however, that the latter criterion would invalidate the Los Angeles Metroport plan.

On the other hand this plan involves a building configuration below the STOLport operations platform which is highly suspect according to recently reported FAA - NASA wind tunnel testing. This testing has indicated that solid building faces create severe turbulence effects over the deck; research suggests that a cure may require (a) leaving about two stories' open space immediately under the deck, (b) curving the deck edges downward on all sides, and (c) using fence-like screens parallel to the runway edges to help control the direction of airflow over the deck, especially at the downwind end, i.e. near the touchdown point for landings. It would appear that a number of details of the plan under review here will have to be changed, possibly with the outcome that the flight deck will be raised and changed in edge shape, at least.

In the current STOL technology study for CTC, little attention has yet been focussed on systems, development work on the part of the participants. Judgment must therefore be reserved on the question of whether this paper puts forth an optimum layout for a facility of the type considered (elevated downtown STOLport in a large metropolitan centre). Such as it is, the scheme seems fairly well developed and outlined in concept. It recognizes the need for such adjuncts as tailhook arrestor gear for emergency use, and is particularly specific in its details of the ground access system internal to the STOLport facility (parking, circulatory roads, ramps, curb areas, elevators and escalators between decks). The runway markings as illustrated are not compatible with FAA's recommendations, however, and the total runway length scales off the sketches a little short of the 1800' FAA requirement, especially inasmuch as the building corners (and hence the flight deck corners) are severely rounded off in plan view.

*FAA requires 1500' plus two 150' overshoot areas, for 1800' total available length.
This study directly concerns a system of three heliports for the New York area, with specific locations at John F. Kennedy International Airport, midtown Manhattan, and the City of Yonkers. Owing to the intense congestion of the zone involved, what may be appropriate to helicopter operations there could well be appropriate to STOL in Canada. In fact, flights of 100 to 600 miles are mentioned in this study, duplicating the lengths normally considered to be in the province of STOL. Much of the conceptual development work on terminal interface and ground access questions could be applicable to STOLports.

United Aircraft, who commissioned this study, incorporate the Sikorsky Helicopter interests. This appears to be an institutional reason for the privately financed investigation to have centred upon heliports. STOL does receive mention in passing at several points, but with little elaboration.

Justifications for considering heliports are, (1) the existing New York airports are approaching saturation, (2) ground access to future remote sites will be a difficult problem, (3) flights of between 100 and 600 miles constitute about 80% of all airline operations (evidently measured in terms of aircraft rather than passenger movements), and (4) a STOL or VTOL can complete a 500-mile flight faster than a CTOL if it can avoid ground and airspace congestion delays. Such justifications also apply to STOLports.

Besides conceptual developments, the report is interesting for its order-of-magnitude cost estimates and a checklist of basic terminal facilities. Some extension of existing design guidelines was necessary to cover the scope of operations proposed. The practical consideration of specific sites as opposed to general theorizing is considered a good feature of the study, and because four quite different site situations in New York were assumed, there still is a fairly general applicability in the findings.

Regarding noise abatement, the main problems for heliports are in the immediate site zone. Sound barriers and absorption adjuncts are proposed treatments. In addition, the possibility of having to accept suboptimal V.23 location is recognized.

Sites should if possible be located at or near multi-mode transport foci and/or important traffic generators. Maximum travel time criteria are given as 10-15 minutes 'between a city centre heliport and the urban transportation centre' and 30 minutes between a suburban heliport and the nearest point of traffic generation' (note that nothing is said about the farthest point).

Rooftop urban heliport sites are preferred to ground level ones, which is probably the reverse of the STOL picture. Advantages of rooftop heliports are (1) relative freedom from surrounding obstructions, (2) reduction of land requirements, since the terminal et al go below the operations surface, (3) turbulence generated by other buildings is minimized, and (4) a broader range of headings is available. Disadvantages are, (1) public reaction to overhead operations, (2) greater cost owing to structural reinforcement, fuelling system, fire and crash protection, and more complicated vertical transport (elevators). Zoning bylaws, building codes and other regulations may create additional problems.

Many design details discussed in this report are peculiar to heliports. There are, however, possible STOL applications to some items, such as the fire extinguishing system outline, and certainly in regard to the passenger terminal facility; the latter, though, is in any case 'similar to that for a conventional airport', with the chief adjustment that average passenger waiting times would be reduced.

This report's cost estimates are not considered directly applicable to STOL facilities and are in any case site-specific. They are too complex to present here. 'A Skyport Design for City-Center Service' and 'Proposed Combined STOL/Air Cargo Terminal for New York's West Side' are related to the present reference, inasmuch as the same site is involved in each instance.
complex serving several transport modes is envisioned. The present proposal contemplates a city-centre STOLport, an air cargo consolidation marshalling and containerization centre for Manhattan, a marine-rail-air transfer facility, and a central post office air transfer facility, all rolled together.

It is postulated that the development of a New York City-centre STOLport is essential to the viability of any V/STOL transport system, particularly in the Eastern U.S. Additionally, the phenomenal growth of air freight traffic is reviewed, and delivery problems (which will only get worse) are pointed out; already cargo delivery delays up to five hours have been experienced between central New York and J.F.K. International Airport.

For the latter problem, it is proposed to consolidate and palletize or containerize air freight at a central Manhattan point, and then ship it to 'the airport' (specifically to J.F.K.) by rail. Since STOL operations are not generally involved in this matter, this part of the compound proposal may be largely skipped over here, except to note that shared land use is considered an economic necessity in Manhattan.

The STOL passenger market is evaluated in the following manner. First FAA has predicted 128 million annual air passengers for the New York area by 1980. Second, Port of New York Authority estimates that 50% of all current New York airport users originate/terminate in Manhattan (presumably this proportion is expected to remain valid in 1980). Third, 70% of all Manhattan air travel is generated between 30th and 60th Streets. Fourth, 80% of New York's airline operations could be served by STOL. Conclusion (1): A 30-million passenger STOL market is predicted. Conclusion (2): A single STOLport will be unable to handle such traffic even if 100-150 seat aircraft become available.

The airlines' market is for 14 million passengers annually. Even this number may be too great for a single STOLport. This fact at least promises very adequate utilization of the proposed facility if built in accordance with the author's concept; the latter involves only a single runway surface, as the total land area to be employed would be just 2000' x 500' (as against FAA's 1800' min. length proposed).

The report goes on to outline quite briefly airspace and site factors, proximity to origin and destination points, road and rail access, real estate values, urban land uses, and generation of employment opportunities. No specific proposals are put forth in regard to passenger terminal and ground access facilities except that they be placed below the aircraft deck.

In final impact, this report seems rather like a prospectus or promotional pamphlet; the firm involved subsequently performed the sponsored investigation reported on in 'Heliport Study'. Owing to the large number of STOLport questions left unanswered -- in fact, not even a preliminary STOLport layout sketch has been provided -- the present document cannot be rated as highly relevant to a STOLport study for areas outside of Manhattan.

NORTHERN SITES AND TRANSPORT

MUSKEG ENGINEERING HANDBOOK
The Muskeg Committee of the National Research Council, Ivan C. MacFarlane, ed. University of Toronto Press Toronto, 1969

'Muskeg' originated with the Chippewa Indian word 'maskeg' meaning grassy bog, but its use has now been extended to cover organic terrain (peatlands) of many types.

As far as site selection, development planning, construction and maintenance aspects are concerned, this handbook's subject must be considered as highly relevant to the northern transportation applications of STOL technology, in particular. In addition, muskeg conditions can occur in many other areas as well, so that possible connections between muskeg engineering and STOLports cannot be dismissed with certainty for any major region in Canada until such time as site studies can be conducted.

In much of the Canadian North, terrain conditions tend to run to rock, sand and gravel, water or muskeg; in some places one condition predominates, in some places another, and at times these conditions are intimately intermixed in complex patterns. One advantage of STOL over CTOL for the north is that it may frequently be found that a modestly sized site suitable for STOL lies much closer to the community to be served than does any larger CTOL site, and/or that the STOL strip can be placed on
better foundation materials. It goes without saying that the more distant an airport is from the community, the greater is the likelihood of mixed terrain conditions between the two, and hence the greater is the chance that at least the airport access road will involve muskeg crossings. To some extent, then, part of the relevance of muskeg to STOL in the north consists of the somewhat negative factor that muskeg is potentially less of a disadvantage to STOL than it would be to CTOL.

At least 500,000 square miles of muskeg lie within Canada's boundaries, but this remarkable terrain has only been scientifically studied in relatively recent years. The widespread distribution of muskeg throughout the world is in part brought out by the handbook's illustrations, one of which shows banana trees, while another is identified as having been photographed in the Orkney Islands, whereas a third consists of a graph with information from Germany and from Massachusetts.

Many different kinds of muskeg have been identified, and may with practice be recognized from index properties explained in this handbook. Technical test methods are set forth, examples are given of what can happen to construction on muskeg, and recommended practices are provided for different situations of construction, reclamation and so forth.

'Airstrips' are specifically covered in pp. 216-219, and are broken down under 'conventional' and 'winter' (i.e. seasonably usable when frozen) categories. Conventional construction avoids peat areas if possible, but sometimes this cannot be done. Muskeg at least has the advantage of being flat and free of rock outcrops, but special stabilizing treatments are required, e.g. by excavation of the peat and its replacement with granular soils, or by preconsolidation by loading the area with a soil embankment to squeeze much of the water out of the peat. Reference is made to a more extensive discussion of muskeg highway construction techniques elsewhere in the handbook. The specific 'airstrip' section includes brief sections on site selection and on construction techniques, but obviously these rely on the supporting information contained throughout the handbook in many places.

The coincidence of muskeg and permafrost conditions in the north must frequently be taken into account. Frozen muskeg may contain very high proportions of water, and if thawed may turn into a rather thin soup. It is not infrequently best to keep such terrain hard frozen.

THE IMPACT OF DEVELOPMENTS IN TRANSPORTATION TECHNOLOGY ON NORTHERN MANITOBA

W. D. Graham

A paper presented to the 6th Annual Meeting of the Canadian Transportation Research Forum, Winnipeg, May 1970

Except principally for its emphasis on sea access to the port of Churchill, Manitoba, this survey-type paper could have referred in its title to Northern Canada at large.

Beginning with a brief physiographic sketch of the Canadian Precambrian Shield which covers so much of Canada (including 60 percent of Manitoba), the paper goes on to discuss means and modes of transportation including, under the Water Transportation heading, draccones (flexible, towed containers made from rubber and nylon), submarine freighters, and icebreaking surface vessels; and under Surface Transportation, off-road vehicles and air cushion vehicles.

Under the Air Transportation heading, various trends and the development of VTOL and STOL are rather briefly surveyed. In terms of aviation technology, nothing new is added by this paper.

Nevertheless, the treatise is not without interest because of the appreciation it helps provide on the northern conditions under which transport systems may in many cases have to operate.

It is unfortunate that certain illustrations used in the verbal presentation of this paper have not been reproduced within it. Two or three interesting slides illustrated conditions at Norway House, Manitoba during the construction of a 5000' CTOL airstrip, and of the access road to it. The airstrip site appeared to consist essentially of a sandy plain pierced by several solid granite hillocks which had in large part to be drilled and blasted out at considerable cost. It appeared that, in contrast, a STOL strip could have been located entirely within the sandy areas, if not indeed in some completely different location more convenient to the townsite.

AIR TRANSPORTATION TO AND WITHIN THE ARTIC

K. P. Peiffer (Nordair)

Paper presented to 6th Annual Meeting of The Canadian Transportation Research Forum

Winnipeg, May 1970

This paper starts with a bibliography of 10 references, none of which mentions STOL in its title.

Mr. Peiffer's paper may be considered in
context with his privately expressed (but not particularly confidential) remarks that his airline currently operates two STOL aircraft only because it must, as a result of constraints at two northern airstrip sites; and that he would hate to see a set of northern airstrips developed to only about 2000' lengths. His part of the overall transport problem, by the way, obviously does not include major facets of airport siting, planning, construction, maintenance and operation, or of operating significantly ground transport to the airports involved.

The paper's text opens with an historical sketch of aircraft operations in the Arctic. At first, the only role of aircraft was in exploration, a function which they still perform with special efficiency even though motives have now shifted away from scientific to commercial ones. In this role, ton-mile and total-cost economic considerations have been relatively unimportant.

The emphasis of this paper subsequently centres upon the commercial transport role.

Northern transportation requirements are seen as the outcome of three major public objectives, classified as
(a) geo-political (sovereignty and defence),
(b) geo-economic (resource exploitation), and
(c) socio-economic (human resources, social needs etc.)

To date, factor (b) has been the most important in its actual effects, followed by (a), and lastly by (c), 'only as a by-product'. (However, with a current program intended to develop numerous new airstrips virtually exclusively for reason (c), at least the possibility of this sequence of importances being changed will arise in future; this may be news to Mr. Peiffer, who showed no awareness of the program in question during his presentation).

The patterns of routes flown by aircraft in two weight categories (divided at 18,000 pounds gross takeoff weight) are reviewed in the paper, and the absence of a major east-west route is noted. Three main south-north routes are identified, together with the existence of various central ports such as Yellowknife, Resolute Bay and Frobisher Bay from which numerous distribution routes fan out to smaller settlements.

In 1968, Boeing 737 jet transports were placed in northern service by Nordair and by Pacific Western Airlines. With their greatly increased productivity in comparison with piston-engined predecessor aircraft, the jets required the levelling out of seasonal fluctuations; incentive rate structures were therefore used, and Nordair has thereby attracted sizeable freight traffic away from sealift. Improved services encourage passenger travel, partially offsetting the uni-directional utilization problem inherent in northern goods transportation. The resulting expansion of main services has had the effect of improving business on the secondary distribution system, permitting the introduction of new schedules on routes which could not previously support these, and allowing the introduction of improved aircraft types. Nevertheless, the established air route structure has not been changed geographically, but rather fortified.

In connection with the relocation of governmental responsibility into the NWT, the CTC held public hearings in 1968 which resulted, amongst other things, in the award of new routes intended to facilitate a new administrative pattern. One special objective was to develop east-west links specifically between Yellowknife (the Territorial Capital) and Frobisher Bay. In the two years since, Yellowknife-Churchill has been abandoned for lack of traffic, while other east-west linkages have not developed enough to provide effective services. These failures have largely come about through a lack of subsidies which might have helped achieve the Government's objectives; 'he who pays the piper calls the tune'.

Although not all germane to STOL technology itself, this paper paints a picture of some of the conditions under which STOL might have to operate in one category of application.

PRINCIPLES OF GECROLOGY (PERMAFROST STUDIES) PART II, ENGINEERING GECROLOGY CHAPTER VIII, BEDS FOR ROADS AND AIRFIELDS. PP. 231-254 G. V. Porkhaev and A. V. Sadovskii (From Academy of Sciences of the USSR V. A. Obruchev, Institute of Permafrost Studies, Moscow, 1959) Technical Translation TT-1220, National Research Council of Canada, Division of Building Research, Ottawa, 1965

'Permafrost' refers to ground permanently frozen, or at least frozen over long periods in relation to the human lifespan. The permafrost layer has both lower and upper surfaces, the lower surface representing the depth to which freezing temperatures have penetrated in the face of slow internal heat
emissions from deep within the earth, and the upper surface representing the depth of annual thaw during the local period of summer conditions. The layer subject to annual cycles of freeze and thaw is known as the 'active' layer, and it may be of variable depth according to local soil composition, moisture content, vegetation cover and exposure conditions, but it basically is deepest near the southern limits of permafrost occurrence and shallowest in the high north where freezing conditions are most severe and thawing conditions least effective.

At the same time, the total depth of permafrost is in general least at the southern permafrost limits and greatest in the high north. As a consequence, permafrost is at the southern limits sometimes amenable to being artificially thawed completely out of the ground prior to such developments as new buildings or airstrip construction, whereas further north it cannot be so treated. Special techniques must be used under the latter circumstances to 'live with' the permafrost; not to do so would release from frozen captivity the accumulated water of centuries, with possibly disastrous results. To illustrate the point, much of the present delta of the Mackenzie River would sink below the Arctic Ocean's level if its ice content were to melt, while even upland permafrost frequently becomes an unstable soup when thawed.

In fact, not only are specific measures taken to maintain permafrost at many northern sites, but it may even be most advantageous to promote the advance of permafrost under certain circumstances. For instance, the design of a rockfilled airstrip embankment at Inuvik, NWT., Canada was intended to allow the permafrost line to rise into the embankment rock, since this would keep the annually thawing active zone within the stable fill rather than within the unstable silty subgrade below. In Canada a goodly proportion of our territory contains permafrost, although its spotty nature along the southern limit has made a reasonably exact determination of its range rather difficult, NRC's Division of Building Research has coordinated the mapping of the limits of continuous and discontinuous permafrost for many years, and is also the country's greatest repository of related knowledge and technology. The report to be reviewed here is only one of a long list of both translations and original works published by NRC-DBR on the subject.

The authors of this paper begin by pointing out that failure to recognize certain conditions may lead to catastrophic distortion of structures. Whereas such distortions can cause the collapse of building, the main problem with 'roadbeds' (applied equally for airfields, roads and railways, as the principles are the same) is usually that distortion beyond a certain stage makes the facility unusable by traffic. In addition, the structure (e.g. a pavement) may be weakened and destroyed, for instance when silt supersaturated with frozen water thaws and deprives the structure of its support. Reliable methods of controlling such problems can be developed and employed only when the causes are understood.

Something of the problem can be understood from the frost heaves which may afflict roadbeds even in the more southerly parts of Canada. However, on permafrost there can be no drainage of water through the soil in a downward direction, and as a consequence water tends simply to accumulate in the active layer of the soil. The problems with which the typical reader may therefore have some acquaintance are in principle very minor compared with those on permafrost. The report under review helps one to comprehend this fact, although being far from the first, it does not go out of its way to dramatize the point. It also explains basic phenomena giving rise to the problems identified, and indicates what might best be done to achieve satisfactory results under different circumstances.

The report's conclusions are as follows:

'tFurther development of automobile roads, railroads and airlines in permafrost areas poses the following problem to research and industrial organizations: to work out a sufficiently complete theory of the stability of a roadbed and to perfect its construction.

'tThe following problems must be solved first:

1. Thermal exchange mechanism in the following systems: roadbed-atmosphere and roadbed-underlying ground.
2. Methods of calculating road and airfield pavements must be perfected, taking into account the settlement of the subgrade and evenness of the pavement.
3. Deformation moduli of frozen and thawed ground and the sod-moss cover must be elaborated.
4. Theories and methods of effectively controlling heaving must be developed.
5. Methods of construction on thawing soils (methods of improving and gradually thawing the ground in the subgrade) must be developed.
6. Methods of constructing roadbeds with local silty soils must be developed.
7. Domestic and foreign road and airfield construction experience must be elaborated.

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be further generalized.'

This report is intended for persons having already acquired a basic understanding of permafrost phenomena and principles, and probably for civil engineers in particular. The subject's relevance is generally high for northern transport applications of STOL, but is nil for other applications. Under the latter conditions, an overall relevance rating of 3 is assigned.

A cross-reference to Muskeg Engineering Handbook should be made here, although permafrost will in fact occur in certain latitudes and areas regardless of soil or formation type (it even theoretically occurs in solid rock in the absence of water), whereas muskeg will likewise occur in many areas independently of freeze-thaw balance relationships, e.g. even in the tropics where freezing is totally absent.

