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THE FUTURE OF SHORT-HAUL AIR TRANSPORT WITHIN WESTERN EUROPE WITH PARTICULAR
ON THE ROLE OF V/STOL-AIRCRAFT

by

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The future of short-haul air transport within Western Europe, with emphasis on the role of V/STOL-aircraft.

by

prof. H. Wittenberg

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Summary

An outline is given on the future of short-haul transport in Western-Europe based on a study of the Netherlands V/STOL-Working Group. The problems of the existing system using aircraft with conventional take-off and landing techniques (CTOL) to cope with the expected growth, are considered. It is pointed out that the introduction of a new category of aircraft, using improved take-off and landing techniques (RTOL and STOL) can relieve these problems. However, their application is not seen to occur within a new, separate short-haul transport system, but as an extension and supplement to the existing CTOL-system.
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1. Introduction

The subject of this paper is the future of short-haul air transport within Western-Europe, with emphasis on the possible role of V/STOL-aircraft. In the last twenty years an enormous amount of literature has been published on V/STOL-aviation and it seems appropriate to indicate firstly some motives for the study from which some thoughts and conclusions are presented.

In 1971 the Ministry for Transports, Hydraulics and Public Works of the Netherlands Government published a brochure on the future of national and international transport for the Netherlands, where all means of transportation were considered (cars, railways, water- and air transport). One of the goals of this study was to stimulate discussions in the Netherlands, which could lead to a more detailed prediction of the development of transport in the future. A fairly large part of the study-known as TP-2000- was devoted to the future of air transport.

Based on the rather optimistic views presented in the literature during the sixties in relation to short-haul air transport, TP-2000 stated: "Major developments in the short- and medium-haul air transport can be expected to come from STOL- and VTOL-aircraft. Some obstacles will have to be overcome, with regard to noise, safety and operating costs. In view of the large efforts, especially in military aviation, it is foreseen that in the eighties civil VTOL-airplanes will become available for regular operation". Moreover, within 5-10 years the use of STOL-aircraft with a capacity of 100-200 passengers was predicted in TP-2000.

To obtain a more thoroughly founded view on the future of short-haul transport in Western-Europe an initiative was taken by one of the Directors of the Civil Aviation Department of the Government to establish a Netherlands V/STOL Working Group. The members of this Group were invited from all civil aviation branches in the Netherlands (fig. 1), but the membership was on a personal base. This paper is based on the final report of the group, which was published in 1973 (ref. 1). The Working Group reached their conclusions only by deliberations and study of available documents; the members did only some "thinking" on the problem, and no transportation studies on a quantitative base were performed.

The results of the study will show to be not at all revolutionary and very much different from the optimistic views on the introduction of V/STOL
aircraft, which were presented in the sixties. However, they are in agreement with the opinions, now considered more or less as common thoughts in Western-Europe.

2. Growth of short-haul transport; limitations of CTOL-system

The most crucial point in the prediction of the future of air transport is the expectation on growth. It is well-known that during the past decennia the growth in world air transport (in passenger miles) was about 15% per year, that is a doubling every 5 years. Although for the coming years a smaller growth can be expected, all sources known to the Group predicted a considerable absolute increase of air transport volume up to the year 2000. A possible growth for Western-Europe is shown in the example in fig. 2 and was considered to be likely for the following reasons:

a. an increase in international activities of the governments, industries, trade companies, banks, etc. which will stimulate business air trips in Western-Europe,

b. growing standard of living, leading to increased time and money for holiday-travels and for private trips over longer distances during the whole year,

c. greater familiarization of the general public with air transport promoted by charter operations for holiday travel.

The sudden appearance of the energy crisis at the end of 1973 has put forward many questions on future growth problems, but the author believes that the increase of transport is one of the most fundamental issues of our developing world, which will not be changed suddenly due to short-term events.

During the deliberations of the Working Group it became quite clear that the future of air transport can only be considered taking into account the fact that the aircraft is only one component of a transportation system. Equally important are the other components:

- the airport (runway-system and passenger/freight terminals),
- the air traffic control (ATC) system,
- the means of passenger access and egress.
The present CTOL-system has serious limitations which can be expected to hamper the future growth of air transport. As possible limitations are to be considered: noise, pollution and congestion.

