STOL COMMUNITY ANNOYANCE DUE TO NOISE
PROPOSED INDICES AND LEVELS
for
TORONTO-YORK TRANSPORTATION COMMITTEE

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MARCH, 1972.

CANADIAN TRANSPORT
COMMISSION GRANT
UTIAS Technical Note No.177
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Submitted March, 1972.

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UTIAS Technical Note No. 177
SUMMARY

Contrasted with conventional aircraft and airport noise, distinctive features relating to V/STOL systems are noted. Currently popular methods for assessing conventional aircraft noise (CNR and NEF, on this continent) are shown to be much less appropriate for V/STOL. Both speech interference and perceived noise annoyances have been included in parallel.

Robinson's Noise Pollution Index is especially well suited to the evaluation of the total perceived noise annoyance since background noise effects are included directly. "A" weighted sound level is adequate for initial assessment of speech interference annoyance. Maximum V/STOL levels for these indices, in urban residential districts of $L_{NP\text{MAX}} = 75 \ (\text{PNdB})$ and $L_{N\text{MAX}} = 80 \ (\text{PNdB})$ are proposed.

Perceived noise contours ($L_{NP}$) calculated adjacent to a hypothetical Toronto waterfront STOLport site confirm that when the aircraft noise exceeds the background by 10 dB or less, community annoyance grows imperceptibly with the number of similar operations flown. Smaller aircraft operating in larger numbers, to fulfill a given transportation task, therefore offer a substantial annoyance improvement over larger similar technology aircraft. V/STOL noise certification rules permitting a substantial noise increase with size (3 or 4 dB per doubling or more) cannot adequately preserve the community amenity.
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1. OBJECTIVES - SCOPE OF STUDY

The principle objective of this study is to define suitable community noise assessment techniques applicable to V/STOL transportation systems. A second objective was to apply the developed techniques to the assessment of the total annoyance due to noise in community areas adjacent to a hypothetical Toronto waterfront STOLport site.

The assessment techniques of interest must incorporate current community disturbance methods and experience to a maximum, but including suitable modifications to accommodate important new noise features implicit to the proposed V/STOL systems. Hopefully these methods would provide a logical basis for the development of techniques for assessing a broader range of new and future urban transportation systems (such as air cushion vehicles, monorails, high speed rail systems, etc.) now under development. These methods are expected to be of assistance in the planning stages associated with the introduction of such systems.

The study includes a brief review of current applicable psychoacoustic work relating to:

(i) Methods for assessing subjective response to individual noise events - including speech interference.

(ii) Indices for assessing total noise exposure.

(iii) Criteria for assessing community reactions (noise/annoyance).

A method for evaluating community noise disturbance, due to V/STOL operations is then proposed, together with maximum criteria levels. Finally, a computer program has been developed and preliminary computer studies carried out, at a hypothetical urban STOLport location, to establish the feasibility of the proposed methods.

2. INTRODUCTION

Much effort has been expended, in several countries, to assess the community annoyance caused by noise, in a variety of special noise situations. Thus annoyance due to conventional aircraft (both jet and propeller powered), motor vehicles, industrial noise, and office noise have all been separately evaluated in some detail. Of these perhaps conventional aircraft and airport noise is the most important and therefore has received the greatest attention. No less than eight different but related noise or annoyance assessment techniques, relating solely to conventional aircraft noise can be found in the literature.

As a result of these individual approaches to specialized noise situations a number of divergent methods of assessing the effects of noise events and even alternative basic scales of subjective measurement have been developed. When the noise environment is largely dominated by a single type of noise, these specialized approaches will be adequate. However, it is clear that when several important and differing types of noise are simultaneously influencing the environment a unified and more general noise rating procedure is required. There is evidence to indicate that this may be increasingly the case in certain urban locations when new forms of urban transportation are superimposed on conventional road and freeway traffic noise. Recently (1970) efforts towards the development of such a generalized rating scheme have been initiated in Great Britain.
Short and vertical take-off and landing aircraft transportation systems have been under active development, for both military and civilian use, for a considerable period of time. An earlier interest in viable V/STOL systems was strongly expressed by the Military for forward supply missions. Subsequently, civil interest in these systems grew in terms of short haul inter-urban applications with direct access to downtown locations. In the mid and late sixties additional civil V/STOL interest developed, in certain areas, as a means to relieve a rapidly escalating congestion of certain airport locations and along certain transportation corridors. Such systems have always involved, implicitly, a significant cost penalty, applicable to most phases of the system, so that a distinct trade-off benefit must be clearly demonstrated in all successful applications. Recently, much concern has been expressed concerning the community annoyance attributable to the noise of V/STOL systems in the civil inter and intra urban short haul transportation role. Unfortunately much confusion understandably still exists concerning the noise levels of V/STOL configurations, the important noise trade-offs which could be effected in a given vehicle design, and perhaps most importantly, the community levels which could be considered satisfactory and generally acceptable.

In attempting to define and assess satisfactory V/STOL community noise disturbance levels, certain important and distinctive features of these systems, including their noise signatures, their operating characteristics and the probable competing noise environments (background) must be carefully considered. In particular the following factors implicit to V/STOL operations are noted:

(i) The noise levels at existing metropolitan airport sites usually located near or outside the boundary of a metropolitan area have grown inordinately. It is now well recognized that the community noise levels attributable to all future inter and intra urban transportation systems including V/STOL will have to be markedly reduced. Levels approaching existing background levels may in fact be required.

(ii) V/STOL transportation systems must provide a capacity which peaks markedly during weekdays, with peaks approximating those occurring due to local road traffic.

(iii) V/STOL aircraft, due to higher installed power levels can reach relatively higher altitudes while within the airport boundaries. Thus potentially noise critical community areas will be located relatively close to the terminal boundaries.

(v) V/STOL aircraft will tend to create noise for longer periods of time at a given community location than conventional aircraft. The possibility of overlapping noise signatures during peak service frequency periods is thus enhanced.

(vi) V/STOL landing and take-off paths at low forward speeds will generate more closely related noise intensities and characteristics than those due to conventional aircraft.

(vii) Demand for V/STOL transportation service will probably be substantially reduced during much of the weekend and holiday periods.

(viii) V/STOL operations will show much greater tolerance to variations in ambient wind conditions during take off and landing than conventional aircraft. The possibility of fewer and tighter flight corridors therefore may exist.
The most popular current method for estimating the community disturbance level due to aircraft on this continent has been the Composite Noise Rating System (CNR) including its several modifications and extensions (e.g. NEF - Noise Exposure Forecast). In view of the special noise features outlined above, and especially the expected important role of the existing community background noise levels, not explicitly included within the current CNR/NEF methods, the search for a method aligned more directly to the special requirements of V/STOL systems appears warranted.