**COMPARATIVE ECONOMICS**

**THE INFLUENCE OF FACTORED AIRFIELD PERFORMANCE OF LESS THAN 2000 FEET ON STOL SYSTEM ECONOMICS**

The de Havilland Aircraft of Canada, Ltd.
Downsview, Ontario, November 1969

De Havilland Canada STOL aircraft designs, it can probably be said in all fairness, have never run to extremely short field performance. This may perhaps be one reason why the DHC-6 Twin Otter is now being widely used in essentially non-STOL applications, for the lack of expressive extra-special STOL design features have produced an aircraft of good economic characteristics for quasi-CTOL operations. For example, the possibilities of increasing the DHC-6's coefficient of wing lift through such expedients as leading edge droop or slats, or as triple-slotted flaps, have not been pursued. We now have a proposal for a DHC-7 model following the same tradition, and the prospects are that it will not be capable of a factored airfield length, at maximum gross weight, of much less than 2000'. Since FAA has been campaigning hard for a total STOLport length of only 1800' (1500' nominal length, plus two 150' overrun areas), de Havilland seems to have found it necessary to put forth their own viewpoint in a series of reports such as that now under review.

The report's own Summary outlines the form of the argument:

'An examination has been made of the variation of operating costs with airfield performance for STOL transport aircraft. The study considers the increase in direct operating costs which result from reducing the airfield performance of a current technology 48-passenger aircraft from 2000 to 1500 feet, and the improvements in direct operating costs which result when the airfield performance is relaxed from 1500 to 2000 feet for a '1980 technology' 100-passenger transport.

'The study goes on to consider the effect on overall profitability and passenger attraction of a STOL system when airfield performance changes and concludes that severe penalties result from a reduction from 2000 to 1500 feet in the case of the current technology aircraft and that a substantial improvement in profitability and traffic levels results from the use of 2000 ft. runways in the case of the advanced technology aircraft.'

The task of designing an aircraft to U.S. regulations (FAR or Federal Airworthiness Regulations Parts 25 and 121) is outlined, and it is indicated in principle that, since designers always work to what they consider to be the maximum practical wing lift coefficient, the only conceivable ways to reduce field length requirements are (a) to off-load the aircraft of some of its useful load, and (b) to increase wing area. It is implied that nothing can be done about the coefficient of lift, i.e. that wing loading can only be reduced for improved performance.

On this basis, it is stated that the DHC-7 would require the removal of 1/3 of its passenger load to save 100' of field length, so that to save 300' it would have to fly empty. This method of improving performance is considered prohibitive.

Increases of wing area bring about numerous changes, such as in structural weight and cost, drag, and in passenger capacity for given engine power. The report examines these, and finds that some are secondary and can be ignored. Taken together, such factors produce a combined direct operating cost increase of 40% (10% for drag and 30% for weight) in comparison with the present DHC-7 figures, if a 1500' field length requirement is to be met by means of a wing area increase only. Cruise speed decreases coupled with increased fares are forecast to reduce passenger appeal as an outcome of this approach to airfield performance improvement.

Costs on the aviation side of the total STOL system may be justified by cost savings on the ground side if the latter should exceed the former, but de Havilland claim to show that this is not the case. Despite the importance
of the fact that the coefficient of lift question has been quickly glossed over in this report, the comparison of aviation and non-aviation costs must be recognized as the real "crunch" or nub of this discussion.

The airport costs quoted are not of de Havilland origin, and have been rather obscured as to meaning unless one can consult their source documents. In addition, the treatment of cost information is quite illogical at times; whereas the real considerations affected by runway length do not normally include such items as the ground access system and the terminal building, these have been mixed in and then later presumably more or less factored out again, on a percentage basis. The treatment does not inspire much confidence in the probable accuracy of the conclusions reached. As to questions of physical feasibility of different runway lengths within different environments, this matter is skirted entirely.

The report's Figure 3.8 graphically compares DHC-7 fleet operating cost with the cost of a network of U.S. Northeast Corridor STOLports, and ostensibly proves that the latter under no conditions approach the former. However, the STOLport system curve is certainly erroneous in at least one respect, for it fails to take cognizance of any increase in costs with increases in runway length. Valid conclusions cannot be drawn on this basis.

Similar reasoning is next applied to the case of an augmentor-wing, 1980 technology jet STOL aircraft, with quite similar results. Again, Figure 4.4 fails to show any variation of STOLport costs with length.

The following passage quoted from the report's page 30 makes an interesting summary of the approaches taken to this study:

'This naturally raises the question of considering an increase in STOLport length above 2000 feet to take further advantage of reduction in aircraft direct operating costs. However when de Havilland discussed longer STOLports with airlines, city planners, and government agencies a very sharp reaction was received.'

To which one might add 'amen', as we already have CTOL and don't need to reinvent it.
airports providing service for the same number of passengers; vertiports have a greater cost advantage in larger cities than in smaller; and, that advantage may be increased by locating the vertiport more distant from the CBD. The vertiport advantage varies, for the cities shown, from $1 per passenger per terminal to about $19 per passenger per terminal depending upon the city land value base, vertiport distance from CBD, and city-airport location.

'Major known omissions from the study are the effects on costs due to air pollution, noise, clear zones and special low-altitude in-city air traffic procedures that might be required.

'It has been anticipated that airline operation of VTOL aircraft in Instrument Flight Rule (IFR) weather will pose new, and as yet unsolved, problems. VTOL aircraft have slower landing speeds than conventional aircraft; therefore, unless separation standards can be reduced in direct proportion to the reduction in landing speed, a given instrument (ILS) runway or pad will accept fewer VTOL aircraft per unit time than conventional aircraft. The FAA has the problem under study. It is not clear at this time the extent to which the minimum separations between VTOL aircraft can be reduced, so the problem remains a serious one. One NASA source estimates that a VTOL pilot can execute an approach and landing in 1-1/2 minutes under visual conditions; a minimum of five minutes of high-power approach time is required under instrument conditions.

'The air traffic control situation is taken into account in estimating costs by employing a VTOL operations rate of 45 movements per hour for a two-pad vertiport with a single ILS pad, and 100 aircraft movements per hour for a conventional airport with parallel ILS runways. It should be noted here, however, that further study of this problem is clearly indicated.'

A regression equation is developed showing land values as a function of the distance from the Central Business District (CBD). It is demonstrated that land values decline very rapidly in absolute value at short distances from the CBD, and much less rapidly thereafter. In Chicago, for example, the estimated 1985 value in 1968 prices is $3.8 million per acre at .5 miles from the CBD to roughly half that value, $2.1 million per acre at 1.0 miles, a difference of $1.7 million. On the other hand, the decrease from the value at 5.0 miles ($512,000 per acre) to the value at ten miles ($281,000 per acre) is only $231,000.'

'The regression model shown in the next section is not intended as a predictor or estimator of the price of any individual parcel of land anywhere. It is used to show a number of general relationships; specifically, that the relationship between land price and distance from the CBD is not linear but exponential, and that land located identical distances from the CBD vary in price from city to city.'

'This regression is used in the calculations which follow ... to estimate prices of unimproved land:

\[ R = \frac{844 \times \left( \frac{P}{10,000} \right)^{0.309}}{(10M)^{0.971}} \times (A)^{0.971} \]

where:

- \( R \) = price of land ($/acre) in 1965 prices
- \( P \) = 1960 population of urbanized area, including urban fringe
- \( A \) = 1960 urbanized land area in square miles, including urban fringe
- \( M \) = distance from CBD in miles.

This model is a further development by the McDonnell-Douglas Company of an earlier, more complex relationship having additional terms for the sum of retail sales and manufacturing value added, and the number of central business districts in a given urbanized area.'

The foregoing assumes, of course, that land costs are fixed by the conditions of an open market. Perhaps this may be said to be so for the 'opportunity costs' of even city parks, for example, for as an alternative to the maintenance of parks as such, the land could theoretically be sold for commercial purposes. (Would such sale, though, drive down values in adjacent areas, perhaps even more than the city might realize in the sale? It is a moot point, but not for discussion here.) In practice, one may perhaps hope to find publicly owned, centrally located STOLport sites to be had almost for the asking, because of the public's acknowledged need of transport. For example, the Toronto Harbour Commissioners have an obligation to maintain a waterfront-area airport, and have shown every sign of cooperation in the provision of new lands as a replacement for the existing Toronto Island Airport, slated for redevelopment; in practice, then, the site for a Toronto downtown STOLport would not seem likely to involve a cash purchase cost related to
the commercial scale of land values in the area, although it is conceivable that some landfill costs might be charged, should a STOL site be sold by the Harbour Commissioners to the Ministry of Transport. (This discussion, by the way, must be viewed as pure speculation, for the sake of illustration only; terms of any possible agreement between the parties mentioned are entirely unknown at the present time.)

While the emphasis heretofore in this review has been on land cost questions, the paper in fact also uses equations for, and discusses in some detail, the costing of carparks, terminal buildings, and aircraft operating areas. The information provided appears very valuable for planning and estimating purposes, but its validity for Canadian applications has not been verified in this review.

The paper explicitly discusses VTOL on one hand and CTOL on the other, without examining STOL in the middle. This fact only slightly lowers the relevance of the paper to STOL studies.

**NETWORK PLANNING, STATISTICS, FORECASTING**

**FORECASTING INTERCITY TRAVEL**

E. K. Culley
Research Division, Canadian Transport Commission, Ottawa


While not based upon it in any way, this paper may be considered to extend the line of enquiry begun in 'An Application Of The Gravity Model to Canadian Domestic Intercity Airline Passenger Traffic' in certain respects; a synthesis of the two somewhat different approaches appears highly desirable.

The present paper goes some way toward quantifying many of the functions which could only be alluded to and guessed at in 'An Application Of The Gravity Model to Canadian Domestic Intercity Airline Passenger Traffic'. This brings the investigation considerably closer to being based upon the fundamental cause-and-effect relationships affecting intercity travel without, however, yet having reached the final disentanglement which might perhaps allow our full comprehension of the phenomena involved, and allow us to make predictions with full confidence in all cases. An ultimate understanding of the entire problem may not be as difficult to achieve as a solution to the mystery of life, but the analogy at least has enough validity to suggest that a good deal of further research effort could certainly be expended in this area.

This paper reports on an investigation into passenger travel between city pairs within the 'corridor' of cities from Windsor, Ontario to Quebec City, Quebec including numerous intermediate points, Toronto, Ottawa and Montreal among them. The thirteen largest cities involved contain 8 million people, or roughly 70% of the combined populations of the two provinces. The investigation deals with intercity distances considered to be relatively short in 'An Application Of The Gravity Model To Canadian Domestic Intercity Airline Passenger Traffic', and helps elaborate upon some of the phenomena noted at the short-range end of the scale in the latter study. It can therefore be seen that the two investigations largely are mutually complementary; however, of the two, Mr. Culley's paper is the more significant to STOL studies, associated as STOL is with short range.

Only travel entirely within the Windsor-Quebec corridor has been dealt with; through and connecting traffic has not been covered. It is early noted that the traffic pattern experienced to date is 'disjoint', i.e. that traffic is very light between city pairs having one member west of Toronto and the other east of Montreal. This finding is taken by Culley to be related to a language difference factor, which seems something of an oversimplification at present; perhaps the linear configuration of the chain of cities, the important intervening opportunities presented by the large metropolises of Toronto and Montreal, and the hierarchical structure which places some cities within the sphere of influence of one central metropolis and some within that of the other should be regarded as having equal potential significance.

Sociological characteristics of the market area population are reviewed as the basis of the various operative factors which are brought into the model which the paper presents. Attention is particularly focussed upon the Toronto-Montreal city pair, which dominates the travel pattern within the corridor studied. Current common carrier modal splits on the more important routes are also indicated. As to the very important place of the automobile for the relatively short range travel involved, 'The approach used is to regard the common carriers and the automobile as two distinct but competitive systems. The model is formulated in such a way that the automobile volumes
need not be known in order to determine the parameters of the common carrier model. This approach is acceptable to the general requirements of the study as all of the new technologies under investigation are of the common carrier type. The model predicts the shift of traffic between automobile and common carrier."

The 'modal split model' arrived at therefore specifically permits predictions for the common carrier modes, including STOL as distinct from CTOL in one instance. The model consists essentially of a fairly complex formula which derives annual intercity common carrier passenger trips on the basis of inputs regarding population masses, language, income, automobile competition, and common carrier characteristics in the main. Intercity distance is indirectly represented by trip time and cost factors.

Approaches such as this are of great importance in establishing the degree of viability of future STOL service markets, because historic data on STOL system performance do not yet exist. In this respect, reference is also made to 'Computer Simulation of V/STOL Services'.

R-2

COMPUTER SIMULATION OF V/STOL SERVICES
D. A. MacLean
R. Dixon Speas Associates of Canada Ltd.
Montreal, 1970

Paper presented at Canadian Transportation Research Forum's 6th Annual Meeting
Winnipeg, May 6, 1970

This paper basically relates to the development of a computer simulation model intended to facilitate study of the STOL - CTOL split of the aviation market between any given city pair. It has taken the Toronto - Montreal pair as an example, but the conclusions reached relative to this example are highly tentative and may in fact only be regarded as proof that the model runs successfully at the present time. Owing to the oversimplification of the test input data used to date, and also owing to the relative simplicity of the model itself at present (it considers only a single pair, for example, with one CTOL and one STOL airport in either one, i.e. without allowing for the Ste. Scholastique airport now being built near Montreal), the main significance of this report is to point out that work has been done which, if eventually carried far enough, could produce a very useful tool for studying a transport system including STOL linkages.

Unfortunately, the paper's introduction immediately makes it clear that the project is considered to be complete as it now stands. This fact prevents an unqualified relevance rating of 1 being assigned, since the study's results could only be considered relevant if they were in some way usable.

This study shows signs that it should have been more closely coordinated with that reported in 'Forecasting Intercity Travel' and could most probably also have benefitted by taking cognizance of factors discussed in 'An Application Of The Gravity Model To Canadian Domestic Intercity Airline Passenger Traffic'.

Certain policy assumptions are adopted by MacLean, 'In order to limit the total work package to manageable proportions within the time and cost limitations of the project.' Such assumptions include those that the major CTOL carrier on the Montreal - Toronto route (Air Canada) will also operate STOL non-competitively, the carrier's profits being maximized, and that the forecasts of air passenger demand would be invariable. The latter assumption flies in the face of Culley's finding in 'Forecasting Intercity Travel' that the addition of STOL competition would attract customers not only from CTOL, but also from rail services. MacLean has stated verbally that the input data could be balanced manually to correct for the latter factor, but to do so would be to introduce an important element of non-computer, non-simulation.

The major part of this paper is devoted to methodology which need not be reviewed here in any detail. Flow diagrams and a sample printouts are included in the presentation.

The summary of findings emphasizes that the air transport system is being compared, with and without the addition of STOL linkages. On the basis of the assumptions made and the approach followed, STOL is found to capture about 15 percent of the air transport market (and of course none of the ground-modes transport market) and is considered marginally profitable to the carrier. Total trip cost and time savings to

*And no doubt even more significantly from the automobile mode as well; this mode now may have the lion's share of the Montreal-Toronto market, and could contribute heavily to the STOL market.
the customer are found to be very marginal (again, comparisons are restricted to CTOL and STOL only). The economics of providing new STOLports instead of new CTOLports is not discussed, and in fact the costs of fixed facilities are not taken into account.

If the investigation were to be expanded and refined it would be capable of providing a very important input to STOL studies.

FUTURE TRANSPORT SYSTEMS
E. E. Marshall
Flight International, Vol. 96, No. 3148
London, 10 July 1969

The article presents extracts from the 16th R. J. Mitchell (Spitfire's designer) Memorial Lecture to the Royal Aeronautical Society, and is mentioned in conjunction with the R. Ae. S's convention on 'Short-range Air Transport' -- other papers from which might well be of interest also.

Noting both the 'total transport system' and the intermodal competitive aspects relating short-haul means of transport, the author first examines costs, capacities, and seat-mile costs of various highway and railway vehicles and systems. The review is then expanded to look briefly at ships, air cushion vehicles and hydrofoils and finally at commercial aircraft.

The caption of a graph relating block time to travel distance for various modes reads as follows: 'The car is competitive for distances less than about 50 miles because it has no fixed time element. Beyond this distance, and up to about 250 miles, the train is best, especially the tracked hovertrain. About 250 miles an aircraft system operating between city-centres would be the best.' These findings require qualification as follows: (a) a 60 mph cruise speed is assumed for the auto, beyond about the first 10 miles, but this performance may not always be feasible, (b) the graph does not very closely bear out the remarks concerning the competitive potential of trains, as the 'city-centre air system' curve cuts the 'train 75 mph average' curve at the same 50-mile range as applied to the auto (the conventional train would thus seem to have no preferred place, as the auto apparently is preferable below 50 mi. and the city-centre air service is at least theoretically preferable about 50 mi.), while the hovertrain curve is overtaken rather shortly above the 200 mi. range; (c) the tracked hovertrain idea is only a somewhat theoretical possibility at present, perhaps even more so than city-centre STOL in view of the right-of-way requirements of the former and (d) there will always be large variations in order of preference among modes according to individual tastes, resources (some people do not own or cannot drive a car), needs (sometimes a car is required at the destination) and convenience of passengers, and according to the types of service and the schedules (if applicable) joining different points of origin and destination, not to mention terrain questions (e.g. bodies of water).

Interestingly, the caption of the next graph, also relating block time to distance, begins 'For short distances up to about 100 miles the car is the quickest form of transport, and when compared with current trains it is competitive up to about 350 miles.' Since these extracts from the original paper contain contradictions, the article's value for some purposes is seriously compromised.

Nonetheless, the author does present some relevant views on STOL, and a 'typical' British Aircraft Corporation project study of a 100 passenger STOL airliner powered by four high bypass ratio turbofans is of some interest, partly for its background illustration of an elevated STOLport concept.

The gravity model for traffic between urban centres is used as the basis for a finding that a rail link between large cities more than 500 mi. apart would be unjustified by the traffic potential, whereas a CTOL air line would be justified and would furthermore give quickest service, even with peripheral airport sites. For large cities closer together, a rail link becomes viable and the speed advantage of air services disappears unless more central airport sites can be employed. However, a single central site in either city is not the answer, as populations are not concentrated in such a pattern. Multiple, compact V/STOLports would then be the recommended answer. For smaller cities at similar ranges, rail services would be uneconomic and fewer STOLports would be used.

Some specific possible STOLport sites for London are identified.

'Forecasting Intercity Travel' is considered to provide a more reliable view of the modal split question, especially in its Canadian application.
AN APPLICATION OF THE GRAVITY MODEL TO CANADIAN DOMESTIC INTERCITY AIRLINE PASSENGER TRAFFIC
Dept. of Transport, Air Services, Const. Eng. & Arch. Branch, Ottawa, November 1968

This paper examined the applicability of the gravity model (evolved by a series of investigators to apply to human interaction the principles of Newton's law of gravity, whence the name) to air travel among eight Canadian cities having international category mainline airports. The basic gravity model attempts to simulate market conditions through consideration of only two basic factors, viz. population masses and distance between their centroids. It was recognized in the paper under review that numerous other factors would in fact come into play, and an attempt was made to correct rather intuitively for these in order to allow a calibration of the basic gravity model, insofar as was possible. Such a calibration having thus been arrived at, it was suggested that the gravity model might next be applied as a means of cancelling out population mass and distance effects, so as to allow the remaining, often more obscure factors to be more easily studied.

The treatment was considered very preliminary and was intended mainly to allow an evaluation of whether additional research in the area might be justified. The results seemed to be quite positive on the latter question, but the author has not subsequently worked in this area whereas several other investigators have done so, as will be apparent from additional papers reviewed here and also from further reference material provided by their bibliographies.

While this study's input data related to CTOL performance in the marketplace, the principles discussed in the paper could largely be applied, with suitable modifications, in an examination of the STOL market as well. Certainly some means of obtaining a reasonably reliable overview of the probable market for STOL services is needed, direct observation being impossible at the present time owing to the nonexistence of commercial services in this category.

Additional papers relating to this subject include 'Forecasting Intercity Travel', 'Traffic Forecasting and the Gravity Model', and 'Computer Simulation of V/STOL Services', more particularly the first two.