At the moment the most serious limitation is the noise-annoyance caused by aircraft to the communities living near airports. Restriction of the number of operations on airports or even closing at night hours, are threatening the expansion of air traffic. Moreover, increased use of secondary airfields, which had up till now very little or no traffic, seems rather impossible due to public opposition. Although this noise problem will stick to aviation during the seventies - maybe the early eighties - because of the use of first and second generation jet-aircraft, it can be expected that the noise problems caused by future aircraft will be greatly reduced. Fig. 3 gives a rough estimate of the noise footprints areas of future aircraft in comparison with the types now in use. From such data it was concluded that in the eighties noise problems would not restrict the traffic of CTOL-aircraft on large international airports, located at relative large distances from the city. However, for short-haul operation using airfields nearer to communities, very quiet aircraft could be desirable, which differ from CTOL-types by the use of special engines (e.g. prop-fans), an extreme acoustical treatment and/or steep-gradient flight techniques.

Atmospheric pollution at low altitudes is not considered as a possible limitation for future growth, because aviation is only a small contributor to the total pollution. Furthermore, actions are already well under way to reduce the pollution content of exhaust gases, in particular for new engines.

The most fundamental limit for growth seems to be in the area of congestion in the air, on the airport and in ground transport to and from the airport. Without doubt much can be done to increase the capacity of the CTOL/system in the future in these respects. Fig. 4 gives a survey of some possibilities, which are for a large part already under development.

Of course the airport saturation problems can also be much relieved by the construction of new large airports. This possibility is, however, very much restricted by a number of reasons:

1. the use of a large land area, which can hardly be found on reasonable distances from the cities,
2. the vast infrastructure required for transportation of passengers, freight and employees to and from the airport,
the large initial costs of the airport and its infrastructure,
the heavy public opposition caused by the noise problem of the air-
craft of to-day, the fear for air pollution and the possible effect on
natural and/or resort areas.

Some people even believe that the new Paris airport Roissy-en-France
will be the last airport to be constructed in Western-Europe. Although this
might be too pessimistic, it is certain that the possibilities to extend
the number of large CTOL-airports in this part of the world will be very
restricted.

The Working Group had no cohearent data available to predict the time
of saturation of the CTOL-system in Western-Europe, taking into account
possible improvements and new airports. It was felt, however, that it was
worthwhile to consider how new aircraft technology could possibly be used
to relieve the CTOL-system. It was the common opinion that long-haul air
transport would remain for a long time the domain of CTOL-technology, but
that for short- and medium-haul transport new other categories of aircraft
could become feasible.

3. Prospects of aircraft categories other than CTOL

During the sixties the aircraft industry produced a large number of
project studies on STOL- and VTOL-aircraft. In 1971 the Institut du Transport
Aérien in Paris - well known under its abbreviation ITA - published a study,
which gave details of 21 civil STOL-aircraft designs and 7 civil fixed-wing
VTOL-aircraft (ref. 2).

In a recent ITA-bulletin of March 1974 (ref. 3) one can read how little
is left of all these projects of the sixties and how little is added on new
civil V/STOL-types.

In the author's opinion the exaggerated expectations on V/STOL in the past
have been caused by two facts. On the one hand, too optimistic views on
the solving of the technical and operational problems and on the funds
available for development. On the other hand an underrating of the fact,
already mentioned, that the aircraft is only one component of a complete
transport system.
A summary of the various categories of aircraft classified according to their take-off and landing performances, is given in fig. 5. Among the aircraft with improved take-off and landing characteristics compared to CTOL, the helicopter and the propeller R- and STOL-aircraft (like the De Havilland DHC-7) are the only types, which can be made available for civil aviation in the near future. Both aircraft categories have limited cruising speed and are of relative small size, which gives them a low productivity in comparison with the CTOL-jets. For Western-Europe, where no immediate need for a supplement to the CTOL-system is required, an introduction of these aircraft on any large scale is not foreseen. Their application is only likely for third-level operations and for low-density traffic in remote areas.