3. METHODS FOR ASSESSING COMMUNITY DISTURBANCES DUE TO NOISE

3.1 General Requirements

The broad requirements implicit to an acceptable technique capable of assessing community annoyance due to intruding noise entails three basic steps which may be briefly summarized as follows:

(i) A judgement must be made concerning which of the several possible individual annoyance attributes of the intruding noise events are likely to be dominant.

(ii) Indices must be determined which quantitatively relate the magnitude of the subjective response (as specified in (i)) to the physical characteristics of the noise events known to be significant, under carefully controlled and commonly accepted environmental conditions.

(iii) A broad rating scheme must be set out providing for acceptable levels of the selected indices (in (ii)) and incorporating as well certain important corrections to account for socio-psychological influences on the noise not directly (or only weakly) related to the physical characteristics of the noise and not included in the environmental conditions of testing implicit to the development of indices in (ii).

3.1.1 Types of Annoyance

The individual annoyance effects associated with the intruding noise which may be considered in a given case include:

(i) Speech masking/interference.
(ii) Loudness.
(iii) Perceived noisiness.
(iv) Auditory fatigue and hearing damage.
(v) Sleep interference.

Of these the concept of perceived noise occupies a central and perhaps dominant position. Numerous tests have clearly indicated that on the average people will consistently assess the noisiness or unwantedness (or objectionableness) of a variety of sounds of varying physical characteristics (tonal composition, spectra distribution, duration, etc.) The strong inference is that people learn through normal experience the relationships between the physical characteristics of sounds and their basic annoyance effects, i.e. speech interference, loudness, auditory fatigue, etc. Thus a basic premise of the concept of perceived noisiness of undesired sound is that it is a true measure of the average unacceptability for normally occurring environmental noises. Since each of the individual annoyance effects have differing dependencies on several important physical characteristics
of the noise, a given noise event will in general exhibit a differing level of acceptability depending on the particular annoyance encountered or dominant. Extensive test data are available covering each of the listed individual annoyance attributes (see Ref. 1).

For a somewhat new noise event, such as V/STOL noise, it appears prudent to retain consideration for two of these annoyance effects. Firstly, perceived noisiness should be retained in view of its central role and its ability to measure average unacceptability. Secondly, speech interference or masking should also be included since it has already been established that this is an important aspect of annoyance for conventional aircraft noise (see Refs. 2 and 3).

3.1.2 Indices

The indices utilized to quantitatively assess the selected annoyance features of the intruding noise must account for the physical characteristics known to be important subjectively. The following physical characteristics of the noise may be accounted for quantitatively:

(i) Maximum noise intensity level.
(ii) Frequency spectrum of noise.
(iii) Duration of noise.
(iv) Tonal content of noise.
(v) Time variation (onset) characteristics of intensity level.
(vi) Intermittency of noise (series of noise events).

In fact two types of subjective indices may be required. If the noise constitutes a series of discrete events, of relatively short duration (minutes), rising clearly above a background level, a first index can be used to assess the disturbance caused by a single noise event while a second index will be used to account for the effects of a series of these events over a longer duration (hours). On the other hand, if the noise comprises a more or less steady signal with individual noise events completely submerged in a complex mix of many simultaneous noise events, the second type of index only will be applicable.

3.1.3 Criteria

The noise rating schemes or criteria are closely tied to the noise indices selected for a given situation. In general they provide a set of acceptable noise levels while introducing at the same time suitable corrections to account for socio-psychological factors not implicit to the subjective testing conditions used in the development of the noise indices. These corrections relate more closely to the total environment with which the intruding noise, or noise events must coexist than to the physical characteristics of the noise itself. These corrections therefore relate to the following types of factors:

(i) Time of day or year.
(ii) Intermittency of noise (if index is based on single noise events).
(iii) Type of community district involved (outdoor noise).
(iv) Type of building(s) involved (indoor noise).
(v) Economic or social ties between community and noise source.
With some exceptions these rating corrections are often sizeable and difficult, if not impossible to properly isolate and evaluate with the desired precision. Important exceptions however include the intermittency corrections and background noise corrections which recently have been incorporated quantitatively into appropriate noise exposure indices through the work in Great Britain of Robinson (Ref. 4) and also Griffiths and Langdon (Ref. 5).

3.2 Noise Exposure Indices

In attempting to develop assessment techniques for V/STOL community noise levels on the basis of the two types of disturbance - perceived annoyance and speech interference - in parallel it is necessary to briefly review indices presently developed, capable of assessing these types of annoyances directly. In each case, two types of indices will be considered; those capable of assessing the disturbance caused by single noise events in isolation, and those intended to apply to a steady stream of succeeding and overlapping noise events.

3.2.1 Perceived Noisiness - Single Events

For a steady broad band noise signal of relatively short duration (a few minutes or less), the subjectively important physical aspects of the noise are limited to

(i) Intensity level.
(ii) Frequency spectrum.
(iii) Duration above background.

Discussing the first two of these characteristics initially four types of scales are currently in use which are capable of reasonably reflecting the subjective perceived noisiness of an arbitrary noise signal. These include the following indices:

(i) Loudness level - (Phon).
(ii) Perceived noise level - (PNdB).
(iii) A Weighted sound level - dB(A).
(iv) D Weighted sound level - dB(D).

Each of these level measurements accounts for both the intensity and frequency content of the intruding noise but in differing ways. The first two of these indices are much more detailed than the latter two, since they attempt to correctly incorporate the changing subjective frequency response with intensity level. The latter two indices, being simple fixed weightings, can only approximate the expected average subjective frequency response over a narrow range of intensity levels.

Two methods are available for calculating loudness levels (phons). An earlier method due to S. S. Stevens is applicable for broad band steady noise signals that can be accurately described by eight octave-band sound pressure levels (see Ref. 6). The second and more detailed method due to Zwicker (see Ref. 7) is much more complicated and requires the definition of the noise signal in twenty-seven one-third octave band levels.

The perceived noise level measured in PNdB, is in fact only very slightly different from the properly-calculated loudness level in phons. However in principle, the latter is based on the qualities of "noisiness" and
"unacceptability". The perceived noise level in PNdB does however give slight additional weighting to a certain limited high frequency region relative to the phon weightings. Additionally the reference in the two levels systems are different. For the PNdB levels the noisiness of a band of random noise between one third and one octave wide centered at 1000 hz is used while in the loudness level determinations the reference loudness of a pure 1000 hz tone is employed. Details of the perceived noise level calculations due to Kryter follow very closely the methodology utilized by Stevens for loudness level determinations (see Ref. 8).

The simple sound weighted indices dB(A) and dB(D) are in wide use as a simple means of assessing the subjective qualities of annoyance and noisiness. The dB(D) weighting has been especially established for the evaluation of conventional aircraft flyover-noise, and contains two main weighting features relative to A weighting, i.e.