OPTIMUM ALLOCATION OF TRANSPORTATION TERMINALS IN URBAN AREAS

This study was carried out in connection with the High Speed Ground Transportation investigations of the U.S. Northeast Corridor project, but its findings seem germane to an urban STOL system investigation, as well.

Considerations of ground access time and cost optimization within a large metropolitan or megalopolitan area tend to lead to the concept of a multi-terminal (or multi-STOLport) solution. This report describes the use of an unusual mathematical model in the study of various such solutions. The model employs the simplifying assumption of homogeneous or continuous conditions, as opposed to the alternative 'network' approach in which an explicit transport network of links and nodes (points of assumed user concentration located at centroids of defined areas, the latter being divided up finely enough to be each considered as a discrete unit with little error) is treated in a relatively complex set of processes.

The assumption of continuity allows the analysis to proceed on the basis of a simple mathematical relationship between transport demand and distance from the urban centre. Such a relationship facilitates the application of calculus to the problem of optimum terminal (or STOLport) allocation within the overall area. Further assumptions concern travel paths and travel impedances and velocities. Calculations are carried out first for the single terminal case, and then for multiple terminals.

While the particular assumptions used in this study produced the city centre as the optimum location for a single transport terminal, the report points out that a close second choice would be a ring of locations at a radius of roughly 3 1/2 miles from the centre. The reason is that congestion around the central area is assumed to be such that this location's obvious advantages are nearly cancelled out by its relative impenetrability to ground access to and from other zones. An assumption of yet further central congestion could presumably have made the 3 1/2 mile ring preferable to the centre as a favoured transport terminal location. (On the other hand, though, it should be noted that any centre not suffering from rather intense congestion is likely to be the preferred location,
by a wider margin than suggested in the report.)

Examination of multi-terminal cases allows a visualization of the quantitative benefits derived by the addition of stations to the system; action of the diminishing returns phenomenon is noted as stations are added.

A comparison of two transport systems each having three terminals, shows in this report that the layout having a ring of three non-central stations is superior to that having one central and two outer stations. On the other hand, a network type of analysis by another author (see below) is described, in which it was found that, 'In every case the best arrangement obtained closely approximated a central station and an equally spaced ring of outer stations, despite the fact that a number of appealing arrangements were tried.' In the practical (Boston) case involved, the latter finding may be the more reliable.

Optimal terminal locations, at least as seen on the basis of criteria used in Mr. Cramer's paper, are found to be independent of size of demand. This finding is tempered, however, by the realization that the size of demand will largely determine the number of facilities which can be supported.

The paper contains an interesting-looking if brief bibliography, but enquiries have been unavailing to obtain access to a further, probably very relevant paper as mentioned above. The reference for this is as follows: O'Doherty, J. D., 'A Location Study for a System of V/STOL Airports in the Boston Metropolitan Area,' M.S. Thesis, Civil Engineering Department, Massachusetts Institute of Technology, Cambridge, Mass., January 1966.

TRAFFIC FORECASTING AND THE 'GRAVITY MODEL'
Rigas Doganis
Flight International, pp. 547-9, September 29, 1966

Although the two papers were composed mutually independently, as is apparent from their texts, that under review here covers essentially the same technique as did 'An Application of the Gravity Model To Canadian Domestic Intercity Airline Passenger Traffic'.

The historical background of the gravity model is better traced here than in the above cross-reference; apparently it was Henry Carey who first applied the gravity model concept to human interaction, in 'Principles of Social Science', Philadelphia, 1858.

Ravenstein and Lill also made 19th century applications of the principle, and in 1951 D'Arcy Harvey suggested its use relative to air traffic, while working for the Civil Aeronautics Board. Since that time, the main problem has been to develop and employ suitable modifying factors so as to produce empirical corrections making the basic theory fit the observed facts.

Harvey corrected for two factors: community economic character (function) and density (number per unit of area) of communities within a region. Since that time, unfortunately, the theoretical formula has usually been employed without such corrections, e.g. in submissions to licensing boards. Wheatcroft has used a single 'community-of-interest' correction factor, but evidently without explaining how this might be established or measured. In the present paper, Doganis makes an initial trial application of Wheatcroft's principle by selecting six European routes supposedly having a constant community-of-interest factor. The problem is that he equates similarity of industrial function to community of interest, thus disregarding such important questions as language differences and cultural factors (e.g. administrative links) which would also affect community of interest. Since the resulting correlation of predicted and measured traffic levels is unsatisfactory, Doganis goes on to examine alternative approaches.

The population factor of a town obviously needs modification, as an assumption that one thousand people will generate constant air traffic whether they are shoemakers or bankers is clearly false. Sub-factors influencing the traffic generative capacity of town populations include town function, income levels and demographic structure, quality of airport service, size of air-passenger hinterland, and degree of over-shadowing by larger centres.

Rather than make modifications for each sub-factor separately, blanket corrections have been applied by employing specially selected populations, e.g. visitors registered as hotel guests, or total air passengers, rather than general community populations. Doganis prefers the total air passengers approach, and points out that it obviates measurements of hinterland boundaries etc, while incorporating a number of correction factors at the same time. On this basis he obtains a considerably improved correlation between forecast and observed traffic.

In search of further improvement, Doganis next examines possible modifications to the distance factor. Although he mentions modal split competition and its
diminishing effect with increasing distance, the analysis here is not very penetrating; he ends by concluding that an exponent between the limits 1.0 and 1.5 should be applied to the distance factor of the gravity model (comparing well with a value of 1.3 found in ‘An Application of The Gravity Model to Canadian Domestic Intercity Airline Passenger Traffic’).

The use of existing air passenger statistics as a basis of gravity model calculations appears at first to be very rational and neat, but one should perhaps wonder whether it is altogether useful? How, for example, could one use it to predict the size of air travel markets in instances where no airport is at present in existence, or possibly even where potentially important routes have not yet been developed even though an airport does exist? Another possible objection is that the Doganis approach fails to delve into the inner workings of the various market influences, and thus fulfils only a limited research function.

In the end, the inability of Doganis to come considerably closer to an ideal correlation than he did may lie almost exclusively in his abandonment, in effect, of Wheatcroft's 'community-of-interest' concept. City A might generate a good deal of traffic in, say Central U.S.S.R., while City B might do the same in Midwest, U.S.A., but owing to a lack of common interests (based on language, religion, political system, family relationship, administrative ties, vacation traditions of whatever), the traffic between them will probably be nil, regardless of the factors considered by Doganis.

It is interesting to note that his forecasts are below actual performance for linguistically similar cities in general, and above actual performance for linguistically dissimilar ones.

Wheatcroft's concept is similar to one fundamentally underlying the cross-reference mentioned above for which reason, along with a point or two of methodology, that report may be taken as an important supplement to the paper under review here. Attention should also be drawn to 'Forecasting Intercity Traffic' which helps to further enlarge the overall scope of our knowledge of the factors involved, to an important degree.

This is definitely a specialists' paper, of interest (and perhaps of greater meaning) principally to economists and statisticians. Since it does not apply directly to STOL systems in any specific manner, it is given a low relevance rating. Nonetheless, economics being central to the present study, the subject cannot be overlooked, and this paper and its references appear to provide a valuable specialist's introduction to the particular questions of economics and statistics as related to transportation as an industry.

The paper considers economic input and output characteristics of the transportation industry, but largely concentrates on the latter, and upon statistical measurements applicable to the output side.

Peculiarities of the transport industry's output include its 'directional' characteristics and the non-storeability of transport capacity, as well as the normal condition that transport vehicles must eventually circulate back to their points of origin, whether a payload can be carried in that direction or not (pipelines are not subject to this condition, as in this instance the commodity is its own vehicle, in a sense). The non-storeability of transport capacity results in capacity production exceeding demand for it, so that partial utilization of production is normal. For this reason, different sets of statistics are kept for transport capacity production, consumption, and utilization rates.

Output statistics are further analyzed by function, i.e. in terms of line transport, terminal handling and support operations. The allocation of factors of production between these activities or functions is reflected in the 'functional' cost classification, whereas the costs of employing the various factors of production are reflected in the 'objective' cost classification; a matrix shows the relationships between these two cost classifications and indicates the general method of accounting for such costs.

Several categories of statistics are discussed in some detail. The degree of specialization of this paper is illustrated by the fact that it enters at length into the rather arcane question of the homogeneity or heterogeneity of ton-mile measurements.
MEANS OF INCREASING AIRPORT CAPACITY

M. A. Warskow

World Airports - The Way Ahead
Proceedings of a conference held in London 23-25 September 1969
The Institution of Civil Engineers
London, 1969; with discussions

The main concern of this paper was how to extend the capacity of the world's system of heavily burdened major international airports. Various means were examined, including Computer Aided Approach Systems (CAAS), and the development of additional major runways.

STOL was treated as another means to the same end. First, STOL could operate at new sites altogether, to relieve demands at the international airports; second, STOL could be used to increase the capacity of the international airports themselves. The latter proposal is summed up as follows:

'In locating a STOLport on the airport itself, it is essential that it be positioned so that its ground and air access are completely independent of conventional aircraft operations. More clearly, then, it must be so established that it is a complete addition to the capacity and operation of the airport and not a substitute for existing operations.'

This proposal is considered fallacious to the extent that it would encourage uncoordinated ground transport, passenger and baggage handling, aircraft servicing and so forth. It is considered sound to the extent that the provision of separate airspace and runway/taxiway facilities is involved. It is evident that the author's expertise is in the latter area, and in fact he works for a firm known for its leadership in airspace/runway capacity technology.

One of the principal lessons provided by the paper and its discussions is how important it is to plan and reserve land for new airports well in advance of antagonistic urban developments and inflationary land speculation. The lack of timely action of this kind has created today's need to expand the existing sites' capacities; one discussion closes as follows:

'Have we not now reached the time when we shall have to stop thinking about how big we can build airports, and start thinking about how big we ought to make them?'

This question raises the very important matter of developing a national strategy of airport sizing, spacing and location, in relation to market requirements, airspace limitations and so forth. A coherent policy in these matters is as important in the realm of STOL as in that of CTOL; several other literature references bearing on this matter will be reviewed in this series. The present report, however, adds little to our appreciation of this subject.

This report is closely associated with that in 'STOL Operations' as the two were presented and discussed more or less together.

FLIGHT SAFETY AND OPERATIONS

ANOTHER LOOK AT ACCELERATE - STOP CRITERIA
T. G. Foxworth and H. F. Marthinsen (ALPA)
AIAA Paper No. 69-772
AIAA Aircraft Design and Operations Meeting
Los Angeles July 14-16, 1969
American Institute of Aeronautics and Astronautics, New York, 1969

Accelerate-stop criteria combine with aircraft performance criteria to define one of the length requirements which any runway must meet. From what is known of FAA's studies of optimum STOLport runway length, the accelerate-stop requirement is believed to be the governing one i.e. to be more critical for STOL than the distance requirements to clear a standard obstacle height upon takeoff or landing. There is an obvious interest on the part of the airport planner (from whose viewpoint this matter is presently under review) in any potential change to such an important feature of his work as runway length, especially where real estate and other restrictions may be very stringent as at a downtown STOLport.

There are very sound and cogent reasons why the certification of aircraft should be carried out on a realistic basis, and if the paper in question here should assist in this regard the airport planner will be among the first to applaud, perhaps especially if the result is that aircraft will henceforth be designed to operate safely within their already established environments rather than calling everlasting for modifications and extensions to the latter.

The paper's Introduction states the problem as follows:

'The airline pilot conducting the takeoff of a civil air carrier transport needs assurance that, should any foreseeable failure occur at any point along the runway, his aircraft has the ability either to stop safely or to continue and clear all obstructions to flight.'

Very simply, today's airline pilot does not always have that assurance.
'During any takeoff, there exists a definite point on the runway beyond which the capability to stop in the remaining distance available is insufficient. Until the airplane has reached this point, it can be safely stopped, but once past this point the airplane is committed to takeoff.

'How does the pilot know when he transits this point? His determination depends on the imperfect parameter speed, not distance. The \( V_1 \) (velocity one) concept was developed for civil air transport certification. Its intent was to provide the pilot sufficient information to decide whether to refuse the takeoff (below \( V_1 \)) or to continue (above \( V_1 \)); precisely at \( V_1 \), the pilot should - for one instant - have a choice, whether to go or to stop, and either way the choice should be equally safe. If the pilot elects to stop, the total distance required for the manoeuvre is called accelerate-stop distance.

'Very little emphasis is put on the fact that \( V_1 \), a speed by itself, is really meaningless unless the distance associated with this speed is also achieved. The \( V_1 \) concept assumes the aircraft acceleration to \( V_1 \) speed is normal. If the assumptions are valid and the speed \( V_1 \) has been chosen correctly, the airplane should reach \( V_1 \) with sufficient distance remaining to be stopped safely. However, it is quite apparent that in operational practice, the factors used to calculate \( V_1 \) and the associated accelerate-stop distance are inadequate, and do not provide the airline pilot with the safe alternative he requires. Under the performance concepts currently in use, the speed \( V_1 \) will not be reached until the airplane has already passed the point where sufficient distance remains for the typical airline pilot to safely stop his transport.

'The \( V_1 \) concepts is based on the sudden failure of one engine, since this was thought to be the most critical case at the time the regulation was developed; furthermore, the criteria for engine failure were readily subject to mathematical calculations, whereas other failures which occurred were not so easily handled. Thus, the speed \( V_1 \) has been labeled the 'critical engine failure speed'......

'This, however, should not have precluded other failures from giving the pilot the same equally safe alternative to the continued takeoff.

'....in airline service, acceleration must be at a rate equivalent to or better than the performance assumed for the airplane in certification; and if the pilot is to safely stop from \( V_1 \), the runway must be 'clean, dry, hard surfaced', and the pilot must apply brakes, retard throttles, and raise speed brakes within the assumed times.

'Service history indicates the assumption made in certification have not been realistic. We continue to have catastrophic overrun accidents, even when failures (for the most part, not engine failures) necessitating the takeoff refusal occur at speeds even substantially below the chosen \( V_1 \).'

'Positioning of the aircraft for takeoff already consumes some runway length, equal to at least the aircraft's length and possibly considerably more in the light of turning manoeuvres often required prior to initiations of the takeoff roll (the British have an end-entry taxiway design which should eliminate this waste and possibly even add to effective runway lengths). In addition, accelerative performance may be degraded by such factors as aircraft weight errors, runway surface conditions such as slush, adverse runway gradient, high temperatures (which at least are mutually exclusive with slush conditions), insufficiently conservative or out-of-date headwind/tailwind calculations, unexpected aerodynamic resistances e.g. resulting from crowinds, friction in brakes and wheels, and degraded engines. Further, the present FAA regulation is considered inadequate in relation to decision and reaction times during which the pilot must effect a transition from acceleration to deceleration. In this respect, British certification requirements and U.S. Air Force scheduling rules are preferred over those of the FAA by the authors.

'A flight simulator study of many pilots' reactions was carried out, and accident records were analyzed in this investigation. Among other conclusions of the paper is the following passage.

'(Under current FAA standards)....attempts to successfully refuse a takeoff -- even at speeds below \( V_1 \) -- will be impossible. Simulator data, for example, indicate that 9 out of 10 typical, experienced, alert airline pilots could not match the presently allowed distance....'

'It obviously would do STOL, and the community naturally, no good at all to suffer a catastrophic overrun accident in the downtown environment, but this report suggests a distinct possibility of such an occurrence if current FAA rules are followed. From the airport view as much as from any other, then, this is a matter of first-rank relevance.

V.38
A STUDY OF FOG CLEARING USING A CO₂ LASER
G. J. Mullaney, W. H. Christiansen and D. A. Russell
(Boeing Scientific Research Laboratories)
AIAA Paper No. 69-670
Fluid and Plasma Dynamics Conference
San Francisco, June 16-18, 1969
American Institute of Aeronautics and Astronautics, New York, 1969

The paper's Introduction reads as follows:

"The economic loss to the airlines in the United States due to the presence of fog at airports now amounts to 70 million dollars per year. In a decade this loss is predicted to increase to over 180 million dollars per year. A number of methods for combating the problem have been tried including fires, ultrasonic sound, and seeding. It was recently pointed out that haze and fog may be cleared by using a CO₂ laser beam, thus providing a new approach. 10.6μm radiation is strongly absorbed by liquid water because of an inter-molecular bond which is not present in water vapor. Thus, the laser selectively deposits its energy in the water droplet, ultimately evaporating it. Such a scheme offers the prospect of a more efficient energy utilization than approaches which rely on heating large volumes of air.

"In this paper the physics of fog removal by a CO₂ laser is investigated and the possibility of clearing airport runways is evaluated. Laboratory measurements have been made of the evaporation rate of fog when subjected to an intensity of 5 to 300 w/cm² of 10.6μm radiation. An induced fog motion was detected during these experiments which led to a re-evaluation of the energy deposition process. Analysis shows that in the range of the experiments a near-equilibrium evaporation of water takes place in the surrounding air. The clearing effectiveness of the laser under these conditions was also investigated with different fog densities, beam dimensions and geometries.

"The results were then extrapolated to airport dimensions and applied to the problem of clearing an airport runway of fog. Estimates of the power required to clear a specific volume to FAA specifications under various conditions of visibility and wind conditions were obtained. These calculations were compared with conditions at Seattle-Tacoma International and Los Angeles International airports using recorded meteorological data. While the estimates of the power required to clear a runway are large for present-day laser devices, they may not be excessive requirements for future systems. A suggested geometry for a laser installation on a runway is described, and the economic feasibility is assessed."

The 'induced fog motion' mentioned above in the second paragraph was a convective motion in which the cleared air moved upward and mushroomed laterally to swirl and mix with the uncleared air. This action, plus the continuous supply of fresh fog created by winds in the open air, would require a more or less constant power input to keep an airfield open enough to permit minimum-level Category II IFR operations.

The alternatives to the local clearing of fog would be (a) the use of instrument systems capable of providing non-visual guidance, or (b) the suspension of flight operations during periods of inadequate visibility. The last-named option could well be the most economical in normally dry and fog-free locations such as on the Prairies in some areas, and it may also be a political necessity forced upon STOL operations within densely developed urban environments. However, ground fogs and sporadic fog patches could conceivably be either cleared away or flown through on instruments even under the latter circumstances; the choice of methods may therefore come down to a matter for thoroughgoing economic comparisons and policy decisions. According to the paper under review, the laser system would cost about $1 million, and 'All-weather landing systems of the more conventional type for Category III-A and III-B conditions have comparable costs. Any system would require an additional investment in ground equipment for surface routing of aircraft during III-B or III-C weather conditions.'

The laser system's power requirements vary not only with wind strength, but also with wind direction relative to the runway orientation. As the report notes, 'Fortunately, airports are usually designed with the runways parallel to the local wind trends...'. For example, at only 100 cm/sec. (approx. 2 kt.) wind velocity, the power requirement is about 1.4 x 10⁶ watts with a pure crosswind, whereas it is closer to 1.2 x 10⁶ for wind parallel to the runway. The relationships indicated in the report's Figure 8 suggest that these power requirements would be further increased by factors of ten or so for 20 kt. winds.

At that, the volume of space which would be kept clear according to the analysis would be only 30 m. x 30 m. x 500 m., i.e. about enough just to cover a minimal STOL runway and provide a 100-foot ceiling. Such a cleared area certainly
does not seem overly generous, and the power consumption of the system becomes enormous for anything but practically still air conditions.

Add to this the fact that a good CAT II ILS system would still be required to bring aircraft down to the cleared air patch, and the laser proposal may be seen to have a questionable economic position vis-a-vis its competitors.

The paper under review may not be at all reliable in its economic judgements, but its technical findings are interesting. If applicable anywhere, the laser system would seem to be most applicable to VTOL, with STOL standing next in line.

THE FULL-SCALE MEASUREMENT OF THE DRAG AND SPRAY EFFECTS OF SLUSH AND WATER ON AIRCRAFT

R. L. Maltby
Royal Aircraft Establishment, Bedford, England
Institute of Environmental Sciences Mount Prospect, Ill. 1968.