From the categories, shown in fig. 5, another group has to be eliminated for use in the foreseeable future: the fixed-wing civil VTOL-aircraft. The technical and operational problems of these aircraft seem so large, that it certainly will last several decades before these aircraft become feasible for economic and safe operation in the civil market, if ever.

In the past, city-centre to city-centre operation was considered as an attractive topic for future air transport, which would demand VTOL-aircraft, either helicopters or fixed-wing. For a number of reasons other than lacking technology, it becomes unlikely that this type of transport will develop on a large scale:

a severe public objections against air traffic in densely populated areas because of noise, fear of pollution and accidents,

b high prices of real estate in city-centres, which will make VTOL-ports with extensive facilities for passenger-handling very costly,

c the passenger origin and destination is quite often not in the city-centre itself, because the city-oriented activities of the past are spreading to the suburbs, as the living quarters do.

From the considerations above it follows that the most likely class of aircraft to be used in addition to CTOL-types in the eighties will be in the R- and STOL-category, which at that time will be powered by turbofan-engines.

4. Some remarks on STOL-technology

It seems appropriate to recall a few fundamentals on STOL-technology, based on the well-known STOL-definition of a runway-length of 600 m (2000 ft); see fig. 6. To obtain this short runway-length in the landing a steeper
approach is required than the conventional glide path with 3° descent angle to shorten the air distance. This leads also to the possibility to operate in an environment with higher obstacles (buildings etc.) and to a reduction of the noise footprint.

According to practical experience a limit is also set to the descent rate (e.g. 5 m/sec = 1000 ft/min), which requires a decrease in approach speed with increasing approach angle. A generally accepted STOL-approach angle is 7.5°, resulting in an approach speed $V_a = 40$ m/sec = 78 knots.

Taking a reasonable deceleration in the ground run, one ends with a runway-length for landing of about 600 m, including the normal runway-safety margin.

From this it can be concluded that the S of the STOL-concept is not only standing for Short, but also for Steep, Slow and Silent as well. Some consequences of STOL are indicated in fig. 7. This figure shows the relation between wing loading and approach speed for two values of the lift coefficient in the approach $C_{L_a}$. Using mechanical high-lift devices ($C_{L_a} = 2$) the approach speed $V_a = 40$ m/sec is only obtained with low wing loadings, leading to a low cruising speed and to unfavourable riding qualities.

Using power-augmentation for the high-lift system - e.g. externally or internally blown-flaps - a value of $C_{L} = 4$ is obtainable, which leads to an acceptable wing loading for a jet-STOL aircraft. The power-loading of this aircraft has to be chosen such that a steep climb gradient of the order of the approach-gradient can be maintained after power-failure (a requirement not always considered in older design studies), otherwise the safe operation in an environment with obstacles is heavily hampered. This condition and the required total take-off distance of 600 m leads to a power loading considerably higher than for CTOL-aircraft. A thrust-weight ratio $T/W = 0.45$ can be considered as a minimum value and some STOL-designs show even values up to $T/W = 0.70$.

These characteristic features of STOL-aircraft will lead to a larger take-off weight and greater complexity in comparison with CTOL-aircraft for the same payload-range capacity. This will result into higher initial costs, higher fuel consumption and increased maintenance costs, all adding to increased direct operating costs (D.O.C.) of STOL-aircraft. Various investigations have produced graphs of D.O.C. versus runway-length (e.g. ref. 4), which all show a steeper increase in D.O.C. the more the VTOL-performance is approached. In overall cost-analyses the effect of the
higher D.O.C.'s is often somewhat reduced due to the expected lower indirect operating costs, which are, however, hard to evaluate on a theoretical base.

Therefore, it seems reasonable to state that R- and STOL-aircraft will only become feasible for operation on a large scale, when the higher costs are compensated by benefits to the passenger and/or the environment.