(i) Less low frequency attenuation, below 1000 hz, than A weighting, approximately 50% reduced.
(ii) High frequency emphasis of +10db at 5000 hz relative to A weighting.

A very complete discussion of the use of these weightings is given in Ref. 1.

The remaining important physical characteristic of steady broad band noise to be included within these indices is the time duration of the noise event. It has been well established that in general man perceptually integrates successive intervals of noisiness (loudness), i.e. frequency weighted sound intensity, into a modified subjective response, for the total duration of an identifiable sound (see Ref. 1). Thus for the comparison of non-steady noise signals, subjectively, it is expected that an equivalent steady broad band noise signal can always be defined, in principle which presents the same acoustic energy to the observer. This principle has in fact been well demonstrated experimentally. A duration allowance may accordingly be defined, to apply with any of the above perceived annoyance indices to cover noise events of time varying intensity as follows:

\[ \Delta L_D = 10 \log \left[ \frac{1}{T} \int_0^T 10^{L/10} \, dt \right] - L_{MAX} \]

where L is the time varying perceived noise level (so that the integral represents a value of the weighted sound energy) and \( L_{MAX} \) is the peak value achieved during the total time duration T(sec). Further discussion of the general duration correction is given in Refs. 9 and 1.

The final physical characteristics expected to be significant, subjectively include the tonal characteristics and the "onset" characteristics of the intruding noise signal. Hopefully (but not certainly) these corrections are expected to be small for V/STOL noise signals. Much study has been associated with the development of suitable tone corrections, for perceived noise level evaluations of conventional aircraft fly-over signals, especially landing. "Onset" corrections have been determined which quantitively reflect the observed result that sound that increases slowly to a given peak elvel and then decreases rapidly is judged to be much more objectionable than signals of the same maximum intensity which increase rapidly and then decrease slowly. Since both of these corrections rely on detailed features of the interfering V/STOL noise
signals which are unavailable at the present time, they have not been included in the present study. However, in the final analysis, due to the nature of the V/STOL operations some accounting for both tonal and onset features of the noise may well be required.

3.2.2 Perceived Noise - Total Noise Exposure

The current perceived noise indices representing the exposure to an ensemble of noise events are chiefly in two broad areas, traffic noise and aircraft noise. No less than eight different indices of total noise exposure appear to have been developed exclusively for aircraft noise; while at least two important traffic indices have been developed.

A summary of the aircraft noise exposure indices has been prepared in Table I. It is noted that these indices differ in only two basic aspects. Firstly, differing indices are employed to assess the perceived noisiness of the individual noise events. Secondly and more significantly varying growths of annoyance with the number of noise events are evident from a lower value of 3 dB per doubling (AI, NI, LE indices) to a high value of 6.0 dB per doubling (Lexp index) with the Q index employing a 4.0 dB per doubling rate.

<table>
<thead>
<tr>
<th>Index (Abbreviation Origin)</th>
<th>Definition</th>
<th>Growth per Doubling of Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite Noise Rating</td>
<td>$L_{PN}$ Time of Day + (i) Time of Day $L_{EPN}$ Runway Utilization (ii) Number of OPNS</td>
<td>3 dB</td>
</tr>
<tr>
<td>CNR - Also NEF (U.S.A.)</td>
<td>$10 \log_{10} 10L_{EPN}/10 + 10$</td>
<td>3 dB</td>
</tr>
<tr>
<td>Aircraft Exposure Level</td>
<td>$10 \log_{10} 10L_{PNM}/10 + 15 \log N - 80$</td>
<td>4.5 dB</td>
</tr>
<tr>
<td>CNR (I.S.O.)</td>
<td>$10 \log_{10} 10L_{PNM}/10 + 15 \log N - 80$</td>
<td>4.5 dB</td>
</tr>
<tr>
<td>Noise &amp; Number Index</td>
<td>$10 \log_{10} 10L_{PNM}/10 + 15 \log N - 80$</td>
<td>4.5 dB</td>
</tr>
<tr>
<td>NNI (U.K.)</td>
<td>$10 \log_{10} 10L_{PNM}/10 + 15 \log N - 80$</td>
<td>4.5 dB</td>
</tr>
<tr>
<td>Störindex (Germany)</td>
<td>$13.3 \log_{10} (1/T) \int_{0}^{T} L_{Q(t)/13.3} , dt$</td>
<td>4.0 dB</td>
</tr>
<tr>
<td>Index de Classification R (France)</td>
<td>$L_{PMAX} - 16 + 10 \log_{10} 960 + \text{utilization factor}$</td>
<td>3.0 dB</td>
</tr>
<tr>
<td>Annoyance Index AI (Australia)</td>
<td>$10 \log_{10} 10L_{PNM}/10$</td>
<td>3.0 dB</td>
</tr>
<tr>
<td>Noisiness Index NI (South Africa)</td>
<td>$10 \log_{10} \Sigma (t/T) 10L_{P}/10$</td>
<td>3.0 dB</td>
</tr>
<tr>
<td>Noise Exposure Index Lexp (Netherlands)</td>
<td>$20 \log_{10} \Sigma 10L_{P}/15 - 106$</td>
<td>6.0 dB</td>
</tr>
</tbody>
</table>

$\Sigma$ performed over all daytime noise events
N number of noise events (daytime)
The most significant study of traffic noise appears to be that due to Langdon and Griffiths (Ref. 5) carried out in the Greater London Area. They postulate a traffic noise index, TNI, of the form

\[ \text{TNI} = L_{90} + 4(L_{10} - L_{90}) - 30 \]

where \( L_{AX} \) denotes the steady noise level due to traffic A weighted which is exceeded for x percent of the time, so that \( L_{90} \) designates an approximate background level. This index appears to exhibit for the first time a clear dependence of measured annoyance on the fluctuating character of the disturbing noise events. The TNI formulation, above, is apparently only applicable to a limited range of traffic noise intensities. Earlier traffic studies were also carried out by the Wilson Committee (Ref. 10), and also in Sweden (Ref. 11). The Swedish work concluded that the energy mean level in dB(A) adequately correlated the measured subjective response.

Finally reference must be made to a more recent noise exposure index introduced by Robinson (Ref. 4). This index incorporates explicitly the concept that the subjective annoyance level of arbitrary time varying noise signals, having constant mean energy level, is enhanced by the magnitude of the instantaneous noise level fluctuations about the mean. The index, the Noise Pollution Level (NPL), incorporates two terms; the first representing a steady energy equivalent noise level, and second term (additive) augmenting the annoyance in accordance with the magnitude of the instantaneous level fluctuations. Additionally there appears to be some expectation that this new index and specifically the recognition of the importance of the fluctuating character of the noise may go a long way towards explaining some of the apparently divergent methods and indices already separately proposed for aircraft and traffic noise events. Additional discussion of the NPL concept is included in Section 4 of this note.