Water and slush on runway surfaces can have important, and sometimes disastrous effects beyond lowering the coefficient of friction between aircraft tires and pavement. Aquaplaning or hydroplaning is a phenomenon in which contact between tire and pavement may be altogether prevented when tire speeds and water depths are such as to allow insufficient time for the water to be displaced away from the contact area. In addition there can be several further phenomena, such as severe drag on the aircraft, the adhesion of slush to the airframe, and the ingestion of slush and water by the engines, with which the present paper specifically concerns itself.

Selections from the paper's Introduction read as follows:

'The hazards to aircraft operation presented by slush and standing water on runways have been studied over the last decade although it is still difficult to forecast the magnitude of the effects in particular cases. During takeoff, the main effects are the possible damage to airframe and engines due to spray impingement and the large increase in rolling drag due to the displacement of fluid by the wheels, although the loss of steering control when the wheels are aquaplaning can also be serious. This paper is concerned with the results of experiments to measure the drag and spray effects on three types of aircraft.

'The term 'slush' is normally understood to describe the state of melting snow when there is a high proportion of water present. If one stamps on ground covered with slush, it splashes, whereas snow could simply be compressed leaving the imprint of the boot in the surface. Slush is rarely a homogeneous material in natural conditions; the density varies from place to place and the material may contain lumps of ice distributed randomly within it.'

For purposes of this paper a simplifying description of slush in terms of its specific gravity is adopted although, 'In particular, it makes no contribution to the prediction of the trajectory of the particles nor of the quality which determines how the material might adhere to the external parts of the aircraft.'

Although at first slush drag was thought to be of negligible importance, 'Subsequent work both at NASA and at the British Road Research Laboratory showed that the drag on wheels isolated from the structure was, in fact, proportional to the square of the forward speed and that it can be expressed in the form common to hydrodynamic forces:

\[ D_s = C_{D_s} \frac{1}{2} \sigma_s \rho V_G^2 w d \]

where \( C_{D_s} \) is the slush drag coefficient, \( \sigma_s \) is the slush specific gravity, \( \rho \) is the density of water, \( V_G \) is the ground speed of the wheel, \( w \) is the width of the tire at the fluid surface and \( d \) is the depth of the fluid.

'The value of \( C_{D_s} \) for the wheel alone was shown to remain constant at about 0.7 for all speeds up to the point where the wheel begins to aquaplane and then to reduce as the speed increased further. Aquaplaning occurs when the speed is sufficient for the hydrodynamic forces on the tire to develop a lift equal to the load carried by the tire so that it is entirely supported by the fluid.

'This aspect of the drag was accounted for by the momentum imparted to the fluid as it is displaced by the wheel. A further source of drag, referred to as the 'mudguard effect', was recognized as coming from the impingement of the spray particles on the structure of the aircraft. Subsequent tests by FAA and NASA at the Atlantic City experiment in 1961 in which a Convair 880 was run through beds of artificially produced slush, showed that the total drag
including the mudguard effect could be expressed in the same terms with a suitable increase in the value of $C_D$. The amount of the increase will clearly depend on how much spray impacts on the aircraft but the total drag may be as much as two or three times the drag attributable to the sum of the displacement drag from the individual wheels. This increase in drag is large enough to have a catastrophic effect on the takeoff performance of many types of aircraft even with quite modest amounts of slush......

Apart from drag, the effects of spray on the airframe and engines can be serious and have to be established for each aircraft type. Ingestion by the engine can cause loss of thrust...... High energy spray can damage the aircraft structure (flaps are particularly susceptible) and impacting slush may accumulate and freeze up exposed mechanisms.'

The paper then goes on to describe research carried out in Britain using several different British (CTOL) aircraft types including two multi-engined passenger transports. In addition, it quotes information from other sources to provide quite a good total sampling of what is to be expected in connection with CTOL.

The question then arises as to the applicability of this work to STOL. It seems reasonable to suppose at the present time that STOL aircraft will be much like CTOL ones in respect of tire configurations et al, but will not reach the same maximum speed ranges while on the ground. Inasmuch as the published CTOL information covers a full speed range from 0 to 100 or 120 knots, at least the bottom half of the coverage would seem generally illustrative of effects to be expected in connection with STOL, given the presence of the indicated depths of water or slush at the STOLport.

It may be a reasonably simple matter to keep STOLports, with single 1800' - 2000' x 100' runways, clear of slush, but this raises the point that the planning of STOLports must provide storage and maintenance space for various kinds of maintenance equipment, including equipment for the removal of slush.
The Problems of Birds as Pests pp.97-105
E. N. Wright
Proceedings of a Symposium
London, September 28-29, 1967

MODIFICATION OF THE HABITAT AS A MEANS OF BIRD CONTROL
E. N. Wright
The Problems of Birds as Pests pp.97-105
Proceedings of a Symposium
Institute of Biology
London, September 28-29, 1967

The relative lack of operational experience which would directly apply to STOLports, and specifically to metropolitan STOLports, would seem to the layman to make the relevance of this report's subject matter somewhat unclear. The low speeds of STOL aircraft during airport operations would seem likely to modify both the probability and the potential seriousness, statistically speaking, of bird strikes at or near the STOLport in comparison with the same factors at CTOLports. In addition, the steps which might be taken to modify the habitat around generally rural CTOLports may seem to have but little applicability around metropolitan STOLports. These problems have been discussed with a bird strikes expert on the Canadian Air Transport Administration staff and he suggested that, at least for jet STOL, climbout power settings will tend to maintain the potential seriousness of the bird ingestion problem, requiring that undiminished care be taken to avoid bird attractions in the forms of food, water and shelter near or on the STOLport site, and to take positive repelling action as well if need be.

Bird strikes may of course occur either near to or remote from airports; short of an organized programme of wholesale destruction of wildlife, which would of course be very unwise for the future of the planet, still speak of it being politically unfeasible in any event, only the chances of bird strikes in the airport vicinity can be controlled through man-made modifications to the status quo. Away from the airport, bird collision avoidance must rely on radar information, on ornithological forecasts of migrations et al, on the appropriate selection of cruise altitudes and routes, and to some extent still on luck.

At the airport, if the number of birds present is reduced, the number of bird strikes will diminish. A variety of methods of reducing the local bird population rely on either killing or scaring off the birds; the birds are, however, resilient in the face of adversity, and scaring mechanisms, if frequently and repetitiously employed, tend to lose their effectiveness. While the effectiveness of scaring methods is high against itinerant birds, the local populations need to be handled otherwise. The best policy seems to be to keep the airport clean of attractants and to use a mixed sequence of scaring tactics (shell crackers, screaming shells, live shot, radio-controlled model aircraft, live falcons et al in rotation) as adjuncts to the basic tactics of good housekeeping.

Airports, at least in the CTOL sense, feature two distinct habitats, viz. the intensely urban terminal area, and the rural 'airfield' or aircraft movements area and undeveloped land zone. Characteristic animal communities inhabit either zone. In most cases, airfields resemble the surrounding environment, with wide open spaces and low vegetation which attract some species (e.g. gulls) but repel others. As normal access by man is virtually prohibited, birds such as gulls find airfields quite secure; such species rely upon flight rather than concealment for their safety, and appreciate good all around visibility. A survey of the airfield and its surroundings must be conducted in each instance to determine, for example, whether birds frequent a given site because it is the best in the area, or perhaps the only one.

As many STOLport sites may be located at or near waterfronts, the presence of gulls may perhaps be expected despite the relatively urban character of part of the environment. In addition, typically urban birds such as pigeons and sparrows may perhaps be expected near some urban STOLports unless steps are taken to make the neighbourhood unattractive to them, e.g. free of garbage, food scraps and weeds.

Some modifications to the environment
may go some way toward deterring the presence of one bird species, while encouraging others. For example, noting that gulls like a clear field of view, airfield grass has been experimentally grown long in Britain and New Zealand. Long grass may, however, encourage a large rodent population and attract birds of prey. In addition, starlings (such as caused a disastrous Lockheed Electra crash some years ago at Boston) have been found to prefer long grass.

This safety-related subject must be seen as fairly significant to sound STOL system operations. However, Canada has been a leader in the field, and it is only by chance that the present paper has become available for review earlier than numerous good Canadian references.

AIRPORT PROBLEMS IN FLIGHT OPERATIONS
E. L. Killip (BEA)
The Aeronautical Journal, Vol. 73 p. 495
The Royal Aeronautical Society
London, June 1969

This is a CTOL - and aviation - oriented paper, being examined in the present instance from a STOL and airports (ground facilities) viewpoint.

Being apparently preoccupied with the goal of keeping his airline's aircraft flying in all weather, the author summarizes his attitude thus in his final paragraph:

'Where a choice has to be made, the complexity of today's operations demands that money shall go first to the construction of a good runway, proper lighting, ILS, radio communications and ATC. Money must also go the training and continued employment of the necessary skilled personnel to maintain and operate these facilities. You can then run a good operation and handle the passengers in a tent. They will be uncomfortable and you will be unpopular but you will not kill any of them that way. It does not work with the priorities reversed.'

The foregoing passage may be described at least as being controversial, but this does not seem the place to enter into controversy. The point here is to understand the background to the conceptions throughout the paper in hand.

The autoland system now in use in BEA's Trident CTOL airliners is apparently quite intolerant of ground irregularities along the last 1500' of flight path downwind from the runway threshold. For example, to be compatible with autoland the terrain in this area may have gentle undulations of only ± 3' relative to the plane of the runway, while a slope discontinuity exceeding a mere 1° near the threshold is considered unacceptable. In real life, it appears that autoland may have few applications as matters now stand, but this article's author seems to believe that the face of the earth should be changed if necessary, rather than that his company's equipment or the desire to use that equipment should be modified.

Certain recommendations are made by the author regarding the adjustment of approach slope angles and lighting. If generally approved and adopted such recommendations could most probably be accommodated without undue difficulty.

In view of important differences (such as 7 1/2° glideslope angle vis-a-vis 2 1/2° to 3°) between STOL and CTOL, the applicability of this paper's arguments to the STOL case is probably low. As to the autoland system in its CTOL application, this is required mainly because current ILS (invented in the 1930's) is now inadequate; the greatly improved microwave scanning ILS of the future promises to make BEA's autoland largely superfluous. It is likely that the new ILS will be used for all classes of aviation, including both CTOL and STOL; this is fortunate for STOL as much as for CTOL, since prospects are slim for ideal terrain outside the STOLport's threshold, among other factors.

THE PROBLEM OF ARRESTING BARRIERS
(Sul Problema Delle Barriere D'Arresto)
Salvatore Caggiani
Rivista Aeronautica, Vol. 45, pp. 432-454
March 1969

The article describes in some detail the physical factors involved in arresting aircraft and considers possible boundary conditions.

It also describes existing arresting devices, their advantages and disadvantages and proposed new developments. The article concludes that any system for civil aircraft would first have to be proven out by use in military applications. In any case such a system would only be considered to be applicable in emergency situations, and could not be used in lieu of longer runways in normal commercial operations. (Such conclusions have already been derived by FAA, as well.)

The subject is quite relevant to elevated STOLport requirements in the U.S., but with luck it may prove irrelevant in Canada if suitable at-grade sites
can be found and reserved for STOLport use. Part of the reason for this paper's 3 rating, however, concerns the language problem for most Canadian readers.

**RUNWAYS, TERMINALS, FACILITIES**

**AIR TERMINALS 1975**
Walter Hart - American Airlines
AIAA Paper No. 69-805
AIAA Aircraft Design and Operations
Meeting, Los Angeles, July 14-16, 1969
American Institute of Aeronautics and Astronautics, New York, 1969

This paper is not an outline applicable to all classes of air terminals as of 1975, but in fact discusses only a number of new American major terminals planned to handle the jumbo jets. These large aircraft were conceived in 1965, and terminal planning for them began in 1966. Completion of the facilities in question is expected by 1975, bearing out the generality that the planning and development of new major terminal facilities takes the best part of a decade.

In view of the sizes of facility involved, the content of this paper is not directly appropriate for STOL systems. The size of the terminals discussed comes about because of the centralization of CTOL activities at few, necessarily large sites, and not because of any particular operating characteristics (e.g. length of takeoff run) of the aircraft used; at least, not directly so.

A basic problem of terminals is how to bring together the passenger and the aircraft on one side, or the passenger and his ground transport vehicle on the other side. Especially the airside access problem can become very difficult, and all sorts of interface convolutions have been examined as means of bringing the passengers to the 'plane in comfort and safety rather than making him walk long distances unprotected over open apron spaces. The problem increases in its complexity and difficulty with terminal system size, so that one might perhaps really want to question whether economies of scale do exist. Since the tendency of CTOL is to go in for centralization and therefore for sheer size of operation, great difficulties have been met in this respect.

On the other hand, the watchword of STOL seems to be decentralization and size limitation. This is because the only appeal of STOL relative to CTOL can be in terms of easier and cheaper access, which implies that the STOLport should be taken to the people rather than the reverse. Obviously, the people do not all live and work in, or even near, a single locality, and 'neighbourhood' STOLports are called for.

We may therefore think of a future STOLport terminal as having more in common, perhaps, with the passenger facility at a modest-sized domestic trunk airport than with one at a major international-category site. It is the latter type, however, which is dealt with in the paper under review here.

Three basic cases may be discerned for the creation of new air terminal facilities. In the first instance there may be a totally new airport, such as at Dallas-Forth Worth, Texas, and the whole airport complex can be planned together. Second, there may be a new terminal developed in an existing airport, as at Boston Logan International Airport (or, for that matter, as at Toronto International where Terminal 2 is now under construction). Third, an existing building may be enlarged, sometimes very extensively; activity of this kind is in progress at several unit terminals at J. F. Kennedy International Airport, New York. All three cases are discussed in this paper.

Analyses have yet to be carried out to determine how passengers and baggage should best be interchanged between a STOLport terminal and the air and ground transport vehicles, and also how the passengers and baggage should best be handled within the building. One thing which seems plain, though, is that few problems can develop which have not already been encountered, and hopefully solved, at CTOL terminals. For this reason it is valuable to have the CTOL solutions on record, so that they will not have to be re-invented when required by STOL.

**AIRPORT CARGO FACILITIES**
FAA Advisory Circular AC 150/5360-2
Department of Transportation
Federal Aviation Administration
Washington, April 1964

This Advisory Circular is given a relevance rating of 2, not because of any direct applicability to STOL systems (it is definitely CTOL oriented), but because of the importance of sorting out the cargo question for STOL early in the current investigations. The content of this document may at least be taken as a baseline for the commencement of the required investigation.

The relative importance of cargo itself
to STOL will probably be quite variable by route type. In some northern transport, for example, parallel surface routes may be nonexistent, and all cargo must travel by air, i.e. by STOL, if only STOL services are to be provided. On the other hand, in many urban services envisaged for Southern Canada the ground links may be excellent, whereas the STOL air route lengths may scarcely justify the use of air transport for goods except in very unusual cases.

In neither circumstance does the flow of cargo via STOL services seem likely to be large. At northern CTOL sites now in existence, cargo is generally simply stacked on the terminal apron and loaded from there with a bare minimum of complication. It may be that with suitable modifications, some such pattern will apply at all, or at most, future STOL sites, owing to the minor volumes of cargo which may perhaps be handled. However, analysis needs to be applied to see whether these speculations are anything like correct.

While it does at present seem possible that STOL system ground facilities for cargo handling may uniformly be quite simple in all or most applications, the aircraft themselves will evidently have to be better adapted to cargo carriage in the north than in the south of Canada. That is to say, it seems likely that the ratio of cargo to passengers will be considered higher in the north than in the south as far as STOL systems are concerned; the aircraft involved may have to adjust accordingly.

Within FAA's AC 150/5360-2, Figure 13 on page 27 shows an air cargo complex with four separate buildings, a network of roads, and a cargo loading apron, which could altogether exceed the prospective size of an entire STOLport. Not specifically illustrated are additional adjuncts such as car parks and truck aprons associated with the separate buildings. Clearly this is not the sort of system that a STOLport either needs or could accommodate.

For years, off-airport cargo processing (containerization, palletization et al) has been mooted among airport planners. Spatial restrictions on STOLports could at last force such a treatment, if much cargo should turn out to be involved. More likely, however, would be the simple designation of a special cargo room within the passenger terminal, as is the case at Ottawa International Airport - an operation which might well deserve study within the present context, by the way. Such an arrangement would necessarily greatly simplify matters; for example, provision of a separate cargo-area car park would be superfluous.

The report under review contains three chapters, entitled 'Air Cargo Industry', 'Airport Cargo Center and Its Buildings' respectively, each chapter being divided into three sections and many subsections.

In special areas, a good deal of the content is of practical potential use for STOL systems; for example, the section on truck docking facilities will remain valid regardless of the type of aircraft involved.

*AIRPORT TERMINAL BUILDINGS*

Bureau of Facilities and Materiel, Airports Division, FAA
Department of Transportation
Washington, September 1960

The preface of this guide reads in part as follows:

'The Federal Aviation Agency presents this design guide to assist airport developers, architects, and engineers in planning airport terminal buildings and associated facilities to meet current and expanding demands of air users. Planners of airport ground facilities must recognize the aeronautical advances and transportation appetites of these users to match the degree of modernization attained by aircraft builders.

'Featured in the guide are discussions and recommendations on building space relationships, area requirements, noise control within the building, and building area planning. The recommendations were developed from material furnished by airport managers, airlines, architects, and from surveys of existing terminal buildings in large, medium, small, and nonhub communities.

'Information provided is intended to reduce but not eliminate research on the part of the architect, which is necessary to achieve an adequate, economical, and functional building. The goal is to answer the question 'How much to build?'

The subject is air passenger terminals. Air passenger terminals may vary from virtually one-room shacks in remote areas to very large, essentially industrial even though sometimes also palatial, multistoried buildings or complexes of buildings at major metropolitan airports. In the case of STOLport passenger terminals, it seems somewhat improbable that the range of facilities will go to the upper extremes already reached at CTOLports for reasons listed in 'Airport and Airport/City Ground Transportation -- Review of Applicable
The terminal has often been viewed as an interface between ground and air transport, although it also has the same function between connecting flights. The FAA broadens this view somewhat by calling it a service centre, thus implying that it does more for passengers and property than simply transferring them between modes. The passenger is in fact provided with seating, toilet facilities, food services, newsstands and so forth, in all but the most rudimentary air terminals.

In addition, important operational and regulatory functions demand that airlines and government services (ATC, meteorological, airport management, security, customs, immigration, health and so forth) be accommodated here or very nearby.

Pertinent terminal planning considerations are discussed under the headings of expansibility, flexibility, stage construction and materials. Because of the rapid growth and evolution of the air transport business, the first three of these are normally of paramount importance. In the case of STOL, which appears to be headed for built-in limitations upon airport and aircraft size, the degree of emphasis on these factors may be expected to change. For example, the theoretical ability to extend a building indefinitely through stage construction, according to a modular plan, might seem somewhat secondary if site or environmental limitations were to preclude developments of beyond one or two modules. The real modules of a STOLport system may in fact turn out to be the ports themselves; since the growth of demand is to some extent associated with the outward growth of urbanized zones, it seems conceivable that suitably high standards of STOLport accessibility may best be maintained through the modular decentralization and repetition of these facilities. An inaccessible STOLport would scarcely improve upon an inaccessible CTOLport. See also 'Optimum Allocation of Transportation Terminals in Urban Areas.'

Even when some air terminals built in the past were at first termed 'white elephants' owing to initial underutilization, they have eventually become overcrowded and have had to be extended or, where this has been impossible, replaced. Well thought out long range planning is called for as a preventative in future.