5. **Application of R- and STOL-aircraft in the air transport system**

As to the application of R- and STOL-aircraft two possibilities can be distinguished:
- to fulfill a short-haul demand with a new air transport system, which is separated from the existing CTOL-system and connected to this system for feeder purposes only,
- to operate within the existing CTOL-system to relieve some of its problems with regard to noise and/or congestion.

To reduce the door-to-door travel time and to relieve the CTOL-system new, separate STOL-air transport-systems have often been suggested in the past, e.g. using a network of peripheral STOL-ports near the cities (ref. 5). Extensive studies have been published for solving the traffic problems in highly-urbanized regions in the USA by the introduction of such a STOL-system (North-East Corridor, Los Angeles – San Francisco area and the Chicago-region). The flexibility of the STOL-system, which allows to fit the network to a changing demand, and the relatively low costs of the infrastructure required, are often quoted as advantages compared to new ground transportation systems. It looks, however, that such a new air transport system will not materialize, because of an existing vicious circle or "chicken and egg"-problem related to its initiation (fig. 8). The aircraft industry is willing to start the development of first generation STOL-aircraft, but cannot find customers, because the airlines do not see readily available, profitable markets. These markets cannot develop without some start of the system. Seeing no definite actions by others, the Governments are reluctant to build STOL-ports, to establish separate ATC-facilities and to give the financial support to the aircraft- and engine-industry for development of STOL-aircraft, which closes the circle.
A break-through in this vicious circle can clearly only brought forward by the execution of a well-defined transportation plan by Governments, which would make available all components of the STOL-system at the same time on a reasonable scale. The experimental STOL-service between Montreal and Ottawa and the development of the De Havilland Canada DHC-7 (ref. 6 and 7) are to be considered as attempts of Canadian aviation to stimulate such a break-through.

Whereas the prospects of a development of a separate STOL-system under governmental lead seems even in the USA still uncertain, this holds the more for the Western-European scene. It is unquestionable that the development of a STOL-system in Western-Europe has to be based on international cooperation, e.g. within the European Economic Community. Neither the political, nor the economical climate, however, seems favourable to expect such a cooperative air transport planning in the seventies for execution in the eighties. Without a supra-national transportation plan, it is unlikely that a separate R- or STOL-system, which can take a considerable share of the short-haul market, will come into being in Western-Europe.

From the considerations above, it is more likely that in our part of the world any introduction of R- and STOL-aircraft will be in a gradual way within the CTOL-system to cope with noise and congestion problems that will arise with increased traffic. These aircraft might offer the following potentials to expand and supplement the CTOL-system:

a to increase the capacity of CTOL-airports by the use of separate runways,
   e.g. in close-parallel operation,

b to use secondary airfields near major cities with saturated CTOL-airports,

c to expand the aerial network by the use of secondary airfields, existing near many cities, with less environmental impact than caused by CTOL-aircraft,

d to prevent closing of existing airports near cities in cases where new large CTOL-airports are built, which are not very suitable for short-haul traffic because of their location at large distances from the cities.

In the expected gradual development of these potentials the first aircraft type of a new category could be a short-haul turbo-fan aircraft, which by careful choice of wing- and thrust loading and the application of sophisticated mechanical high-lift devices, obtains take-off and landing performances in the RTOL-class. This aircraft may have quieter engines with a higher by-pass-ratio than comparable CTOL-types and also steeper flight paths in
approach and climb-away.

In this scenario jet-aircraft with STOL-performances, requiring powered lift, do not appear as a next generation of short-haul aircraft. This aircraft class, which may become technically feasible during the eighties, might fulfil a transportation task after 1990, when the CTOL/RTOL-system described above, needs further extension.

Despite this rather modest outlook in the application of V/STOL-aircraft in the European civil aviation, there are in the opinion of the author still enough challenging opportunities for the development of air transport in Western-Europe.