### 3.2.3 Speech Interference

In a similar manner to loudness and perceived noisiness, interference with speech is directly related to the physical characteristics of the intruding noise, chiefly intensity and spectral distribution for steady noise. However, rather different dependencies on these basic characteristics have been obtained with a number of specialized speech interference indices derived. The preferred technique for the evaluation of speech intelligibility in the presence of masking or interfering noise is through the determination of the articulation index (AI), as developed by French and Steinberg (Ref. 12). It has been shown that the important frequency range for speech communication lies in the range 250 to 6000 hz, i.e. about 5-1/2 octaves. By plotting the spectrum level of normal connected speech, together with the spectrum level of the masking noise, on a distorted frequency scale, over the range 250 to 6000 hz, it is possible to assess the intelligibility from the relative interference of the two resulting curves. Complete interference and loss of intelligibility is assigned an articulation index of zero; no interference is assigned, AI equal to unity. The following qualitative relationships between speech communication and AI values has been established.
TABLE 2

<table>
<thead>
<tr>
<th>AI Values</th>
<th>Acceptability of Speech Communication</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.90 - 1.0</td>
<td>Excellent</td>
</tr>
<tr>
<td>0.70 - 0.90</td>
<td>Very good to excellent</td>
</tr>
<tr>
<td>0.50 - 0.70</td>
<td>Good</td>
</tr>
<tr>
<td>0.30 - 0.50</td>
<td>Acceptable for some purposes</td>
</tr>
<tr>
<td>0.10 - 0.30</td>
<td>Usually unacceptable</td>
</tr>
</tbody>
</table>

 Modifications and simplifications of the original AI work have been introduced by Fleming (Ref. 13) and Kryter (Ref. 14) to permit the use of conventional one third octave and octave band analysis information pertaining to the interfering noise. In addition a number of additional masking refinements may also be included (see Ref. 1), which are especially significant when the noise spectrum is peaked or humped.

For initial assessment purposes the AI calculations are however usually rather impractical and overly detailed since reliable detailed spectra information may not be available. For such purposes a broader assessment is available through three additional indices all of which are much simpler to apply. These include:

(i) NR Noise rating curves.
(ii) SIL Speech interference level.
(iii) \( L_A \) A weighted sound level.

Several studies have been performed to assess the accuracy and limitations of these simplified criteria (see for example Refs. 15 and 16). The general conclusion reached is that there is not much difference between any of the more approximate indices, A weighted sound level included. The NR and SIL indices have both been widely used in noise control work, however they both suffer from a rather narrow assessment of the masking noise, limited to the frequency range between 500 hz to 2000 hz (see Ref. 1). Comparison of these indices is shown in Fig. 1 adapted from Ref. 1 which indicates the variation in speech intelligibility in terms of the masking noise level rating and speech level used.

If the interfering broad band noise signal is steady in time any of the approximate methods of speech interference are very straightforward to apply. However if the intruding noise signals have a time varying noise intensity, communication predictions, based on steady signal data, are very much less certain. Fortunately there is some experimental indication that smoothly rising and falling noise signals (similar to fly-over type noise signals) results in measured speech interference that is conservatively predicted by the conventional calculations (see Ref. 1). Consequently it would appear conservative to assume that the maximum value of NR, SIL, or \( L_A \)
achieved during a time varying masking noise event is applied as steady single interfering noise signal, for speech interference calculations.

3.3 Community Disturbance Criteria

A great variety of noise criteria and codes have been developed for a number of specialized noise situations. The great majority of these are single event maximum level criteria expressed with A sound level weighting. Two important exceptions are noted however, as follows:

(i) Current aircraft regulation requirements which are specified in terms of maximum "effective perceived noise level" which includes pure tone and duration corrections applied to the maximum perceived noise level (see Ref. 17).

(ii) Guideline criteria recently developed by the U.S. Federal Department of Housing and Urban Development which have adopted the noise pollution criteria, i.e. NPL (see Ref. 18).

The criteria outlined in the following studies, in three countries, appear to be especially pertinent for the present work and have therefore been reviewed in particular.


Adequate noise criteria, in general, should provide, in addition to stated maximum limits a set of suitable corrections to account for particular socio-psychological factors likely to apply to those particular environments where the stated noise may be found. Corrections of this type have been discussed in Section 3.1 of this report. In this connection, study (iii) above, was noted to include a rather straightforward approach (see Table 4).

4. ASSESSMENT OF V/STOL COMMUNITY NOISE LEVELS

As outlined in Section 3 above, three basic steps are involved in the general assessment of the environmental impact of intruding community noise events. A judgement must be made as to the type or types of annoyance likely to be dominant, secondly indices must be selected to assess quantitatively the selected annoyances and finally noise criteria for the selected indices are required.

Two types of annoyance have been selected rather arbitrarily, for the assessment of V/STOL community noise levels, in this study. These include speech interference, and perceived noise, with the latter measuring the average
qualities of "noisiness" or "unacceptability" associated with interfering noise events. Indices and criteria for both of these annoyances are to be selected and evaluated in parallel, with the more restrictive annoyance applying in each case. The preferred V/STOL community noise indices and criteria, adapted from those generally available, as briefly reviewed in Section 3, are discussed below.

4.1 Proposed Perceived Noise Exposure Index

As noted a variety of noise exposure indices have already been developed, usually with a specific transportation noise source clearly under consideration (e.g. conventional aircraft, road traffic). In attempting to apply or extend any of these schemes directly to V/STOL noise sources certain new noise factors must be carefully considered and reflected in any scheme selected. Some of these factors have been outlined in the Introduction, Section 2 (page 1). A consideration of these factors underlines the required features of a suitable V/STOL perceived noise exposure index, as follows:

(i) The index must assess adequately the role of the background noise, including variable background noise conditions.

(ii) The index must assess adequately a stream of noise events which emerge only marginally (max 10 db) above background.

(iii) The index would preferably be compatible with conventional road transportation noise exposure indices, so that estimates of the total V/STOL community disturbance can be assessed.

The importance of background noise in establishing the overall subjective awareness and annoyance of an intruding noise has frequently been assumed and considered. The exact role of the background noise is not explicitly and accurately known, however it has been established that in general:

(i) When the intruding noise levels are very much louder than the existing background, the absolute level of the added noise is likely to be the decisive factor in setting the subjective annoyance, thus dominating any minor role of the existing background noise (see Ref. 19).

(ii) When the intruding noise levels are comparable with and only moderately in excess of the level of the already existing background, the excess over background is likely to be the decisive subjective factor.

Only two of the noise exposure indices already described appear capable of adequately incorporating the effects of background noise levels and therefore noise signatures closely related to background levels. These indices are the Noise Pollution Index, NPI, due to Robinson, and the Traffic Noise Index, TNI, due to Griffiths and Langdon. It is however interesting to note that several of the remaining and earlier noise indices imply the existence of a background noise and even specific steady background levels. (NNI, see Ref. 20, effectively assumes a steady background level of about 80 PNdB lower than the interfering noise levels.)