As seen by FAA in 1960, there were two basic types of passenger terminal, viz. centralized (characterized by the use of a single building) and unit operation (characterized by separate airline areas sometimes in separate buildings, but again sometimes merely in different portions of a single building). These two types in fact overlapped, and this reviewer prefers to categorize air passenger terminal concepts as follows:

A. centralized (with fingers, satellites, mobile lounges et al)

B. decentralized:
   i) unit (separate airline buildings, e.g. JFK)
   ii) extensible modular
   iii) nodal (a) with individually centralized nodes
       (b) with modular nodes

A basic problem with air terminals is how to connect numerous far-flung aircraft parking positions with relatively compact processing and service areas, and also with one another. To a large extent the foregoing conceptual classes denote varying attempts at solving the problem. A perfect solution is probably impossible at a large CTOLport, even though the stated classes have been arranged and rearranged in countless ways. Finding more modest STOLport solutions may be relatively simple, though, and perhaps relatively inexpensive, as well. Certainly the bulk of the basic terminal system investigations would seem to have been carried out already in connection with CTOL, as the guide under review helps illustrate.

Besides reviewing layout ideas, the guide provides traffic demand forecasting aids such as curves relating peak hour to total annual passengers. Another series of curves relates desirable floor areas, seats, feet of counter space and so forth to peak hour passengers, explaining how each facility involved should operate. Chapter III discusses jet noise control in terminal buildings and Chapter IV, somewhat out of sequence (the subject matter is more basic than that of building design), considers terminal area planning. Last but not least, ground access planning is covered, at least in outline.

In Canada, the function of air passenger terminal area design is largely centralized in the hands of the Department (or Ministry) of Transport, which has its own sets of policies, standards and procedures. For this reason, the FAA publication under review cannot be considered to have any official validity in this country; nor does it discuss the STOLport case, having been issued before STOLports were much thought of. For these reasons, important though terminals are, a relevance rating over 2 cannot be assigned to this guide.
This manual comprises a number of more or less independent sections, each of which forms in its own right a manual on a given topic connected in some way with airport pavements. In addition, the Engineering Design Division has printed a number of separate reports which supplement the content of the Pavement Design and Construction Manual.

Within the scope of its subject matter there is little left unsaid by the Manual, which is frequently updated to take into account the development of new aircraft types, especially when these are in the larger categories. However, the emphasis to date has been on CTOL (conventional takeoff and landing) aircraft and the pavements which these require, be the CTOL versions large (Type A design aircraft are typified by the C5 and the Boeing SST) or small (Type J typical aircraft include the Beech 18 and King Air, the de Havilland Dove and the Piper Aztec, while Type K involves unspecified smaller types).

While the Manual's specific reference to CTOL has no bearing on the structural design of pavements, on pavement strength testing techniques, or on drainage requirements and the like, it does somewhat compromise the applicability of the Manual's Section 13, 'Geometrical Criteria for Airport Pavements' (March 1968).

Section 13 is composed of parts on (a) aircraft pavements and related (airspace) geometrics, and (b) roadways. It is of course part (a) which is of limited STOL applicability. As it happens, however, part (b) is also under review at the present time, as it contains only standard Canadian Good Roads Association roadway design guidance, without specific adaptions for airport requirements.

It seems probable that future STOL aircraft will be more akin to the DC-3 than to the 747 or SST in this respect. While STOLport pavements should still be properly constructed, this matter does not at present seem of any unusual significance to the present study.

This rather technical analysis, brought about through a study of roughness problems at Anchorage (Alaska) International Airport, considers in the main the largest long-range aircraft of the day, with some reference to the DC-3 in relation to its own era but with chief emphasis on such current and future large types as the Boeing 747 and SST models.

Aircraft response to runway roughness becomes particularly significant if harmonic reinforcement builds up the aircraft's vibratory energy as an outcome of a coincidence of bump impact spacing (relative to time) with the aircraft's natural period of vibration. Relationships are such that severe problems may be encountered with large aircraft having high-speed landing and takeoff runs. Problems of this sort were minor or even unrecognized in the day of the DC-3.

It seems probable that future STOL aircraft will be more akin to the DC-3 than to the 747 or SST in this respect. While STOLport pavements should still be properly constructed, this matter does not at present seem of any unusual significance to the present study.
The low relevance rating applied to this paper is assigned from the standpoint of the majority of persons concerned with the present STOL technology study. To airport and ground access planners, and to other persons of similar interests, the paper's relevance would normally be considered much higher than the above rating suggests. Even for such persons, however, the importance of possible intra-airport transport would be diminished in the case of STOLports for several reasons:

(a) STOLports should be quite compact, with entire runways not over 2000' long, as compared with certain CTOL terminal proposals of the recent past involving lengths up to 5000' for the building alone. For the sake of further comparison, it may be noted that the tip-to-tip length of the present Montreal International Airport passenger terminal, with its attached Domestic and Transborder fingers, is about 2500', and that mechanical transport (other than vertical) is not provided along this axis;

(b) since CTOL will probably carry most longer-distance air passenger traffic on through hauls, the number of transfer passengers changing flights at a STOL terminal may be very minor, so that there may be few people travelling between arriving and departing aircraft through the system;

(c) if STOL terminals should involve the minimal passenger processing, as seems probable at present, then compact arrangements minimizing transport requirements seem feasible and desirable, again cutting down probable ground travel distances;

(d) if STOL is to succeed in attracting business, it must be for the reason of accessibility. This factor suggests a decentralization of STOLports to suit the distribution of demand, rather than the current normal CTOL approach of expecting users from far and wide to congregate at a single, central, and frequently huge CTOLport. For this reason, STOLports may be expected rarely to become really big, implying once more that intra-airport transport may rarely become essential for reasons of facility size.

As to the airport/city transport case, it seems self-evident that a STOLport must normally be considered only as a node in the overall metropolitan, municipal or regional transportation network. As such, the STOLport can scarcely expect to influence the systems employed very extensively, but only in very localized terms. This will particularly be true if, as suggested by point (d) above, urban STOLports are to remain modest in size and hence constitute minor traffic generators within their overall environment.

The report is not totally without foreseeable STOLport relevance, however, e.g. in connection with the carriage of invalids (a tractor drawn vehicle suitably equipped with ramps for wheelchairs was employed).

Either internally or externally, Expo 67 was served in some degree or other by automobile expressways, large carparks, the city subway system (an unusual rubber-tired type), various bus services, the Expo Express rapid transit system, two types of elevated 'minirail', hovercraft, helicopters and various other minor systems such as the invalid carriage mentioned above. This report outlines and gives performance figures for the major systems which are considered by IATA to have potential applicability to airport and airport/city transport. One feature, fairly likely to be relevant to STOLports in some degree, concerns the organization of carparks.

It is of course possible that even the minirail idea may find STOLport application when practical site studies are begun. However compact the STOLport, there could be a special site used, e.g. an island site offshore from the city's central business district, which might most readily be accessed by some such means. We shall have to wait and see.

APPENDIX V

General Perspective

THE AIRPORT PROBLEM
N. R. Montanus (Port Authority Trans-Hudson Corp., New York, N.Y.)
IN: World Airports: The Way Ahead;
Proceedings, London, Institute of Civil Engineers, 1969, pp. 31-33

Discussion of problems posed by the rapidly diminishing capacity of the air traffic system and airspace. It is noted
that ten years from now, traffic at the principal airports is expected to triple. The intervening decade will see a rapidly diminishing capacity of the air traffic system and airspace.

A solution to the problem of increasing the use of existing facilities requires additional airport facilities for general aviation, a concept embodied in a 1961 extension of the Federal Airport Act. STOL aircraft operating from either small independent STOLports or STOL runways may have great potential for relieving major airport congestion. In those metropolitan areas where airspace and airport capacity are not yet congested, general aviation growth should be anticipated and provisions made for it. Separate special purpose airports, STOL facilities, and where feasible, general aviation runways at major airports are the major elements of a planning program.

AIRCRAFT DESIGN AS DETERMINED BY AIRPORT FACILITIES AND THE ENVIRONMENT
D. R. Newman
Hawker-Siddeley Aviation Ltd.
Hatfield, Herts., England
Royal Aeronautical Society Inter-Relations and Inter-Face Problems Symposium

Consideration of the facilities of an airport, defined as the strength of its pavements and the sophistication of its passenger and baggage loading and aircraft handling provisions, and their effect on aircraft design. In addition to a high load classification number (LCN), thus making efficient landing gear layouts possible, runways must be smooth enough to keep vibration at an acceptable level. The use of auxiliary power units to make aircraft more self-contained with respect to terminal environment, especially with respect to noise and its abatement.

THE PERFORMANCE OF STOL AIRCRAFT
C. R. Newnes
Britten-Norman, Ltd. Bembridge Airport
Isle of Wight, England
Flight International Vol. 95, May 1, 1969 pp. 721-722

Discussion of the characteristics of short takeoff and landing (STOL) aircraft. Factors affecting their performance are discussed, and takeoff and landing data for a typical range of current STOL aircraft are tabulated. The certification of STOL aircraft is dealt with, and it is shown that at the present time their classification is the same as that of any other fixed-wing aircraft, capable of complying with Section K of the British Civil Airworthiness Requirements. STOL airfield requirements are considered, and it is shown that, while no special regulations for STOL airfields exist at the present time, they are under consideration by the Board of Trade. The FAA publication of 'Interim Design Criteria for Metropolitan STOLports and STOL Runways' is reviewed.

A REVIEW OF THE V/STOL SITUATION
Clifton F. von Kann
Air Transport Association of America
Washington, D.C.
Vertical World, Vol. 4, March - April, 1969, pp. 7-10

Discussion of the further evolution of such proven aeronautical technologies as VTOL and STOL aircraft. It is pointed out that the statutory obligation of the Federal Government must also include the development of V/STOL concepts. The subjects considered include operational concepts, the place of the V/STOL aircraft within the U.S. air transportation system, noise problems, and air and ground environments. The initiation of demonstration projects in some areas is recommended. The financial aspects of V/STOL transport need fuller exploration. Market estimates indicate that 350 to 450 commercial V/STOL transports can be exported in the next decade.

INTERCITIZEN

Review of intercity tests recently concluded by Eastern Airlines, Breguet Aviation, and McDonnell Douglas over the Boston-New York-Washington shuttle route. The aircraft, a Breguet 941 STOL, features full-span triple-slotted flaps and mechanically interconnected propellers. Of particular interest during the tests was the demonstration of a technique, developed by Decca at Eastern's request, that permits in effect a curved ILS approach. An onboard computer translates altitude and distance data into a conventional ILS display. Details are presented.

STOL AND VTOL OPERATIONS IN THE NATIONAL AIRSPACE SYSTEM
J. B. Barriage, L. N. Douglass and R. C. Conway
Federal Aviation Administration

Discussion of research on the ground and airspace facilities to be provided for V/STOL aircraft. FAA efforts include continuing research on instrument
landing systems, development of flight characteristics criteria, and planning for operations near or within metropolitan areas. Various air traffic control studies are being conducted by the agency. Several approach conditions, various glide slope angles, and separation criteria were investigated when advanced STOL and VTOL aircraft were introduced into a terminal area during a simulation study. Flight tests under way with STOL aircraft further examine the relationship between glide slope angle, rate of descent, and approach speed. These investigations are serving to provide FAA with criteria for planning of future ground and airspace facilities.

STOL/VTOL AIRCRAFT CHARACTERISTICS, TERMINAL NAVIGATION AND AIR TRAFFIC CONTROL
Joan B. Barriage and D. Michael Brandewie
Federal Aviation Administration
Washington, D. C.
Society of Automotive Engineers
Aeronautic and Space Engineering and Manufacturing Meeting, Los Angeles, Calif.
October 7-11, 1968, Paper No. 680666

Discussion of the characteristics of STOL and VTOL aircraft as a background to the manner in which they will be operated in both intracity and intercity operation. The impact on navigation and ATC is considered. It is pointed out that studies and research and development efforts to date indicate the approaching availability and requirement for STOL and VTOL service. The STOL-type vehicle is available today in a variety of forms, a large passenger-carrying STOL, and eventually VTOL, aircraft will be available in the future.

GENERAL STUDIES OF THE CHARACTERISTICS AND PROBLEMS ASSOCIATED WITH V/STOL OPERATIONS
Norman W. Boorer and Bernard J. Davey
British Aircraft Corp./Operating/Ltd.
Weybridge, Surrey, England
International Council of the Aeronautical Sciences, Congress, 6th Munich, West Germany, September 9-13, 1968, Paper 68-05

From a choice of a wide range of V/STOL applications, the paper is concerned with the civil aircraft aspects. It deals with the main parameters to be studied in resolving VTOL and STOL aircraft characteristics, the weighing of these toward favourable performance and to meeting the proposed certification rules for this form of transport. The part to be played by electronics in all weather operations is also discussed. Competition from surface transport, and V/STOL airport requirements are referred to, and some general characteristics of the many different aircraft configurations are discussed. Some conclusions are reached suggesting the direction and weighting of future work.

A REVIEW OF COMMERCIAL V/STOL AIRCRAFT AND THEIR OPERATING ENVIRONMENT
Bernard L. Fry and R. William de Decker
IN: NAECON '68; Proceedings of the Twentieth National Aerospace Electronics Conference, Dayton, Ohio, May 6-8, 1968
New York, Institute of Electrical and Electronics Engineers, Inc. 1968, pp. 1-7

Discussion of general commercial V/STOL aircraft and their operating environment, both as it is now and as it is likely to be in the near future. Emphasis is placed on modification to the operating environment which will promote consumer acceptance and commercial success for V/STOL aircraft. A review of current work indicates that economically attractive intercity VTOL service is feasible in the coming decades, if a major effort is made to develop the present potential. It is concluded that the current air traffic control system must be greatly modified, if it is not to impose severe economic restrictions on VTOL service. An examination of the terminal environment indicates that well-developed service may require VTOL airports with an overall size approaching 1000 feet square.

VTOL AIRCRAFT OF THE FUTURE
Philip L. Michel
United Aircraft Corp., Stratford, Conn.
VertiFlite, Vol. 14, May 1968 pp. 2-10

Discussion of future uses of VTOL aircraft and of recent studies proposing a megalopolitan traffic system using VTOL aircraft for both intra-urban and intercity transportation. The need of properly designed airport terminal facilities, air traffic control systems and automatic flight systems is stressed. The inherent low-speed flight characteristics of helicopters can provide a ten-fold increase in arrival and departure rates over existing fixed-wing aircraft. Instrument landing aids are needed that can bring VTOL aircraft to spot landing at zero ground speed from steep approach paths. Another important consideration is economy: the VTOL aircraft system must translate its basic ability to operate free of runways into profitable operations. It is believed that the use of liquid natural gas can improve propulsion-system efficiency and that a revolution seems imminent in aircraft materials. The tilting rotor appears to be a promising concept.
VTOL AIRCRAFT - COMPETITOR OR ASSISTANT
P. A. Colman, G. N. Sarames, and W. C. Messecar
Lockheed Aircraft Corp., Burbank, Calif.
Society of Automotive Engineers
Air Transportation Meeting, New York, N.Y.
April 29-May 2, 1968, Paper 680325

Discussion of arguments in answer to the question of whether the VTOL commercial aircraft will compete with or complement conventional aircraft.

VTOLs of the type being studied by Lockheed-California Co. are designed to compete with conventional commercial aircraft in short-range operations. The Lockheed Airline Systems Simulation model was used to investigate this competition. The results from the U.S. Northeast Corridor show that a fully developed VTOL system will assist the airlines by turning short-haul operations from a losing to a profitable operation and by offering the passenger better service. Cities will be assisted by the amelioration of airport congestion and this, in New York, could obviate the need for construction of at least one additional major conventional airport.

THE PLACE OF CARGO AIRCRAFT IN TOTAL AIR TRANSPORTATION
Robert E. Hage and Lloyd B. Aschenbeck
McDonnell Douglas Corp., Santa Monica, Cal.
Society of Automotive Engineers, Air Transportation Meeting, New York, N.Y.
April 29-May 2, 1968, Paper 680325

Economic forecasts predict a vast expansion in the use of air transportation for cargo movement. Planning must begin now for airports, terminals, scheduling, air traffic control, etc., to meet this expansion. Also needed are new generation all-cargo aircraft, automated loading systems, intermodal delivery coordination and containerization. These elements are discussed in detail, in relation to meeting the needs of all users of air transportation (passengers, cargo, general aviation). All factors are part of the decision to develop aircraft and systems to carry cargo.

A DESCRIPTION OF THE VTOL AIRLINE SYSTEM
Edward J. Nesbitt and Kenneth D. Camarro
United Aircraft Corp., Stratford, Conn.
Society of Automotive Engineers
Air Transportation Meeting, New York, N.Y.
April 29-May 2, 1968, Paper 680275

The objective of the paper is to show the probable composition of the VTOL transportation system of the future and to provide some specific predictions concerning some of its key elements. Two types of service are recognized: metropolitan area service, connecting airports with downtown and suburban heliports - which will continue to be done by helicopters - and intercity downtown-to-downtown service employing high-speed future-type VTOL aircraft.

Currently operating VTOL airlines are demonstrating the practicality of metropolitan area helicopter service. Advanced, high-speed VTOL vehicles, introduced in the 1970's, will make possible the extension of current routes to intercity service. To fully develop the potential in the future, large 'transportation centres' will be established in major cities. Separate air 'corridors' and approach facilities and improvements in equipment and operations will insure the high utilization and efficiency necessary to insure a firm economic footing for the VTOL airline of the future.

VTOL DEMANDS IN THE 1970'S
John A. McKenna
United Aircraft Corp., Stratford, Conn.
Vertical World, Vol. 3, April 1968, p.20

Study of the role of VTOLs in future transportation networks. Increasing congestion in and around airports has aroused widespread interest in VTOL aircraft. The U.S. Intercity market for VTOL aircraft is studied and evaluated, as well as resources and requirements for VTOL transportation. It is concluded that the value of the helicopter for commercial application must be converted into an organized effort to force the potential benefits. This implies integration of VTOL aircraft into the transportation planning scheme, development of the total concept, construction of heliports and other operational facilities, financial support, and encouragement of the operators, when necessary, development of new aircraft, communications stations, routes, schedules, regulatory procedures, and navigation aids.

THE IMPENDING CRISIS IN AIR TRANSPORTATION
Bernard A. Schriever, B.A. Schriever Assoc.
Technology Review, Vol. 70, April 1968, p.19

Essay on the impending crisis in air transportation based on the report of the co-chairmen of a Transportation Workshop conducted between June and December 1967. The topics discussed include inhibitions in preparing facilities for the growth in transportation, the airport problem, APC, air freight and cargo, and transportation policy. It is pointed out that, unless we begin now to take steps to meet the demands of the future sheer growth in population and the accompanying economic demands could
so saturate our transportation system, especially the air system, that mobility could become a premium service instead of a routine accommodation.

DEVELOPMENT OF V/STOL SIZE, RANGE AND SPEED REQUIREMENTS
Paul H. Kesling
Lockheed Aircraft Corp. Burbank, Calif.

The design requirements for the V/STOL transport are studied from the system viewpoint. The extent of the study is limited to the size, range, and speed requirements for V/STOL transports for use in the next decade. The short haul transportation system environment is defined for its impact on the system, and, therefore, on the aircraft design requirements. The system is synthesized for use in the analysis. Tradeoffs are identified for analysis, and selection criteria are developed. A brief analysis is made using a typical route segment to establish recommendations for the aircraft design requirements.

THE EVALUATION OF V/STOL FLIGHT TEST FACILITIES
E. G. Riesenfeld

A quantitative method is presented which can be used to evaluate potential V/STOL flight test facilities and to choose the location most compatible with the aims of the using organization. A numerical model is developed to evaluate quantitatively several facilities. This model can assist management in arriving at a conclusion based on quantitative evidence, as well as on opinion and judgement. Four types of V/STOL aircraft anticipated in the 1975-1980 era form the basis of this investigation. An industry questionnaire is used to develop the model; various V/STOL industry managers determined the magnitudes of significant variables. Facility locations, community relations, heliport/airport criteria and associated facilities, and environmental and financial considerations are investigated. The derived model indicates the relative importance of these parameters. Several airports are evaluated to test the validity of the model.