These challenges can be found in the improvement of the existing CTOL-system to relieve noise and congestion problems, as well as in its expansion by the introduction of suitable new aircraft types and their operation. This expansion should not only be directed to an increased transport volume on existing routes, but also an extension of the route-network in Western-Europe should be emphasized. Up till now the network of scheduled air transport is on the one hand very much restricted to connections between the capitals of the countries and on the other hand to strictly domestic networks. Many important industrial and commercial regions in different countries of the Common Market have no direct connections by air. Already in 1965 the late Dutch aviation pioneer from the period after World War 2, Frits Diepen of Fokker-VFW, pointed out the large differences in short-haul air transport between Western-Europe and the USA and showed the large, dormant, possibilities for a denser international network within the countries of the European Economic Community (ref. 8). This challenge still exists and to meet it, concerted efforts will be required by the West-European aircraft/engine industry, the airlines and not in the least the Governments involved.

In a last remark it can be questioned whether the need for STOL- or even RTOL-aircraft will be more pressing in the less developed area's of the world to avoid the vast infrastructure required for the operation of CTOL-aircraft. It seems to the author that the highly sophisticated technology and operation of powered-lift fixed-wing jet aircraft is in contradiction to the requirements of the aircraft operators in these area's. Their needs might be better fulfilled by propeller-STOL-aircraft with relatively low wing loadings or by helicopters, when VTOL-capability is required. In the
transport scene considered in the less-developed area's the lower cruising speeds of these aircraft may be of lesser importance than the complexity of the more advanced aircraft types.

6. Conclusions

a. For the existing CTOL-system the expected growth in air transport in Western-Europe will lead to considerable problems due to noise and congestion.

b. Despite the improvements in noise of future CTOL-aircraft and in the air traffic control system, it is expected that the CTOL-system has to be relieved by the introduction of aircraft with reduced and/or short take-off and landing performances (RTOL and/or STOL-aircraft).

c. The development of a new short-haul air transport system with R- or STOL-aircraft, which operate independently from the CTOL-system, is not considered likely for Western-Europe.

d. The most likely development seems to be a gradual extension of the existing CTOL-system (including an extension of the route-network) by the introduction of jet-aircraft of the RTOL-class (without power lift) during the eighties, to relieve noise and congestion on existing airports and to make use of secondary airfields.

e. STOL-jet aircraft (with power lift) are only expected to fulfil a possible role when the CTOL/RTOL-system becomes saturated.

f. City-centre to city-centre operation with vertical take-off and landing aircraft (VTOL-class) is not considered feasible within the foreseeable future, mainly because of operational, environmental and socio-economic problems.
7. References


Members of Netherlands V/STOL Working Group

Experts from:

- Fokker-VFW aircraft industry
- Netherlands Agency for Aerospace programs (NIVR)
- National Aerospace Laboratory (NLR)
- Civil Aviation Department of the Ministry of Transport, Hydraulics and Public Works
- KLM Royal Dutch Airlines
- Schiphol Airport Authority
- Delft University of Technology

Fig. 1: Netherlands V/STOL Working Group
Fig. 2 = Example of predicted growth for air transport in Western Europe (ref. RAeS-Proc. Aviation's place in transport, May 1971)
<table>
<thead>
<tr>
<th>Class</th>
<th>Engine-noise technology</th>
<th>Approach angle</th>
<th>Climb-away angle</th>
<th>Footprint (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>90 PNdB</td>
</tr>
<tr>
<td>CTOL</td>
<td>a. 1960</td>
<td>-3°</td>
<td>5°</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>b. 1970 (FAR-36)</td>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>c. FAR-36 minus 10dB</td>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>RTOL</td>
<td>d. same as c.</td>
<td>-4,5°</td>
<td>8°</td>
<td>4</td>
</tr>
<tr>
<td>STOL</td>
<td>e. same as c.</td>
<td>-7,5°</td>
<td>13°</td>
<td>2</td>
</tr>
</tbody>
</table>