4.1.1 CNR and NEF Indices

The most widely used and basic method of predicting and evaluating
environmental noise, especially due to aircraft, on this continent, has been
the Composite Noise Rating System (CNR) including its many modifications and
extensions (e.g. Noise Exposure Forecast - NEF). For the prediction of the
community noise impact due to V/STOL operations the possibilities of this
scheme must therefore be considered carefully. In this connection, the following
limitations are noted with respect to the present NEF procedures.

(i) The effects of an existing background noise are not included. (The
original CNR method (see Ref. 23) did incorporate a type of steady
background noise correction which has subsequently been abandoned.)

(ii) The variability of the interfering noise signal is not included as
an explicit parameter in the calculation of the total noise exposure.
Recently, this has been shown to be an important aspect affecting the
subjective or perceived noise level.

(iii) When the intruding noise peaks emerge only marginally (10 db or less)
above the background levels, the noise calculations currently used in
the NEF procedure are not effective.

On the other hand the CNR (NEF) method has been found to be quite effective
for assessing the community reaction to interfering noise streams when these
involve moderately intense to intense (aircraft) noise signatures, standing
out appreciably (10 db or more) above the original background noise levels.
In these cases it is known (see Ref. 19) that the background level is of
secondary importance in establishing the subjective annoyance levels.

In view of the above factors, the CNR/NEF noise exposure procedures
do not appear well suited to the special features likely to dominate an accurate
assessment of the community noise impact attributable to V/STOL operations.

4.1.2 Noise Pollution Index

Due to the certain importance of the prior community background
noise levels, in establishing the subjective annoyance rating of V/STOL
operations in the community, the work of both Griffiths/Langdon (see Ref.
5) and Robinson (see Ref. 4) has been carefully examined. The methods show
important similarities, each containing a term accounting for the variability
of the interfering noise signal with respect to the mean noise level. However
since the Griffiths and Langdon index is specifically adjusted to cater to
traffic noise signatures (at a medium to high intensity level) and since the
Noise Pollution Index of Robinson is to an important degree built upon the
TNI formulations but adjusted for application to a broader range of noise
signatures, the latter appears better suited for V/STOL noise assessments.
The recommended Noise Pollution or Noise Exposure Index can be expressed as
follows:

\[
L_{NP} = L_{eq} + K \sigma \\
= 10 \log_{10} \left[ \frac{10^{L_{eq}/10} \, dt}{T} \right] + K \sigma
\]

where \( K \) = adjusted constant = 2.56
\[ \sigma^2 = \frac{1}{T} \int_0^T (L-L_m)^2 \, dt \]

\[ L_m = \frac{1}{T} \int_0^T L \, dt \]

\[ L(t) = \text{instantaneous noise level} \]

\[ \sigma = \text{standard deviation of the instantaneous noise level, background included, considered as a statistical time series over time } T. \]

**Note**

(i) That for steady noise signatures \( L_{NP} = L \).

(ii) That for cases where \( L(t) \) is increased to \( L'(t) = L(t) + \Delta L \) where \( \Delta L \) is independent of time, \( L_{NP}(L') = L_{NP}(L) + \Delta L \).

The first term in this exposure index, \( L_{eq} \), represents the total amount of acoustic energy reaching a given observation point compared to the amount that would be received in the same time with a reference source of steady intensity. This energy may be frequency weighted, to include desired subjective response characteristics through appropriate frequency weightings applied to \( L(t) \). This term is influenced, through the logarithmic averaging, by:

(i) **The intensity and duration of the intruding noise only** when these noises are substantially in excess of the background levels (10 dB or more) and when their duration represents a significant fraction of the exposure time (10% or more).

(ii) **The intensity and duration of the intruding noise and the existing background levels as well**, when the intruding noises are only moderately in excess (10 dB or less) of the background levels and when the duration of the noise exposure represents a small fraction of the exposure time (15% or less).

The second term, \( K_0 \), is governed, by the time-dependence of the intruding noise stream rather than on its mean energy content. This term is greatly influenced in all cases by the background noise level; it is somewhat less sensitive to the duration of the interfering noise signal. The constant \( K \) in the second term has been optimized by Robinson (see Ref. 4) to match \( L_{NP} \) closely with the subjective annoyance response measured with several types of noise signatures including both conventional road traffic and aircraft fly-over noise. In the simplest terms, the Noise Pollution Index embodies the following important subjective features:

(i) For a given background noise level, the more intense the interfering noise stream becomes; and the greater the duration of the noise events above background, the higher the annoyance indicated.

(ii) For a given intensity and duration of the interfering noise events, the larger the excursions of the instantaneous noise above the background level the greater is the annoyance indicated.

It should be stressed that the Pollution Level implies much more than a simple measurement of the amount of noise reaching the community.
The remaining important physical aspects relating to annoyance, as discussed above, (i.e. frequency content, tonal content, etc.) are readily incorporated in the Noise Pollution Calculation through appropriate frequency weightings and corrections applied directly to the instantaneous noise values, \( L(t) \) used. For V/STOL assessments it appears preferable to express the instantaneous noise values used in terms of tone-corrected, perceived noise units. If discrete tones are absent, then "A" weighted noise levels could be substituted with no significant compromise resulting (see Kryter, Ref. 1).

### 4.2 Proposed Speech Interference Index

As discussed in Section 2.3.2, the AI index is the most reliable means of assessing speech interference directly. The evaluation of this index however, requires detailed spectrum data pertaining to the masking noise, not always or normally available at the early planning stages. The more approximate indices NR, SIL and \( L_A \) based on limited spectral information, appear quite adequate for initial assessment purposes. Of these, the A weighted sound level appears the most appropriate and has been adopted for present purposes. This selection rests primarily on the following:

(i) Data of References 15 and 16 indicate that all three of the simpler speech interference criteria, NR, SIL and \( L_A \), exhibit similar accuracies in assessing a variety of masking noise signatures.

(ii) The A weighted sound level information may also be used to assess the "perceived noise" annoyance in the community, as discussed above.

It should be stressed, however, that the AI index invariably produces a noticeably better estimate of the measured speech interference for a wide variety of masking noise situations. Therefore this method (or preferably the adaption of this method due to Fleming) should be utilized as soon as adequate spectral information covering the interfering V/STOL community noise signatures becomes available.