CAN VTOL AIRCRAFT SOLVE THE AIRPORT CONGESTION PROBLEM?
Alan S. Boyd
Department of Transportation, Washington, D. C.
VertiFlite, Vol. 14, February 1968 pp.4-10

General observations made by the Department of Transportation concerning the need and feasibility of VTOL operations at airports of such large cities as New York, Los Angeles, and San Francisco. The arguments presented are backed up by a presentation of air-traffic statistics which clearly indicate the need for such operations in the near future.

IATA LOOKS AT THE TERMINAL CRISIS
Journal of Air Traffic Control Vol. 10, January 1968, pp. 5-8

Discussion of problems connected with the overloading of airport and ATC capacity throughout the world. Considerable discussion deals with the use of restraints and incentives to get general aviation (GA) traffic moved to satellite airports, or at least out of the jet stream of the main airport runways during peak airline hours. Suggestions include a differential landing fee which would be higher during prime time. Another idea is to charge the same landing fee to all aircraft, regardless of size or weight. It appears that the main gain in airline passenger capacity during the next five years would come through the use of larger aircraft.

PROBLEMS OF VTOL AIR TRAFFIC
H. Spintzyk
Dornier-Post, No. 1, 1968, pp. 3-7

Discussion of some specific aspects of VTOL air traffic in which the latter differs from conventional air traffic. The advantages of VTOL air traffic and its importance for future, still more congested traffic conditions are outlined. The noise problem, safety aspects, and economic viability of VTOL air traffic are examined, together with problems associated with the siting of VTOL terminals (in heavily built-up city centres) and with the establishment of an air-traffic-control network for VTOL aircraft.
AERODYNAMIC CHARACTERISTICS OF PROPELLER-WING-FLAP SYSTEMS
Kenji Matsuoka
Osaka Prefecture University, College of Engineering, Department of Aeronautical Engineering, Sakai, Japan
Masaaki Yonezawa, and Masahiro Takahashi
Osaka Prefecture University, Bulletin Series A - Engineering and Natural Sciences, Vol. 17, No. 1, 1968, pp. 65-78

Study of the aerodynamic characteristics of propeller-wing-flap systems of the type used on deflected-slipstream STOL aircraft. Equations are derived for estimating the aerodynamic forces. The momentum deflection angles of the propeller slipstream are determined, taking into account the mixing effect between the free stream and the propeller slipstream. A wind-tunnel test is carried out with a propeller-wing-flap configuration model. The results are found to be in good agreement with the theory.

CIVIL TRANSPORT REQUIREMENTS
G. R. McGregor
Air Canada, Montreal, Canada
Canadian Aeronautics and Space Institute
Transport Aircraft Symposium, Toronto
October 5, 1967, Paper
Canadian Aeronautics and Space Journal
Vol. 13, December 1967, pp. 454-456

Study of the facilities and support needed to operate the Canadian civil transport system with aircraft now coming into use. The civil transport requirements in Canada are discussed in general terms including large capital investments, the development of a fuel and powerplants more efficient than those currently used, the construction of airport passenger and cargo terminal facilities for handling much greater numbers of arrivals and departures, improved passenger and cargo handling procedures, and improved ground transportation facilities.

POTENTIAL APPLICATION OF THE HELICOPTER IN URBAN MASS TRANSPORTATION
J. P. Loomis
 Battelle Memorial Institute, Columbus, Ohio
Prepared for New Systems Study Project
Urban Transportation Administration
Department of Housing and Urban Development, Washington, D. C.
October 1967, Monograph Number 18
Contract Number H-778, Battelle Project G-8532

In the first part of this monograph, the current feasibility of VTOL type machines in intra-urban transportation is briefly explored. It is shown that at 50 percent load factors, the helicopter could economically compete with taxicabs for stage lengths of 10 or more miles. The seat-mile costs for such stage lengths would be about $0.34 per occupied seat-mile. However, it is observed that the helicopter would not enjoy the operational fluidity of a taxi, but would likely be restricted to certain high-density, point-to-point routes. This, together with current noise levels and the disruptions often caused by weather, seems to rule the helicopter out as a 'mass transportation' device.

A rather cursory examination of the effects of future research and development on VTOL feasibility is also made. Economically, it might be possible to reduce seat-mile costs by as much as 30 percent. Using the 50 percent load factor case again, and assuming 1967 dollar values, the helicopter could compete with taxicabs (in some respects) over routes as short as 5 miles. However, even these rates are not likely to permit the VTOL machine to service in the role of mass transportation. Apart from economics, the noise problem, air-traffic-control requirements with numerous vehicles in operation, and the effects of weather almost certainly preclude VTOL in the mass transportation role.

With regard to operations, the prospects for reducing the noise of VTOL type machines do not appear promising. The high thrust-to-weight or horsepower-to-weight ratios for these machines and the devices for developing the necessary lift at low or zero forward speeds prevent all but limited progress in this area.

The Department of Housing and Urban Development should not invest in the expectation that VTOL type of aircraft can be generally applied to urban transportation. The use of these aircraft will be relegated to those types of transportation needs that they are presently filling (e.g. transport between discrete, widely separated points).

STRUCTURAL DYNAMIC RESPONSE OF LARGE LOGISTIC V/STOL AIRCRAFT
Melvin J. Rich and Richard F. Stebbins
United Aircraft Corp., Stratford, Conn.
American Helicopter Society, Journal
Vol. 12, October 1967, pp. 22-37

Preliminary designs are developed for five V/STOL 10-ton cargo transports capable of a 1800 n mi range. The peak loads and stresses are calculated from the structural dynamic response to ground handling, flight manoeuvre, gust penetration, and landing. These loads and stresses are then compared to those used to originally design the aircraft. The results of these
Investigations are tabulated in a matrix showing the degree of relative criticalness for the conditions investigated for each V/STOL configuration. The most critical condition is found to be the takeoff run with a 10 in. ground dip. The results of the analysis show that there are dip wavelength to landing wheel base ratios in which the dynamic loadings are further amplified by the elastic characteristics of the aircraft. Special devices are shown to be a possible way of minimizing critical structural response. The use of energy absorption and load limiter devices are found to be effective for towing and rough terrain taxi conditions.

OPERATION OF JET AIRCRAFT FROM GRAVEL RUNWAYS
Erik S. Lund
Boeing Co. of Renton, Washington

Examination of the problem of developing devices to protect the 727 and 737 airframes and engines from foreign object damage during operation from gravel runways and to demonstrate to the FAA and to Boeing customers that such operation would be safe and economically practical. The approach to the problem included an evaluation of gravel runway bearing strengths and surface conditions, analysis of existing propeller-driven airplane operations, and laboratory evaluation of protective devices utilizing a simulated landing gear driven over a gravel runway test strip by a jet-engine-powered truck. Most of the work was directed toward developing landing-gear-mounted deflectors to prevent foreign objects from reaching the areas of concern. To accomplish this it was necessary to study a wheel rolling on a gravel surface to determine how stones are thrown by the passing wheel. It was concluded that airplanes can be protected from foreign object damage in a manner acceptable to the FAA and to the customers. The conclusion is supported by high-speed motion pictures of the action of a wheel on a gravel surface, comparison of deflector effectiveness, and motion pictures of airplane operation. The 727 airplane has completed gravel runway takeoff and landing testing to establish field lengths and operational safety to the requirements of the FAA. Gravel runway certification was issued by the FAA in March 1967 for the Boeing 727, the first jet engine aircraft to be so certified.
en route congestion, terminal congestion, airport delays and closures, terminal-area traffic density, and all-weather operations.

Comprehensive Planning and General Discussions

REGIONAL PLANNING AND AIRPORT LOCATION

P. G. Hall
Reading University, Reading, Berks, England
Proceedings
London, Institution of Civil Engineers, 1969 p. 53

Discussion of the types of airport needed in Britain (international, regional, and subregional) and of the land requirements for each. The number of people likely to be dependent on the airport is considered. The suitability of various sites in southern England is discussed from the point of view of land requirements, noise nuisance, and the ways in which they can be integrated into the total transport system.

AIRPORT LOCATION -- THE FACTORS INVOLVED

R. S. Doganis
IN: World Airports: The Way Ahead
Proceedings
London Institution of Civil Engineers 1969, pp. 47-51

Brief outline of the various technical and operational factors involved in the supply of airport facilities, and discussion of their significance in airport location. These factors include altitude, temperature, wind, visibility, land gradient, accessibility, noise, cost of land, regional planning, aircraft performance, and air traffic control. All these will influence the actual site to be chosen, but the broad locational pattern should be determined by the distribution of the demand for air services. It is necessary to know not only the total demand for air transport in a particular area, but also the peak-hour passenger and aircraft movements, the length of the longest haul, and the directional breakdown of the demand. Forecasts of the air transport needs of various regions should be based on a variety of socio-economic variables which have been shown to affect the demand for air transport. The most significant of these are population size, age, urbanization, personal income, business interaction, competition from surface media, tourist attraction, level of education, and the distribution of immigrant communities. The various supply and demand factors are not only interrelated but often contradictory. The only way they can be reconciled is through some form of cost-benefit analysis.

THE IMPACT OF STRUCTURES AT AIRPORTS ON FLIGHT OPERATIONS

Arvin O. Basnight
Federal Aviation Administration, Los Angeles, Calif.

Discussion of the need for larger structures, office buildings, airport passenger terminals, hotels, and aircraft servicing facilities, arising from increasing acceptance of air travel and population growth. Proponents of structures near airports are required to submit proposals to the FAA in accordance with Part 77 of Federal Aviation regulations. The proposals are evaluated from the standpoint of obstructions, ATC tower visibility, and their effect on existing and proposed future navigation aids because of reflecting surfaces. The effects on radar coverage can be predicted with reasonable accuracy; the effects on omnirange and instrument landing systems cannot be predicted with any degree of confidence. Work continues on the use of better antenna systems, improved shielding screen techniques, and higher frequencies.

AIR TRANSPORT FACILITIES AND REGIONAL PLANNING

K. R. Sealy
London University, London School of Economics and Political Science London, England

Study of the relationship of regional planning to air transport development using London as a model of planning to meet the needs of both the city and the airport. An detailed analysis of the Heathrow airport design is presented, and the industrial distribution in the Heathrow and Stansted areas are illustrated. It is concluded that the airport planning is intrinsically bound up with regional planning, which has as its main aim the social and economic development of a given area.
INTERNATIONAL AIRPORT PLANNING AS INFLUENCED BY AIRCRAFT DEVELOPMENT
J. V. Block
Royal Aeronautical Society

Examination of the aircraft characteristics affecting mainly runways, taxiways, and apron planning. The trend to bigger and heavier aircraft leads to strengthening of runway and taxiway bridges, widening of runways, and enlargement of hangars. Manoeuvring characteristics of aircraft in the neighbourhood of airports determine the amount of airspace to be reserved for holding patterns and for radar vectoring before landing. Aircraft noise is another major constraint. Various terminal layouts, present and future, are discussed.

HANNOVER REGIONAL COMPLEX INCLUDING AIRPORT
Heinz P. Piper
Flughafen Hannover-Langenhagen Gmb H, Hanover, West Germany

Discussion of airport planning which is affected by problems of air transportation as well as by problems of city planning. The growing demand for air transportation brings about serious problems for airport authorities as well as for users of airports and for those people living in the vicinity of airports. The main problems are noise in the air and traffic congestion on the ground. To handle these problems, all persons and authorities concerned in airport planning, city planning, and regional planning are called upon to work closely together with the object of making the airport an organic part of the city and region it is to serve.

CIVIL AIRPORT DESIGN CRITERIA
Edwin W. Harn
Federal Aviation Administration
Washington, D. C.
Transportation Engineering Journal Vol.95 February 1969, pp. 13-22

There cannot be a standard design for an airport, or even for a type of airport. Each design will be different, reflecting the ideas of the designer, the requirements of the users, and the conditions prevailing at the selected site. To provide a national system of airports there must be some common denominators to guide the design of individual airports. These are airport design standards.

While design criteria surely require sound technology as their basis, to be effective, they must be comprehensible to the engineer who will apply them. The engineer must have the ability to understand and professionally apply them as guides in his design. Design criteria should satisfy functional requirements while providing parameters which will promote the economical development of a safe and efficient airport.

Fundamentally, there are six basic considerations in the development of airport design standards. The factors are so interrelated that it is difficult to discuss them separately:

1. The users--airplanes, people, ground vehicles.
2. Relative cost versus benefit, or cost effectiveness.
3. Operational requirements.
4. Probability of occurrence of conditions affecting design.
5. Longevity of facilities.
6. Expansion potential

The intended use of any facility will be the primary factor in its design. Planning information, therefore, is essential to the design effort.

......While this resume of the airport requirements for new aircraft may look fairly complete today, how far away may another markedly different change be? Will transports of supersonic speed be operating into all air-carrier airports? There was a time when the subsonic jet was considered as a long-range aircraft, and it was only recently that this type airplane entered the medium range and general aviation operations. Obviously, design standards cannot stand still while the aircraft continue to change. Based on the best picture of future needs, the FAA airport design criteria will strive to keep pace with aviation requirements.

THE MODERN AIRPORT AND ITS FUTURE
Peter G. Masefield

Discussion of the evolution of the modern airport from Hounslow Heath in 1919 to an idealized airport of sixty years later. The growth of world civil air transport between 1945 and 1966 is reviewed in terms of load/ton per mile. A brief survey is presented of airport finances, including an expenditure analysis. The role of the modern
An operational evaluation of two aircraft which are candidates for metropolitan area STOLport operation is made in the approach, landing, and takeoff regimes of flight. Information is obtained on such characteristics as instrument approach angle, beam width or softness, deviations from approach course, approach obstacle clearance planes, threshold crossing heights, landing distance, takeoff distance, and offset approach angles.

FUNDAMENTALS AND BACKGROUND FOR THE ADMINISTRATIVE AND ECONOMIC ORGANIZATION OF AIRPORTS (Fundamentos y Antecedentes Para La Organizacion Economic y Administrativa de Los Aeropuertos)
Luís Valenzuela Cervera
Ingeniería Aeronáutica y Astronáutica, Vol. 20, September-October 1968, pp. 21–31
In Spanish

Analysis of the application of certain basic principles of transportation to airport operations, considered as part of the air transport infrastructure. More concretely, the principles of financial autonomy and coordination of investments, insofar as they affect the exploitation and supplying of airports, are studied. Various aspects of air transport development over the past 20 years are reviewed. Airport costing and tariffs to be imposed are discussed in detail. The administrative setups of various Spanish airports are outlined.

BREAKING THE GROUND BARRIER FOR FUTURE TRANSPORT AIRCRAFT
W. E. Parsons and W. F. Pieper
McDonnell Douglas Corp., Santa Monica, Ca.
Society of Automotive Engineers,
Air Transportation Meeting, New York, N.Y. April 29-May 2, 1968, Paper 680306

Tremendous growth has been projected in air transportation for both passenger and cargo markets. The projected growth is so great in fact that a total system concept approach is necessary not only to solve the problems of today, but to provide solutions which satisfy the demands of tomorrow. In using the systems approach it is necessary to determine the significant parameters in the description of the operations, interrelationships, and environment of the airport/aircraft system. The paper discusses the approach being utilized in evaluating airport/aircraft compatibility which is one element of the total system concept. Both short- and long-range considerations are presented. Market data are presented to illustrate the projected growth trends and numbers of aircraft. Long-range planning factors, such as requirements for wider and stronger runways, are discussed. A method is presented for establishing interface requirements for flotation, ground service equipment, passenger and cargo loading, community noise, and maintenance facilities between future transport aircraft and the airport. A total transportation system on the scale projected for the 1980s has implications far beyond the vehicles themselves. Consequently, it is mandatory that communication and coordination between all elements of the air transport industry
be continually improved to effect the integration necessary to achieve such expansion.

PORTS FOR STOL - SOME OBSERVATIONS
R. D. Hiscocks and R. J. Taborek
de Havilland Aircraft of Canada, Ltd.
Malton, Ontario, Canada
Society of Automotive Engineers
Air Transportation Meeting, New York, N.Y.
April 29-May 2, 1968, Paper 680274

It is becoming increasingly evident that STOL aircraft operating into metropolitan stolports will make a significant contribution to the development of short-haul air transport in and about metropolitan areas. A consideration of aircraft operating costs and the costs of providing metropolitan terminals shows that terminal costs are a minor part of the total system cost, with the result that the difference between VTOL and STOL indirect costs is negligible. Therefore, STOL aircraft are generally preferred over VTOL for these operations because of lower direct operating costs. The availability and proved reliability of STOL aircraft reinforce this conclusion, and it is unlikely to be altered by near term future developments. STOL operating regulations and safety aspects become a critical development to be achieved before extensive stolport operations become widespread. Procedures for determining the takeoff and landing field lengths required for the operation of small (under 12,500 lb.) commercial transport aircraft into stolports are examined. IFR operations are expected to pose initial problems because of the inadequacy of present terminal guidance equipment. It is anticipated that microwave equipment should reduce this problem. STOL aircraft are shown to possess low speed handling qualities that significantly ease the task of landing in IFR conditions.

ADVANCED TRANSPORT AIRCRAFT - AIRPORT SYSTEM INTERFACES
James E. Gorham
Stanford Research Institute,
Menlo Park, Calif.
February 12-14, 1968, Paper 68-211

Analysis of interfaces between existing aircraft and airports and related ground systems. Analyses performed indicate that the several functions that comprise airport services group into those that are essential to the interchange between ground and air vehicles, those auxiliary to this function, and those parasitic upon it. The primary advantages of emerging aircraft types are found to be sensitive to inadequacy of airport and ground systems. On the basis of the ability of existing airport systems to accommodate advanced aircraft requirements, major disaggregation of ancillary airport functions and changes in aircraft operating practice will be necessary to provide a well-functioning air transport system.