Fig. 3: Footprint area's for medium-/short-haul aircraft in take-off and landing (qualitative example only).
<table>
<thead>
<tr>
<th>Component</th>
<th>Aim</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>aircraft</td>
<td>increased transportvolume per unit</td>
<td>- larger aircraft size</td>
</tr>
<tr>
<td>air traffic control-en-route</td>
<td>higher aircraft density by reduced separations</td>
<td>- improved communication/navigation systems (e.g. area nav.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- computerized traffic control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- collision avoidance systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- integration civil/military aviation</td>
</tr>
<tr>
<td>TMA and runway-system</td>
<td>increase of aircraft movements/hr</td>
<td>- improved TMA-control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- wake turbulence counter measures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- high-speed exits and entrances on runways</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- dual-lane operations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- improved landing systems (MLS)</td>
</tr>
<tr>
<td>airport terminal</td>
<td>increased passenger flows</td>
<td>- improved lay-out of terminals</td>
</tr>
<tr>
<td>passenger access and egress</td>
<td></td>
<td>- improved passenger/luggage handling techniques</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- improved high-way systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- airport-city connections by train</td>
</tr>
</tbody>
</table>

Fig. 4: Means for increasing the capacity of the CTOL-system.
<table>
<thead>
<tr>
<th>Category</th>
<th>Abbreviation</th>
<th>Runway length</th>
<th>Thrust/weight ratio</th>
<th>High-lift system</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional take-off and landing</td>
<td>CTOL</td>
<td>≥ 1500m</td>
<td>0.22–0.30</td>
<td>mech. flaps</td>
<td>all current larger civil fixed-wing aircraft</td>
</tr>
<tr>
<td>Reduced t.o. and landing</td>
<td>RTOL</td>
<td>900–1200m</td>
<td>0.30–0.35</td>
<td>mech. flaps (evt. BLC)</td>
<td>to be considered as advanced CTOL</td>
</tr>
<tr>
<td>Short t.o. and landing</td>
<td>STOL</td>
<td>600m</td>
<td>≥ 0.45</td>
<td>mech. flaps power lift, props power lift, jets</td>
<td>small propeller aircraft only e.g. Breguet 941 e.g. AMST: Boeing YC-14 and McDonnell Douglas YC-15</td>
</tr>
<tr>
<td>Vertical t.o. and landing</td>
<td>VTOL</td>
<td>0m</td>
<td>≥ 1</td>
<td>rotor propellers jet-lift</td>
<td>helicopter e.g. tilt-wing concept vectored thrust (Harrier), lift engines, fan in wing</td>
</tr>
</tbody>
</table>

Fig. 5: Aircraft classification
1. **Steep final approach**: $\bar{\delta} = 6 - 7.5^\circ$ (CTOL: $\bar{\delta} = 2.5 - 3^\circ$)

   - Shorter air distance
   - Operation in built-up areas
   - Noise reduction

2. **Reduced approach speed**

   \[ \bar{C}_a = V \sin \bar{\gamma}_a \]

   \[ \bar{C}_a \leq 5 \text{ m/sec} = 1000 \text{ ft/min} \]

   For $\bar{\gamma}_a \approx 7^\circ$: $V_a \leq 40 \text{ m/sec} = 78 \text{ kts}$

3. **Landing runway length**

   With $V_a = 40 \text{ m/sec}$ a runway length for landing of about $600 \text{ m}$ (2000 ft) is obtained (safety margin included).

   \[ S_{\text{landing}} = \frac{h}{\tan \bar{\gamma}_a} + \frac{V_a^2}{2\bar{a}} \]

   ($\bar{a}$ = mean ground deceleration)

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**Fig. 6: STOL-definition**
1. Wing loading: \( W/S = C_L a \frac{1}{2} \rho v_a^2 \).

2. Thrust loading.
   a. to clear obstacles with engine failure: \( \gamma_{to} \geq 6^\circ \)
   b. take-off length with engine failure: \( s_{to} \leq 600 \text{ m} \)

   Result: thrust loading \( T/W \geq 0.45 \) dependent on power-lift system.

3. Direct operating costs.

   Increased d.o.c. because of:
   - higher initial cost
   - higher fuel consumption
   - increased complexity (maintenance)
   - lower relative payload

   Fig. 7: Consequences of STOL
Fig. 8: Vicious circle of STOL