### 4.3 Proposed Community Noise Criteria

Assessing the total community V/STOL noise exposure in terms of the Noise Pollution Index, and assessing the V/STOL speech interference on the basis of the A-weighted sound level, it remains to define plausible and acceptable limits for each of these criteria. Since the noise exposure criterion is to be applied outdoors, while the speech interference criterion is taken to apply indoors, an adjustment is required, for the latter, accounting for the transmission losses of typical residential and office buildings. Based on the data of Reference 24 a minimum transmission loss of 10 PDN\( \text{dB} \) is seen to be appropriate for a brick-veneer urban/suburban house, with open windows (summer conditions). Accordingly, the following limiting noise levels are proposed as maximum values not to be exceeded during V/STOL operations in the most critical adjacent residential community areas.
TABLE 3
PROPOSED V/STOL NOISE LEVELS
(Urban Residential Districts)

<table>
<thead>
<tr>
<th>Maximum Total Noise Exposure</th>
<th>- $75L_{NP(EPNdB)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{NP(MAX)}$ (outdoors)</td>
<td>($62L_{NP(A)}$)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Maximum Single Event Level</th>
<th>- $80L_{EPNdB}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{MAX}$ (outdoors)</td>
<td>($67L_{(A)}$)</td>
</tr>
</tbody>
</table>

These values apply only to:
(i) Urban residential neighbourhoods.
(ii) Daytime period 7.00 a.m. to 10.00 p.m.

Adjustments in these proposed values would be required under differing neighbour­hood conditions. Following closely the methodology contained in B.S.4142 (Ref. 25), the adjustments to $L_{NP(MAX)}$ only, which would be proposed for modified background conditions are as follows.

TABLE 4
BACKGROUND ADJUSTMENTS

<table>
<thead>
<tr>
<th>Type of District</th>
<th>Adjustment $\Delta L_{NP}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural-Residential</td>
<td>-10</td>
</tr>
<tr>
<td>Suburban-Residential Light Traffic</td>
<td>-5</td>
</tr>
<tr>
<td>Urban-Residential Light Traffic</td>
<td>0</td>
</tr>
<tr>
<td>Urban Residential including some Light Industry or Main Roads</td>
<td>+5</td>
</tr>
<tr>
<td>Industrial/Commercial (Predominantly)</td>
<td>+10</td>
</tr>
</tbody>
</table>
Although the proposed maximum community noise levels for V/STOL operations are necessarily somewhat arbitrary, there is a growing amount of relevant community noise data which materially assists in the specification of such levels. The principle evidence for the selected limits indicated above is as follows:

(i) In establishing the maximum single event noise level limited by speech interference indoors, an articulation index value in the range 0.50 to 0.60 was selected on the basis of good to excellent speech intelligibility with normal speech levels at distance of 1 meter. See Figure 1. Note dBA values shown here are indoor values. A maximal level, indoors, of 57 dBA is indicated for the A weighted masking noise level.

(ii) In terms of perceived annoyance, outdoors, the proposed single event maximum noise level is quite conservatively placed as evidenced by several community noise surveys. Figure 2 adapted from Reference 1 indicates that the selected level is somewhere between "not loud at all" and "fairly loud", while data from Reference 26, see Figure 3, indicates that this level is of "no concern".

(iii) In terms of traffic noise, the proposed single event maximum noise limit is closely equivalent to the community noise measured 750 ft. from expressway traffic moving at approximately 60 m.p.h. with a density of 2850 vehicles/hour, see Reference 27.

(iv) The maximum V/STOL noise exposure index proposed is 10 db below the maximum urban noise value tentatively suggested by Robinson (Ref. 28), and therefore plausibly consistent with the restricted community areas of interest. The exposure index is slightly higher than Robinson suggests for urban residential districts based on his interpretation of B.S.4142 (Ref. 25). In this case, the interpolated permissible exposure value for urban residential districts is approximately $L_{NP(A)} \approx 60$ dB.

(v) The maximum total noise exposure limit is placed on a qualitative scale adopted by the U.S. Agency H.U.D. (Dept. of Housing and Urban Development) at the boundary between "clearly acceptable" and "normally acceptable", see Figure 4, adapted from Reference 18.

(vi) Based on the recorded background community noise levels measured within the City of Ottawa recently (Ref. 29) by the National Research Council, the following points are noted with regard to the maximum V/STOL exposure index proposed.

- At Location (1) of that reference, which is a residential area about 400 ft. from two intersecting streets with local traffic, the noise exposure index is in the high fifties, A weighted, approaching $L_{NP(A)} \approx 60$ in the late summer measurement. The proposed V/STOL noise intrusion would therefore extend the pollution by a maximum of about 5 db at this location which is judged to be acceptable.

- Location (2) is a private home in a predominantly commercial zone with heavy traffic dominating the noise. In this case the existing exposure index appears to be just over 70 (approximately $L_{NP(A)} \approx 72$ during the summer readings), so that the corrected exposure index $L_{NP(A)} \approx 72$ db including V/STOL operations is again in context.
- Location (3) is a private home in a suburban/rural region well away from appreciable traffic. The corrected proposed exposure index in this case is estimated to lie between $L_{NP}(A) = 57$ db and $L_{NP}(A) = 52$ db. The estimated exposure index without V/STOL operations is $L_{NP}(A) = 49$ db, so that the introduction of the additional V/STOL noise stream could increase the exposure by a value between 3 and 8 db at this location.

- Location (4) is a private home in a predominantly residential area, with only moderate traffic noise. The noise exposure index at this location is extremely high ($L_{NP}(A) = 75$ db), during the daytime due to the operation of local buses. The proposed V/STOL limits would therefore not influence the noise exposure at such locations.

5. ADAPTATION OF N.P.L. CONCEPT TO STOLPORT NOISE

A computer program has been developed to study the total noise exposure levels in the community adjacent to a proposed STOLport site in the downtown Toronto waterfront area. Discussions with the Toronto Airport Technical Committee indicated that a site located on land fill to the east of the Toronto Islands was under active consideration as a possible STOLport location for the downtown region. This site was therefore selected for the necessary computer program development work. The finalized computer program including a discussion of the methods adopted to implement the prediction of the aircraft noise signatures at arbitrary points in the adjacent community are contained in Reference 30. Results obtained from certain studies, utilizing this computer program are contained herein, however it is emphasized that the purpose of these studies was not to attempt, initially, to predict actual community annoyance data for actual aircraft operations under actual background noise conditions. Initially, only plausible values for the necessary input data have been taken in order to assess the potential of the developed techniques.

The main results, included here to indicate the feasibility of the developed methods are in the form of contour charts containing contour lines of equal total noise exposure, N.P.L., under a variety of aircraft and community noise level conditions, in the adjacent city areas. These are shown in Figures 5 to 11 (grids 1 to 8). Additional studies were carried out at certain fixed community locations (four) from the computer printouts. In these cases the main interest was in the effect of background noise level, and operation number, on the total observed annoyance, see Figures 13, 14, 15 and 16.

In order to clarify the results presented in these figures, the following brief outline of the developed prediction technique and the necessary input data utilized is included (see Ref. 30).