<table>
<thead>
<tr>
<th>Airport Design Standard Advisory Circulars</th>
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<tr>
<td>150/5300-2</td>
<td>Airport Design Requirements for Terminal Navigations Aids</td>
<td>Provides information regarding location, functions, and siting requirements of air navigation aids on and in the immediate vicinity of airports.</td>
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<tr>
<td>150/5300-4</td>
<td>Utility Airports -- Design Criteria and Dimensional Standards</td>
<td>Contains FAA standards for airports for general aviation operations of small airplanes of 12,500 lb. or less gross weight.</td>
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<td>150/5325-2A</td>
<td>Airport Surface Areas Gradient Standards</td>
<td>Provides standards for establishing the gradient of airport surface areas used for landing, takeoff, and other aircraft ground movement.</td>
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<td>150/5325-3</td>
<td>Background Information on the Aircraft Performance Curves for Large Airplanes</td>
<td>Provides airport designers with information on aircraft performance curves for design which will assist them in an objective interpretation of the data used for runway length determination.</td>
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<tr>
<td>150/5325-4</td>
<td>Runway Length Requirements for Airport Design</td>
<td>Presents aircraft performance curves and sets forth standards for the determination of runways lengths to be</td>
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<th>Code</th>
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<tr>
<td>150/5325-5</td>
<td>Aircraft Data</td>
<td>Provides a listing of principal dimensions of aircraft in common use in the civil fleet affecting airport design for guidance in airport development.</td>
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<tr>
<td>150/5325-6</td>
<td>Effects of Jet Blast</td>
<td>Presents the criteria for treatment of jet-blast effects which are acceptable in accomplishing a project meeting the eligibility requirements of the FAA.</td>
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<td>150/5330-2</td>
<td>Runway and Taxiway Widths and Clearances</td>
<td>Presents the FAA recommendations for landing strip, runway, and taxiway widths and clearances.</td>
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<td>150/5335-1</td>
<td>Airport Taxiways</td>
<td>Provides the criteria for airport taxiways which are acceptable in accomplishing a project meeting the eligibility requirements of the FAA.</td>
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<td>Airport Aprons</td>
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<tr>
<td>150/5360-1</td>
<td>Airport Service Equipment Buildings</td>
<td>Provides guidance on design of buildings for housing equipment used in maintaining and repairing operational areas.</td>
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<td>Airport Cargo Facilities</td>
<td>Provides guidance material on air cargo facilities.</td>
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<td>150/5360-3</td>
<td>Federal Inspection Service Facilities at International Airports</td>
<td>Describes and illustrates recommended facilities for inspection of passengers, baggage, and cargo entering the U.S. through international airport terminals. The material is for guidance of architect-engineers and others interested in the planning and design of these airport facilities.</td>
</tr>
<tr>
<td>150/5390-1</td>
<td>Heliport Design Guidance</td>
<td>Contains design guidance material for the development of heliports, both surface and elevated, to serve single- and multi-engine helicopters operating under visual flight rules.</td>
</tr>
</tbody>
</table>
AIRCRAFT NOISE ABATEMENT--THE PROSPECTS FOR A QUIETER METROPOLITAN ENVIRONMENT
Robert L. Paullin
U.S. Department of Transportation
Washington, D. C.
James F. Miller
U.S. Department of Housing and Urban Development, Washington, D. C.
American Institute of Aeronautics and Astronautics, Aircraft Design and Operations Meeting, Los Angeles, Calif.
July 14-16, 1969, Paper 69-800

Aircraft noise abatement is oriented toward compatibility between airports and the adjacent metropolitan environs. The effectiveness of technical, operational, and land use strategies of noise alleviation, including proposed aircraft noise certification regulations, can be forecast. The impact of aircraft operations on people and communities near airports is presented. Consideration is given to area-wide land use requirements and interrelationships between the airport and local agencies. Criteria for evaluating aircraft noise abatement are being quantified at an increasing rate; the use of these criteria by the air commerce industry and by metropolitan planners, at individual airports, is shown to lead to greater compatibility between the airport and its neighbours.

INTEGRATING THE AIRPORT INTO THE COMMUNITY PLAN
Joseph A. Foster, ATA
ASCE Aero-Space Transport Division
Conference on Transportation Engineering
February 23, 1968, San Diego, Calif.
Transportation Engineering Journal, Vol. 95, pp. 279-287, May 1969

Introduction

The subject of community planning and airport requirements is a most timely and important subject.

It is not difficult to predict the future growth of the air transport industry, because it is increasing daily and in doing so is making all estimates of future industry activities look rather conservative by comparison with the industry's day today.

The problem of dealing with new generation aircraft is not unusual. The airlines have done it in the past and will be doing it in the future. Today, however, the problem is of much greater magnitude than it has ever been in the history of aviation. One can still remember the problems, real and imagined, that the airline and airport industry faced in the 1950's when the commercial jets were first introduced.

Most of these problems were solved and some still haunt the industry.

The airlines and airport operators have been trying to control the explosive growth of air transportation, instead of trying to solve the problems related to their mutual interests so that air transportation can grow intelligently. In this respect, it is time to stop looking at the individual segments which compose the air transportation system and channel energies into building an adequate national system of air transportation with its integrated components.

Total planning of the airport and its community is not something to be passed off as somebody else's problem. In the early stage, where the airline industry dealt only in airplanes and air traffic and the community and airport planners only in concrete and local funding is a thing of the past. It is imperative that airlines, airport operators and community leaders work closely together on a coordinated planning and development program to bring the air travelling public the best system possible for their money. In fact, they have already started to arrive at mutually agreeable solutions to the problems facing aviation today, and the challenges facing it tomorrow.

The best way to start this total system concept moving into a realistic philosophy is to approach airport planning on the basis that the airport has become a centre of economic gravity within communities much the same way that industrial and commercial activities have contributed to, and enhanced, the financial stability and economic value of the community.

Conclusion

The airport is a major factor in the economy of the community it serves. The airport is an integral part of the community and should be carefully considered in community planning, compatible land usage is a vital factor in airport development.

In developing new airport facilities, consideration should be given to the establishment of a system of satellite airports for the use of private aviation. The productive operation of an airport and the harmonious relationship between the airport and its community depend largely on the foresight and imagination of the municipal planner at the community level. The airline industry, airport operators and community planners must act in concert in planning for future airport development as an integral part of the community's cultural life and economic well-being.
AIRPORT NOISE AND THE COMMUNITY
C. S. Waters
Loughborough University of Technology
Dept. of Transport Technology
Loughborough, Leics, England
Society of Environmental Engineers
Transpo '69 Symposium
Imperial College of Science and Technology, London, England
April 15-18, 1969

Outline of a method of controlling airport noise which clearly delineates the responsibilities of both the airport and the community planners. As a means of assessing aircraft noise annoyance, the perceived noise level (PNdB) is considered to be a good measurement of human response to noise, since it makes allowance for the acceptability of low-frequency noise. A schedule is described, in use for the Heathrow and Gatwick airports, which makes use of published Noise and Number Index (NNI) contours to provide a criterion for planning decisions concerning residential development. Attention is given to the Index of Community Annoyance (ICA) and its use as a planning tool.

AIRBORNE TRANSPORTATION NOISE - ITS ORIGIN AND ABATEMENT
John O. Powers
Federal Aviation Administration
Washington, D. C.
Acoustical Society of America, Meeting 74th, Miami Beach, Fla., November 13-17, 1967
Sound and Vibration, Vol. 2, June 1968

Discussion of the sources of subsonic jet-aircraft noise, and some possible solutions to the problem. Relationships between aircraft noise generation and mechanical power required to produce a given aircraft speed are presented. Fan and compressor noise sources of a gas-turbine engine due to the rotor-stator interaction pattern are discussed. The effects of various parameters - i.e., flight altitude, ground condition (reflectivity), airplane speed, and airplane weight - are treated. The structure of the Aircraft Noise Abatement Program (under the Department of Transportation) is charted. System solutions to the air transportation noise problem are discussed according to the following categories: technical options, operational options, and airport options.

A REALISTIC ASSESSMENT OF THE AIRPORT/COMMUNITY NOISE PROBLEM
Nathan Shapiro and Gerald J. Healy
Lockheed Aircraft Corp., Burbank, Calif.

Discussion of problems connected with the complex community-noise problem associated with short-haul air transportation. It will not always be possible to meet arbitrarily established criteria, such as the ambient for a residential neighbourhood, particularly on the landing and takeoff paths around vertiports located in established areas. Current and planned vehicles using the quietest known propulsion systems, at 1000-ft flyover, are shown to exceed the ambients of a variety of community areas, but established modes of transportation also exceed these ambients. It is also shown that low-noise requirements dictate low-disk loadings. It is doubtful that community noise levels below 80 to 90 PNdB (perceived noise) can be achieved in a practical vehicle.

Comparative Economics

THE INFLUENCE OF THE AIRPORT, ITS FACILITIES AND ENVIRONMENT ON AIRCRAFT DESIGN AND OPERATING ECONOMICS
K. S. Lawson
British Aircraft Corp., Ltd.
Weybridge, Surrey, England
Aeronautical Journal, Vol. 73, June 1969

Discussion of airfield performance, noise, and aircraft utilization, each of which has a major influence on aircraft design and operating economics. It is necessary for the designer to make a fine judgement when deciding on the design takeoff distance. The aim must be to minimize the direct operating cost penalty on most of the operations, but at the same time to achieve a worthwhile operation out of most of the critical airports. An important consideration is obstacle clearance. Proposed noise regulations will impose severe limits on total thrust unless quieter engines can be designed. Greater efforts must be made to increase aircraft utilization, and hence ATC must be improved and turnaround times minimized.
Discussion of proposed solutions to airport congestion. These include (1) the building of more airports to expand peak capacity, (2) improvement of air traffic control capability to enhance safety at peak times, and (3) various forms of rationing whereby airport officials and regulators would allocate scarce landing and flight space. The advantages and disadvantages of each method are discussed. It is proposed that the pricing system be used more effectively by instituting time-and-location differentiated pricing systems to relieve congestion.

A TECHNIQUE FOR ESTIMATING V/STOL MARKET SHARES
Alexis N. Sommers
Vitro Laboratories, Silver Spring, Md.
Transportation Science Vol. 3, No. 1
February 1969

A theory and technique is presented for estimating the business travel market shares of future V/STOL aircraft as functions of the nondemographic mode choice factors of time, cost, safety, comfort, convenience, and weather reliability. A linear mathematical model is described. Inputs to the model are derived directly from questionnaire surveys incorporating semantic differential and multiple choice questions. The technique is demonstrated on a city-pair 112 miles apart where business travel currently favours automobiles. Two V/STOL aircraft types competing with conventional modes in a hypothetical 1985 environment are predicted to attract 48 percent of the business travel in this city-pair market.

MATHEMATICAL MODELS FOR OUTGOING TRAFFIC FLOW IN AN AIRPORT TERMINAL
B. Avi-Itzhak
Technion-Israel Institute of Technology, Dept. of Industrial and Management Engineering, Haifa, Israel, and M. Mandelbaum
Israel Institute of Productivity, Research Dept., Tel Aviv, Israel

In designing an airport terminal, problems arise in specifying the capacities of service facilities and waiting areas that will provide some minimum acceptable level of service. The terminal is characterized by the two main flows of incoming and outgoing traffic. The incoming flow of passengers from arriving aircraft proceeds through several sequential service stations such as passport control, baggage retrieval, and customs, resulting in congestion at various points in the system. Other congestion points are generated in the outgoing flow of departing passengers who also undergo several stages of service before embarking. The number of people in the system at any given time is significantly increased by those who meet arriving passengers or deliver
departing passengers. The service level is measured by the distributions of flow times and congestion densities in the system. The paper provides mathematical models describing the behaviour of the outgoing traffic flow at Lod Airport. The models serve to determine service capacities and sizes of congestion areas to meet service requirements at a given future time. The results of the study, based on actual data, provide a quantitative basis for the physical planning, the architectural design of the terminal, and for determining when to expand the terminal or, alternatively, when to build a new one.

Flight Safety and Operations

RECENT STUDIES ON EFFECTS OF RUNWAY GROOVING ON AIRPLANE OPERATIONS
Upshur T. Joyner, W. Pelham Phillips and Thomas J. Yager

Runway grooving is a significant way of improving tire traction in adverse weather conditions, and this technique has been under study by NASA. Various groove patterns have been evaluated for wet traction; one of the better groove patterns (with grooves 1/4 in. wide and 1/4 in. deep on 1 in. centres) was installed on a research runway. Full-scale traction studies were made using a Convair 990A transport and an F-4D fighter aircraft. Braking traction values obtained on the wet grooved runway were substantially higher than those obtained on the wet ungrooved runway. The results from these investigations were used as the basis for calculations of the effects of grooving on aircraft landing field length and takeoff balanced field length under wet conditions. Grooving is shown to be very beneficial on both counts.

INFLUENCE OF A CONSTANT INCLINATION OF THE TAKEOFF RUNWAY ON THE TAKEOFF LENGTH OF JET AIRCRAFT
(Zwyczajna Stala Pochyla Drog Odlotowa na Dlugosc Startu Samolotow Ordnzutowych)
Zdzislaw Lopatek
Technika Lotnicza i Astronautyczna, Vol.24 June 1969, pp. 20-22 In Polish

Discussion of the relation between the runway grade and the takeoff length of jet aircraft, on the basis of rules established in various countries. It is emphasized that, in assessing this problem, the aircraft type should be taken into consideration, and the correction coefficients for runway length should not be determined as a function of runway mean grade.

POSSIBILITY OF CALCULATING THE INFLUENCE OF MUD AND WATER COVERING RUNWAY SURFACES ON THE TAKEOFF LENGTH OF JET AIRCRAFT
(Mozlwości Obliczania Wplywu Blota i Wody na Nawierzchni Pasa Startowego na Dlugosc Rozbiegu Samolotow Odrzutowych)
Zdzislaw Pytlewski
Ministerstwo Obrony Narodowej, Wojska Lotnicza, Instytut Techniczny, Warsaw, Poland
Technika Lotnicza i Astronautyczna, Vol. 24, May 1969, pp. 18-20, In Polish

Discussion of the factors affecting the runway friction of jet aircraft on a runway surface covered by mud and water from the viewpoint of reducing skidding accidents. These factors are described by equations and diagrams which make it possible to determine the expected aircraft takeoff length as a function of the mud thickness and its density.

V.63
SENSORY-PHYSIOLOGICAL BASES OF COURSE-KEEPING DURING GUIDANCE BY RUNWAY LIGHTING
(Sinnesphysiologische Grundlagen Des Kurshaltens Bei Orientierung An Der Startbahnbefeuerung)
H. Merguet
Ruhr-Universität, Klinikum Essen, Chirurgische Klinik and Poliklinik Essen, West Germany

Evaluation of the sensory physiology of pilots attempting to land by means of runway lighting. It is noted that, when basing his landing on fixing and sighting, the pilot can be aided by (1) conventional boundary lighting, if he has a certain minimum ground visibility; (2) a narrow-gauge lighting, which provides enhanced safety of course-keeping under the same conditions; and (3) an additional centre-line lighting, which still further enhances the safety of course-keeping under the same conditions.

EFFECTIVE BRAKING--A KEY TO AIR TRANSPORTATION PROGRESS
L. S. McBee
Society of Automotive Engineers, National Air Transportation Meeting, New York, N.Y., April 21-24, 1969, Paper 690376

Review of recent progress in aircraft braking systems, taking into consideration current areas of study relating to systems, brakes, tires, and the runway interface. These studies include the topics of brake designs, heat material, braking control, tire-runway interface, and tire design. The specific subject of tire-runway interface received considerable consideration during the past few years. Particular emphasis is directed to friction measurements of runways both for wet and dry conditions, aircraft braked roll-out distances while on wet and dry conditions, aircraft braked roll-out distances while on wet runways, and friction improvements which may be realized through grooving and water removal. A practical review is made of brake materials, cooling concepts, and skid control systems which may be expected in the future. The most radical concept for commercial air transportation is the use of recovery equipment which can potentially eliminate many braking problems.

THE PILOT'S CHOICE--OFF THE END OR OFF THE SIDE OF THE RUNWAY
Philip Donely

Description of the forces, favourable and unfavourable, acting on an aircraft during ground roll when the pilot is faced with a slick surface and a crosswind. Since aircraft differ widely in their detailed characteristics, a 'composite' jet transport has been developed on which to base some simple calculations. The discussion may be considered as calling attention to the fundamental elements of the deceleration and control of aircraft on the ground.

METHOD FOR DETERMINING THE VALUE OF AIRFIELD WEATHER FORECASTS (TAF) (TAF VERIFICATION)
(Wolfgang von Bezold
Meteorologische Rundschau, Vol. 22 March-April 1969, pp.43-46. In German

Examination of a method for determining statistically the accuracy of airfield weather reports on takeoff and landing conditions, visibility, and cloud ceiling. Correlations are made between forecasts and actual conditions, and a form developed for tabulating the results is illustrated. The use of the form and its application are elaborated.

SLIPPERINESS OF AIRPORT RUNWAYS AND REMEDIES FOR IT
(Philippe Slama
Secrétariat Général à l'Aviation Civile Revue, March 1, 1969, p.44. In French.

Discussion of tests conducted by various U.S. and foreign aviation administrations and private enterprises since 1965 on the subject of slipperiness and grooving of runways. Wet runways seriously affect the length of landing run (e.g., from 1350 m on dry concrete to more than 2200 m on wet concrete). Various factors affecting the coefficient of friction on wet runways, such as tire form, speed, wheel arrangement, etc., are discussed. To improve stopping power, it appears that grooving the surface yields the best results.
AIRPORT EQUIPMENT FOR RETRACTED GEAR
LANDING ON A FOAM CARPET
(L’Equipement Des Aerodromes Pour
Atterrissage ‘Train Rentre’ Sur Tapis
de Mousse)
Francois Ansart
Secrétariat Général à l’Aviation Civile,

Study of ways of preventing and re­
tarding the development of aircraft
fires which might be caused by landing
with retracted gear. A foam carpet is
recommended, which would have the ef­
teffects of cooling the fuselage and torn­
off metal particles, of penetrating
the fuselage through rents and then
extinguising internal fires, and, by
dispersing itself behind the aircraft,
preventing the formation of explosive
mixtures. The dimensions of the foam
carpet, and means of setting it, are
discussed.

ALL-WEATHER LANDING
(Allwetterlandung)
Hans J. Zetzmann
Deutsche Versuchsanstalt für Luft-und
Raumfahrt, Institut für Flugfunk und
Mikrowellen, Oberpfaffenhofen,
West Germany
DGLR Mitteilungen, Vol. 2
February 1969 pp. 2-5, In German.

Discussion of the landing of aircraft
under various weather conditions, in­
cluding landing at zero-zero. The
various categories into which landings
can be divided with respect to airport
visibility are outlined. It is pointed
out that air traffic of the future will
make it a necessity to be able to land
even under conditions of complete lack
of visibility. Two approaches to the
objective depending on fully automatic
control, as proposed by the British,
are considered, as well as a more
flexible method advocated by the
Federal Aviation Agency.

AIRPORT FOG DISPERSAL WILL SOON ENTER
OPERATIONAL PHASE
W. Boynton Beckwith
Air Transport Association of America
Sacramento, Calif
Space/Aeronautics, Vol. 50, October 1968

Discussion of methods of dispersal of
warm fog (above 32°F) over airports.
The procedure has been demonstrated
successfully in full-scale tests of
aircraft seeding with polyelectrolyte
materials which cause droplets to
coalesce. A ground dispenser is de­
scribed which uses a large air fan and
a flexible 100-ft. plastic tube to
squirt both dry and liquid chemicals
to a height of 200 ft. Observable
improvements were produced.

A REAL-WORLD LOOK AT THE SAFETY PROBLEMS
OF FUTURE AIRCRAFT
Joseph D. Caldara
Flight Safety Foundation, Inc.
New York, N.Y.
Air Line Pilots Association, Air Safety
Forum, 15th, Seattle, Wash, July 9-11, 1968

Consideration of future aircraft safety
problems from the standpoint of sys­
tems analysis and program assurance.
Since at the present time it is felt
that systems development has ended
when the aircraft leaves the factory,
it is emphasized that, if systems
development is to include systems ana­
lysis and program assurance, it must
be continued by the operating echelon
to include air crews, facility, and
ground support personnel. This in­
volves airports and airways, the
weather, air traffic control, collision
avoidance systems, and ground support
in the form of runway safety and air­
port fire and rescue capabilities.

OPERATIONAL PROBLEMS WITH CURRENT
COMMERCIAL V/STOL AIRCRAFT
J. W. Clyne
United Aircraft Corp.
Sikorsky Aircraft Div.
Stratford, Conn
Society of Automotive Engineers
Air Transportation Meeting, New York, N.Y.
April 29-May 2, 1968, Paper 680283

Discussion of design, maintenance, and
performance problems of VTOL aircraft
from the viewpoint of future commer­
cial operation. The analysis is based
on the Sikorsky S-61L and N models as
representative of a maximum-experience
helicopter with both the commer­
cial-airline and offshore-oil operators the
world over. Topics discussed include
VTOL airline operating losses, the
noise problems, and heliports.

AVIATION SAFETY - TODAY’S CHALLENGE,
TOMORROW’S CRISIS
Richard L. Ottinger
U.S. Congress, Washington, D. C.
Astronautics and Aeronautics, Vol. 6
January 1968, pp. 36, 37

Discussion of the role of the FAA in
determining aviation safety. It is
suggested that the FAA should imme­
diately undertake a national aviation
safety survey with a view toward set­
ting standards in terms of runways
and terminal facilities, electronic
traffic-control systems and the air­
craft and pilot procedures necessary
to reduce the danger of accidents.

V.65
GROUND MOVEMENT GUIDANCE AND CONTROL AT MAJOR AIRPORTS IN LOW VISIBILITY
G. Harrison
Ministry of Technology, Royal Aircraft Establishment Farnborough, Hants. England
International Air Transport Association Technical Conference, 17th, Lucerne Switzerland, October 9-14, 1967, Paper

Discussion of the problems involved in ensuring that airport ground movements of both aircraft and vehicles can continue efficiently in low visibility conditions, considering measures which can be taken to minimize these problems. Requirements of categories I, II, IIIA, IIIB, and IIIC, operations are briefly compared. It is noted that Air Traffic Control can safely and efficiently monitor and control all movements on the runways and taxiways. It appears probable that the number of aircraft operating at London Airport under category II and IIIA conditions will become comparable to the number presently operating under good visibility conditions. Therefore, it is concluded that consideration should be given now to a control system involving a degree of automation backed up by high-resolution ASMI (airfield surface movement indication) radar.

PROBLEM OF CALCULATING THE PROBABILITY THAT CONTINUOUS ICING CONDITIONS OF VARIOUS DURATIONS WILL OCCUR AT AN AIRPORT
(K Voprosu O Raschete Obespechennosti Periodov Razlichnoi Nepreryvnoi Prodolzhit'-'nosti Gololeda Na Aerodrome)
A. P. Pen'kov.
IN: Aviation Climatology (Aviatsionnaia Klimatologiya), Edited by V.I. Tarhunova Moscow, Gidrometeoizdat (Nauchno-Issledovatel'skii Institut Aeroklimatologii Trudy, No. 27), 1968, pp.64-68. In Russian

Application of the methods of variational statistics to hourly meteorological data collected during the period from 1960 to 1964 at Sheremetievo Airport of Moscow, to obtain a basis for predicting the time and duration of icing conditions on the runways of the airport. Families of curves showing the distribution of continuous icing conditions of various durations at this airport are plotted. Examples of the application of these curves in solving practical problems of air traffic are given.

SOME PROBLEMSPOSED BY THE LANDING GEARS OF MODERN AIRCRAFT. II
(De Quelques Problemes Poses Par Les Trains D'Atterrissage Des Avions Modernes. II)
P. Lallement
Societe l'Exploitation des Materiels Hispano-Suiza, Paris, France

Detailed description of the metallurgy, machining, and plant layout for the construction of the Concorde landing gear. Ways of producing 35 NCD 16 alloy steel are outlined. The fabrication of major components such as the barrel, the sliding tube, the compensating linkage, and the cross-link is described. The machine tools used, the forging processes, and heat treatment are discussed.

INSTRUMENTAL MEASUREMENT OF THE VISUAL RANGE OF A RUNWAY
(Misura Strumentale Della Portata Visuale Di Pista)
IN: Associazione Geofisica Italiana, Annual Convention, 16th, Naples, Italy May 22-24, 1967, Proceedings

Description of an instrument for measuring light transmission through the atmosphere in order to determine the visual range of a runway. The instrument consists of a projector and a receiver, the measurement being made by balancing the received light with the intensity checked at the projector output. The information is transmitted in pulsed form and is recorded on a strip-chart recorder.

ESTIMATION OF THE LENGTH OF THE TAKEOFF RUN - A SIMPLE PROBLEM SOMETIMES MISUNDERSTOOD
(L'Estimation de la Longueur de Roulement au Decollement - un Probleme Simple Parfois Meconnu)
R. Bournat
Nort-Aviation, Paris, France
Technique et Science Aeronautes et Spatiales, May-June 1967, pp. 213-222 In French.

Study of the use of simplified formulas to determine the length of the takeoff run. A comparison is made between a rigorous calculation and approximate formulas of high accuracy. Attention is given to simple formulas and to attempts to improve their accuracy. In the case of the design and development of an aircraft it is important to know
whether the takeoff estimate is pessimistic or optimistic, and an attempt is made to determine this information.

WHAT AIRCRAFT FLUIDS FIRE HAZARD MEANS TO THE FEDERAL AVIATION AGENCY
Harold D. Hoekstra
Federal Aviation Administration, Washington, D. C.
IN: Daniel and Florence Guggenheim Aviation Safety Center at Cornell University, Aircraft Fluids Fire Hazard Symposium, Fort Monroe, Va., June 7, 8, 1966, Proceedings.

Summary of the conclusions reached by the Federal Aviation Agency with respect to minimizing the aircraft fire hazard attributable to flammable fluids. Research and development programs undertaken to alleviate the problem are outlined in terms of the principal causes of fire accidents and their significance in complex future aircraft. It is recommended that fire-prevention programs be undertaken in the following directions: (1) design improvements to flammable-fluid installations, (2) use of ruggedized tank structure and fuel lines with flexible containers to improve fuel containment, (3) research on improved fuels, (4) increased passenger protection, and (5) improved ground assistance and fire-fighting capability.

Runways, Terminals, Facilities

EVALUATION OF VTOLPORTS FOR IMPROVED AIRPORT ACCESS
Edward S. Wright and Stephen Hall
United Aircraft Corp. East Hartford, Conn.
American Institute of Aeronautics and Astronautics
Aircraft Design and Operations Meeting
Los Angeles, Calif., July 14-16, 1969
Paper 69-804

The concept of metropolitan shuttle VTOL airport access system is described and analyzed for the New York area. The resulting VTOL airport network consists of VTOL airports located at La Guardia, Newark, and Kennedy Airports, Manhattan, and surrounding high-density metropolitan counties. A congestion analysis program is described which estimates potential air traffic delays at the VTOL airports, taking into consideration projected high-density intercity demand as well as metropolitan demand. Typical VTOL airport designs are presented which are sized to support a no-delay system. An economic analysis made using S-61 operating costs shows fares averaging one-half of existing taxicab fares and an estimated system operating profit of five million dollars per year.

SIZING OF DEPARTURE LOUNGE IN AIRPORT BUILDINGS
Robert L. Paulin
Federal Aviation Administration
U.S. Dept. of Transportation
Robert Horonjeff
Institute of Transportation and Traffic Engrg. University of California, Berkely.
Presented at the ASCE-ASCI Specialty Conference on Airport Terminal Facilities, April 10-14, 1967, Houston, Texas

Introduction

By 1970, large jet transports with capacities in excess of 400 passengers are expected to be in operation. This increase in passenger capacity can cause congestion in airport terminal buildings during periods of enplaning and deplaning. Herein, enplaning passengers are primarily dealt with.

Loading large numbers of passengers into airplanes will present problems not now encountered with present day jet transports. One problem is the congestion at the final passenger congregating area, commonly called the 'departure lounge.' This study deals with the flow of passengers into and out of departure lounges; it is based on observations at San Francisco International Airport. Deterministic queuing theory has been applied to describe passenger flow to the departure lounge, as well as into the airplane.

The flow of passengers follows predictable patterns. These patterns are dependent, in part, upon (1) the loading procedures followed by individual airlines; (2) the type of terminal building; and (3) habits of airline passengers.

Conclusions

Mathematical models for the cumulative flows of passengers to departure lounges and into airplanes can be developed. From these models the relationship between the size of lounge, number of entry doors into an airplane, and time allowed for boarding passengers can be determined. The size of a departure lounge depends on: (1) size of air airplane; (2) number of available entry doors into the airplane; (3) arrival pattern of passengers to the lounge; and (4) the time allowed for boarding passengers. For a fixed arrival pattern to the lounge and a specific size of airplane the size of the lounge increases as the time allowed to board passengers decreases. Increasing the number of entry doors into the airplane permits a reduction in boarding time at the expense of increasing the size of departure lounge.
To accommodate passengers in current lounge areas (of approximately 1,500 sq. ft.) would require a boarding time of about 35 min. for a 500-passenger airplane assuming all seats were sold. Only one entry door would be required. If it were desired to reduce the boarding time for the 500-passenger airplane to 10 min. the lounge area would have to be about 7,000 sq. ft. and 4 entry doors would be required.

SPACE CRITERIA FOR AIRCRAFT APRONS
Paul H. Stafford and D. Larry Stafford
Paul Stafford Associates, Elizabeth, N.J.
Presented: ASCE-AOCI Specialty Conference on Airport Terminal Facilities, April 10-14, 1967, Houston, Texas
Transportation Engineering Journal Vol. 95, pp. 237-243, May 1969

Primary planning criteria for design of passenger terminal aprons involve size of aircraft parking or gate positions, parking configurations and number of positions. The plan must meet the normal demand at any time during the useful life of the airport terminal. This may include development in stages, since a substantial excess of apron facilities increases capital costs and may result in less efficiency and convenience of operations.

Many years ago we drew circles to indicate aircraft parking positions. With various diameters these are still used by some as a simple graphic representation. However, airplanes are not round. They come in a variety of shapes and sizes and for several years there has been a trend toward the use of plan forms for more accurate presentation and analysis.

With advanced procedures of parking and loading aircraft, the ideal gate position is a wedge. This wedge conforms to aircraft size and shape by moving the aircraft along the radial bisector, or by changing the angle of the wedge. The outer and wider segment of the wedge serves as the manoeuvring area and the inner segment concentrates the servicing in and near the building. For simplicity, the writers have shown most aircraft positions aligned on a circle. More flexibility can be achieved by moving the aircraft radially. It might be noted that the wing tips do not move radially, but parallel to the axis of the aircraft.

Another point to remember is that airplanes are not flat. With the increasing variations in floor and wing heights, there is need for three dimensions for aircraft space on the apron. Vertical clearance can be valuable in reducing the horizontal space requirements.

Time is the fourth dimension to consider as a vital element in planning. As aircraft size and shape continue to change, accommodating the changing number and composition of the aircraft fleet becomes a primary problem. It requires flexibility to meet planned and unplanned situations.

The growing range in sizes of aircraft using a major airport makes it inefficient for all positions to be capable of accommodating the largest aircraft. Both length and wing span of the Boeing 747 will be more than twice that of the new twin engine jets. Since specific models of aircraft may be modified to some extent, the family of future aircraft has been divided into five basic size groups. To provide for growth, the lengths and wing spans are slightly more than the average of present and proposed models. The groups are generally described as follows:

1. Small two and three engine jets - wing span, 100 ft; length, 150 ft.
2. Air bus and four engine subsonic - wing span, 150 ft; length 200 ft.
3. Jumbo jets - wing span, 200 ft; length, 250 ft.
4. Supersonic (small) - wing span, 100 ft; length, 200 ft.
5. Supersonic (large) - wing span, 125 ft; length, 300 ft.

The facilities most affected by changes in aircraft sizes are the loading bridges and the gate lobbies. One simple way to accomplish this adaptation is to make continuous lobbies, separated only by movable partitions, screens or rails and served by bridges which can be moved modularly along the face of the structure. The total area available for lobbies must be initially planned for ultimate capacity. Improvements in schedule reliability and passenger processing will reduce the space required per passenger and increased daily use of each position will add to the productivity.

Another approach is to provide portable lobby structures which can be moved, expanded or replaced to meet changing needs. These would not be continuous, could be doubled-decked and may extend beyond the nose of parked aircraft. Using standard modular units, these lobbies could probably be constructed at a cost comparable with fixed structures, yet be moved or modified quickly and economically. Mounted on a track,
like seats in a stadium, or supported on a special pavement, these units would have a self-contained heating and air conditioning units with minimum connections to the fixed structure.

Changes will come so fast that complete new structures cannot be built. The key is planning in four dimensions and maintaining options for future aircraft and servicing equipment. Different situations will bring a variety of optimum aircraft parking configurations. The studies and solutions at many of the major terminals now under construction demonstrate ingenuity and development. Each design contributes to progress toward providing the best service to the customers. Some passengers may not be pleased, but all will be spared the monotony of conformity.

AN OPERATIONAL VIEWPOINT OF JET AIRPORT RUNWAYS
Mel Volz

Discussion of certain aspects involved in runway development for increased airport capability. The objective of runway development programs, as outlined in the paper, is to maximize the operational capacity of an airport within the geographic area available for development. A computer simulation model of airport operations was developed by a leading U.S. aviation consulting firm. From this model every possible combination of runway patterns, taxiway patterns, operating rules, and weather conditions can be considered. Some broad guidelines are listed for planning runways. Recommendations are made to keep runway occupancy time at a minimum.

A COMPARISON OF ACCESS SYSTEMS TO PRESENT WORLD AIRPORTS
Secor D. Browne
M.I.T. (Now CAB Chairman)

This Note deals with existing airport access systems and basically utilizes data compiled by the Port of New York Authority and published in July 1968. This report was based on a survey conducted by the Authority beginning in November of 1966 to which 23 of the world's major airports responded.

There is every indication that in the choice of an airport access mode there is relatively little fare sensitivity or preference for vehicle type compared with such matters as exclusive right-of-way, transfers, baggage conveyance and handling, number of stops, or the actual distance the passenger must walk with or without luggage between the access vehicle and the aircraft.

The questionnaires reveal that about one-half million daily airport travellers of all types enter the 23 airports surveyed in this study of ground access between central business districts and airports. Practically all of them use highway transport modes: automobile, taxis, coach-limousine services, and to a considerably lesser extent, public bus, subway-bus combinations, and helicopter services.

Rail passenger services link 11 of the 23 airports with the central business districts, but collectively serve few airport travellers. Several of the
rail lines reach only the peripheries of the airports, and not all of these have bus connections to the airline passenger terminal buildings, drastically limiting their value. Only four of the 23 airports actually have direct rapid transit rail service to the airline passenger terminal buildings.

Central business districts (CBD) now generate 17 to 50 percent of total airport traffic at the ten airports reporting this information. Most airports are within 30 minutes of their central business districts during midday and evening hours, but 30-to-60 minutes travel times are much more common during peak hours. The London-Gatwick rail service is a real time saver, being 15 to 45 minutes faster than highway travel. Travel time on the rail service to Brussels Airport and the Tokyo monorail to Haneda Airport is only comparable to highway travel. The new installations to Cleveland-Hopkins and London-Heathrow are expected to save considerable travel time compared to highway travel, according to advance estimates.

In this survey, airline passengers account for 27 percent of all the airport trips, employees 36 percent, and all others (including visitors) 37 percent. In general, the planned new rail links will be of service to the airline passengers and 'all others' if they are exclusively oriented to central business district-to-airport travel. If links are added to serve intermediate districts, more employee traffic would be accommodated, but en route stops would delay travel and thus inhibit the full development of airline passenger potential. Estimates vary widely with local circumstances and conditions, but as reported, rail service handles anywhere from 20 to 80 percent of total traffic between central business districts and airports.

The results of this survey suggest that rail access can provide valuable service connections in some cases, but only the most careful analysis of an individual situation can determine its potential patronage and feasibility. However, it is clear that highway travel will continue to be important from the central business district because of personal preferences for automobiles and taxi services. In addition, highways will, of course, continue to be indispensable for access from all non-CBD areas served by the airport.

This review of access systems for major world airports at present and in the immediate future has re-emphasized the overwhelming role of highway transport and the very minor role of existing alternatives. Such things as the decrease in the New York area of airport bus passengers, despite major highway congestion, may emphasize the absence of attractive alternatives other than the automobile and taxi, but the extent to which the most convenient high-speed, nonstop airport CBD service will attract the passengers away from 'their own wheels' must certainly be evaluated with extreme caution. The economics of such alternatives also demand careful attention since there may be the need to justify very heavy subsidy for construction and operation on the basis of some sort of total system or total transportation concept. Finally, there is every indication that airport employees and their private vehicles will become an increasing and well-nigh irreducible portion of the airport traffic and parking problems of the future.

AIRPORT ACCESS - 1980, A VTOL APPROACH
Chaim Pearlman

At the current rates of air passenger growth, congestion into the airports from the air and from the ground is worsening exponentially. A VTOL network that includes terminals at city centres as well as airports could alleviate both aspects of the problem. Direct city centre-to-city centre flights would remove a significant portion of the traffic flowing through the airport and postpone the requirement for additional airports. Flying from city centre to airport would avoid the ground congestion and curtail the total trip time anywhere between 45 min and 2 hr, depending on the uncertainty associated with a particular route. VTOL lends itself admirably to the regional and satellite airport concepts, facilitating a wider choice of lower cost sites further from the city centres. Neither road nor rapid transit is equal to this task.

*It should be noted that travel time cited in this report generally reflect time spent between the downtown airline terminal and the airport, for both rail and bus modes and do not include travel time to reach the downtown terminal, baggage checking time or distribution time within the terminal. These times, however, are usually reflected in data for automobile and taxicab modes.
A SIMPLE EFFECTIVE CURRENT REGULATOR FOR AIRPORT LIGHTING
Kenneth Wallace, Dennis M. Swing, and Stuart P. Jackson
Solidstate Controls Inc., Columbus, Ohio
IN: National Electronics Conference
Chicago, Ill. October 23-25, 1967
Proceedings, Volume 23
Chicago, National Electronics
Conference, Inc., 1967, pp. 797-802

Description of an effective current regulator intended to provide reliable power for airport lighting purposes. A saturable reactor is used to control output voltage by varying the point of core saturation. Constant effective load current is obtained by using a feedback regulator to provide final correction of control current to the saturable reactor. The heart of the feedback regulator is an rms load-current sensor. This sensor is quasi-solid-state in that it combines a light source and a photosensitive cell. Proper choice of operating potential provides the low maintenance desired. P-n junction devices serve to amplify the difference between the reference potential and the potential proportional to the effective load current. A differential arrangement of sensors compensates for ambient temperature changes, as well as long-term variations of sensor characteristics. Electrically, the complete unit accepts an input of 240 v ac ± 10%, single phase, 60 Hz, and delivers an output of up to 2300 v ac, 6.6 amp.

THE PROBLEM OF BRAKING BARRIERS - THE HISPANO-SUIZA DESIGN
(Le Problem Des Barrières D’Arret - La Realisation D’Hispano-Suiza)
M. Laining

Description of the development of a barrier capable of strongly braking a civil aircraft as it reaches the end of the runway still rolling at high velocity but where the takeoff is aborted. The braking barrier consists of a stretched, flexible net placed across the runway; the aircraft, running into the net, would carry it away if it were not connected by links to a system of brakes. The solution presented by Hispano-Suiza uses direct braking by means of a flat strap arranged in accordion fashion. The characteristics of a military braking barrier capable of stopping an aircraft of 30-ton takeoff weight and rolling at 300 km/hr are described.

PERIPHERAL PARKING AND DIRECT CITY-TO-AIRCRAFT CONNECTION
(Estacionamientos Perifericos y Enlace Directo Ciudad-Avion)
F. Fernandez-Amigo
Instituto Nacional de Técnica Aeronáutica
Madrid, Spain
Congreso de Aeronáutica, 8th, Paris, France, May 1967, Paper

Proposal of an airport layout and arrangement of ancillary facilities to expedite the transfer of passengers from a city centre to the aircraft itself. The proposal deals with the arrangement of runways, taxi tracks, peripheral roads, and aircraft standing spaces with methods of connection aircraft and terminal buildings; and with city-to-aircraft links.

COMMENTARY ON APPROACH LIGHTS (FROM THE VIEWPOINT OF VISUAL PERCEPTION)
Norifusa Iwataki and Hiroshi Kansaku
Air Self Defence Force, Aeromedical Laboratory, Tachikawa, Japan

Discussion of the optimal characteristics for an approach light to help pilots land at night or in bad weather. Factors such as color, intensity, and configuration of the approach light as a function of visual perception are discussed. Red was evaluated as the most desirable color for the approach light, and the optimal intensity of light was found to be related to the color of the light used. Since strong illumination will cause glare, the intensity of the approach light must be adjusted according to the environmental conditions on the airfield. Stroboscopic light was found to be effective for increasing conspicuity. The visual-approach slope-line indicator system was found to be the best configuration for an approach light.