(i) Flight Paths

A single runway condition at the STOLport was taken with orientation roughly east-west and parallel to the corresponding runway at the existing Toronto Island Airport. Straight flight paths, in the direction of the runway, were assumed for take off, climb out, landing approach and landing. (The capability for including arbitrary curved flight paths has been incorporated within the computer program but was not exercised here.)
Take-off, climb-out speed was taken as 120 m.p.h. with a constant climbing angle of 9.5°. Landing approach speed was selected as 100 m.p.h. with a descent angle of 7.5°.

(ii) Aircraft Noise Levels

Three types of aircraft were studied, having altered perceived noise levels, tone corrected, at 500 ft. as follows:

<table>
<thead>
<tr>
<th>Type</th>
<th>Landing Level</th>
<th>Take-Off Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>94 EPNdB</td>
<td>108 EPNdB</td>
</tr>
<tr>
<td>2</td>
<td>92 EPNdB</td>
<td>100 EPNdB</td>
</tr>
<tr>
<td>3</td>
<td>90 EPNdB</td>
<td>92 EPNdB</td>
</tr>
</tbody>
</table>

These noise levels are hypothetical, however Type 1 is expected to be close to the characteristics of the de Havilland DHC-6 aircraft, while the proposed DHC-7 noise characteristics are believed to lie between Types 2 and 3. The decay of noise from all aircraft has been assumed to be at a rate of 7.5 EPNdB per doubling of distance, in all cases. This figure has been found to be quite accurate for propeller driven aircraft at the distances of greatest interest for this study.

(iii) Community Background Levels

Noise exposures have been evaluated over a 15 hour daytime period extending from 7.00 a.m. to 10.00 p.m., with the background noise level steady during this interval. (Greater accuracy can be possibly achieved, accounting for variable daytime mean background levels by subdividing further the total 15 hour period.) Background levels have been assigned in blocks having approximately constant levels within a given block. Nineteen blocks were assigned to cover the southern metropolitan region, according to the following scheme:

- Lake Area: 55 PNdB
- Parks (Island): 60 PNdB
- Residential: 70 PNdB
- Industrial: 80 PNdB
- Commercial: 85 PNdB

Smoothing calculations have been carried out along the boundaries between adjacent blocks so that a continuous background level variation is obtained, see Ref. 30. This background distribution is shown on grid 1, Fig. 12. The values shown were used in all subsequent calculations, excepting studies involving changes in background wherein constant increments were applied at all community locations.

(iv) Cases Studied

Seven contour studies have been carried out to assess quickly the effects of aircraft noise improvements, the effects of an increased number of aircraft operations and the effects of alternative mixes of aircraft operations involving both easterly and westerly landings and take-offs. The cases are as listed below:
### TABLE 5

<table>
<thead>
<tr>
<th>Grid No/Fig. No.</th>
<th>Number of Aircraft Operations in 15 hours</th>
<th>Aircraft Type</th>
<th>Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/5</td>
<td>100</td>
<td>1</td>
<td>50/50</td>
</tr>
<tr>
<td>3/6</td>
<td>200</td>
<td>1</td>
<td>50/50</td>
</tr>
<tr>
<td>4/7</td>
<td>400</td>
<td>1</td>
<td>50/50</td>
</tr>
<tr>
<td>5/8</td>
<td>100</td>
<td>2</td>
<td>50/50</td>
</tr>
<tr>
<td>6/9</td>
<td>100</td>
<td>3</td>
<td>50/50</td>
</tr>
<tr>
<td>7/10</td>
<td>100</td>
<td>1</td>
<td>75/25</td>
</tr>
<tr>
<td>8/11</td>
<td>100</td>
<td>1</td>
<td>100/0</td>
</tr>
</tbody>
</table>

**Note**

1. An aircraft operation implies a take-off or a landing. Operations are evenly divided so that 100 operations imply 50 take-offs and 50 landings.

2. Mix refers to the percentage of flight path utilization. 75/25 implies that 75% of the aircraft take off to the west while 25% take off to the east. 75/25 also implies that 75% of the aircraft land from the east and 25% land from the west.

The studies of the effect of background noise level changes at specific community locations, see Figures 13 to 16, were restricted to the following conditions:

(i) Aircraft Type 1.
(ii) Mix 50/50.

### 6. RESULTS AND DISCUSSION OF RESULTS

None of the details in the suggested V/STOL noise limits should be interpreted as hard and fast values. Rather it is believed that the general methods and approaches discussed represent an improved technique for these particular noise sources. It is certainly to be expected and hoped that these preliminary suggestions can be modified and extended in the light of needed additional work in this area.

On the basis of the computer study results for community annoyance adjacent to the hypothetical STOLport site, it is clear that Robinson's noise pollution concept can be readily applied for a series of disturbing V/STOL noise signatures. A steady background noise level at any one community location has been assigned for this work and the importance of this level is clearly seen in the detailed results obtained at specific community locations (see Figures 13 to 16). It is noted that in cases where the background noise is unknown, a priori, it will not always be conservative to assign an arbitrarily high or upper limit for initial planning studies.

The expected tolerance on the quoted limits is very difficult to assess, however it has been a deliberate plan to select criteria data consistently on the conservative (low annoyance) side. In view of the several reasonable cross checks available it would appear that the expected error for the suggested maximum annoyance limits is about 5 - 8 db, with
the expectation that there is a somewhat greater tolerance to be expected upwards than downwards.

While it has been demonstrated that the N.P.L. concept can be readily applied for community annoyance predictions "deterministically" for flyover type noise signals superimposed on a steady background level, it will be more difficult, in practice, to carry out similar calculations for such signals on a statistical basis in combination with a varying background level, also defined statistically. The latent potential of the method however appears to lie in this direction and additional study in this direction is therefore warranted. An important situation within this class would be the combination of conventional road or freeway traffic noise signatures with V/STOL flyover type signatures. The former are most conveniently handled on a statistical basis and a useful approximation for many community locations is to represent the traffic noise as a statistical time series with a Gaussian distribution of noise events. Superimposing the disturbing aircraft noise signals, one might then reasonably expect a bimodal probability distribution of noise events to emerge.

Emergent from the calculated community annoyance data (see Figures 13 to 16) is the quite important conclusion that when the aircraft noise stands out only moderately above the existing background level, 10 dB or less, then the integrated annoyance (N.P.L.) increases extremely slowly as the number of noise events increase. This is in sharp contrast to earlier annoyance indices (and even indirectly, the existing civil aircraft registration requirements) which demonstrate increases of between 3 and 4.5 dB per doubling of the number of similar noise events. An important corollary indicates that the integrated community annoyance due to V/STOL noise will be substantially reduced (for a given system passenger capacity) if larger numbers of smaller aircraft are employed rather than fewer numbers of larger aircraft, employing similar technology at increased scale. This is again in direct contrast to the existing situation with conventional aircraft flyover noise, where large regions of the adjacent community are influenced by noise signals considerably in excess of background levels. In this case the community disturbance changes by a factor as high as 4.5 dB for a doubling/halving of the number of noise events, while on the other hand civil transport aircraft regulations (see Reference 17) designate a 5 dB change (take-off) for a doubling/halving of aircraft size. Under these conditions there is a negligible trade-off in the resulting community annoyance whether a given transportation capacity is provided with few or many similar technology aircraft.

Accordingly it appears mandatory to establish V/STOL permissible noise levels, in terms of prior community background levels. From the computer studies carried out herein, based on the N.P.L. index, a maximum excess over background of approximately 10 dB would appear to be about right. Combining this requirement with measured average community noise data (North America), see Reference 18, where residential and semi-commercial/residential zones are currently found to have background noise levels in the range 50-62 dB'A', it is seen that the presently suggested single event maximum V/STOL noise level is adequately placed. Adoption of a noise requirement of this type (10 dB over background level) would permit the introduction of V/STOL systems into many urban residential locations with minimum and negligible annoyance change. Future system growth can then be readily accommodated with no measurable change in community annoyance through a greater number of aircraft and operations at
equal maximum noise levels. Finally it should be noted that noise regulations permitting a substantial increase in noise with vehicle size, say 3 - 5 db per doubling cannot in any case adequately preserve the general community amenity even if the number of operations is correspondingly reduced.

The maximum suggested V/STOL noise limits may be approximately related to the expected percentage of the community to be annoyed through the data available in Reference 28. The percentage expected for the maximum total exposure level of $L_{NP} = 75$ PNdB is then approximately 28%. Unfortunately the percentage of the community disturbed is quite sensitive to the level of exposure. Thus if the exposure is increased by only 5 db the percentage annoyed jumps (by 25%) to 35%, and with a 10 db increase the percent of the community annoyed would be about 42% (50% change).

The noise levels of the expected V/STOL aircraft configurations of the 1970's are estimated to be in the region 90-95 PNdB at 500 ft. or higher. Based on the proposed V/STOL noise limits proposed above it is implied that flight paths in the terminal area be selected so that a minimum separation of at least 1500 ft. exists from all critical community locations. The implications of this restriction would appear to be more severe for STOL systems, especially if dual runways are to be provided, than for VTOL systems. The increased noise intensity for a given size for the latter system appears to be more than offset by the requirement for fewer and tighter access corridors including all weather operations.
<table>
<thead>
<tr>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
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</tr>
</tbody>
</table>
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**Figure 1**

**Comparison of Speech Interference (AI) Predictors**

<table>
<thead>
<tr>
<th>AI Values</th>
<th>Speech Masking Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.90</td>
<td>EXCELLENT</td>
</tr>
<tr>
<td>0.70</td>
<td>VERY GOOD TO EXCELLENT</td>
</tr>
<tr>
<td>0.50</td>
<td>GOOD</td>
</tr>
<tr>
<td>0.30</td>
<td>ACCEPTABLE FOR SOME PURPOSES</td>
</tr>
<tr>
<td>0.10</td>
<td>USUALLY UNACCEPTABLE</td>
</tr>
</tbody>
</table>

LONG TIME RMS LEVEL OF SPEECH AT LISTENERS EAR

SPEECH MASKING AS PREDICTED BY:

- $d_{B}(D) = 58$
- $d_{B}(A) = 52$
- $SIL(300-2400) = 45$
- $NC(R) = 49$

STANDARD DEVIATION (dB) OF ESTIMATION OF AI FOR SEVEN REPRESENTATIVE NOISES:

- $88$ (82)
- $92$ (86)
- $75$ (89)
- $89$ (84)
Figure 2

Street Noise

Extremely Loud

Very Loud

Fairly Loud

Not Loud at All

Traffic (Street) Level

dBa (London)

(Reference 31)
Figure 3

Acceptability - Judgement Curves

Combined Aircraft, Take-off and Landing Noise, Reference 26
**Figure 4**

**Residential Noise Criteria**

![Graph showing the criteria for residential noise levels.](image)

- **Leg** - Mean square A-weighted level
- **Lnp** - Noise Pollution Level

See reference 18.
FIGURE 5: STOLPORT NOISE CONTOURS

TOTAL PERCEIVED NOISE - \( L_{NP/EPNdB} \)

(GRID 2, See TABLE 5)
FIGURE 7: STOLPORT NOISE CONTOURS

TOTAL PERCEIVED NOISE - $L_{NP\text{EPNA}}$

(GRID 4, See TABLE 5)
FIGURE 8: STOLPORT NOISE CONTOURS

TOTAL PERCEIVED NOISE - L*P

(grid 5, see Table 5)
FIGURE 9: STOLPORT NOISE Contours

TOTAL PERCEIVED NOISE - L_{NP}^"EPNdB"

(GRID 6, See TABLE 5)
FIGURE 12: STOLPORT BACKGROUND NOISE

PERCEIVED NOISE - LEPNGAB

(GRID 1)
Figure 13

Background levels in PNDB

Number of aircraft operations in 15 hours

Location number 1 given by position
X = 16000.0 feet
Y = 1500.0 feet
(See figure 12)
Figure 14
LOCATION NUMBER 2
GIVEN BY POSITION
X = 16000.0 FEET
Y = 3000.0 FEET
(see figure 12)
Figure 15
LOCATION NUMBER 3
GIVEN BY POSITION
X = 16000.0 FEET
Y = 6000.0 FEET
(see figure 12)
Figure 16
LOCATION NUMBER 4
GIVEN BY POSITION
X = 16000.0 FEET
Y = 12000.0 FEET
(see figure 12)
Contrasted with conventional aircraft and airport noise, distinctive features relating to V/STOL systems are noted. Currently popular methods for assessing conventional aircraft noise (CNR and HEF, on this continent) are shown to be much less appropriate for V/STOL. Both speech interference and perceived noise annoyances have been included in parallel. Robinson's Noise Pollution Index is especially well suited to the evaluation of the total perceived noise annoyance since background noise effects are included directly. "A" weighted sound level is adequate for initial assessment of speech interference annoyance. Maximum V/STOL levels for these indices, in urban residential districts of L_{PN}^{MAX} = 75 (PNdB) and L_{PN}^{MAX} = 80 (PNdB) are proposed. Perceived noise contours calculated adjacent to a hypothetical Toronto waterfront STOLport site confirm that when the aircraft noise exceeds the background by 10dB or less, community annoyance grows imperceptibly with the number of similar operations flown. Smaller aircraft operating in larger numbers, to fulfill a given transportation task, therefore offer a substantial annoyance improvement over larger similar technology aircraft. V/STOL noise certification rules permitting a substantial noise increase with size (3 or 4 dB per doubling or more) cannot adequately preserve the community amenity.

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