SUBSONIC JET TRANSPORT NOISE
THE RELATIVE IMPORTANCE OF VARIOUS PARAMETERS

by

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SUMMARY

The area of the 80 PNdB noise footprint of subsonic jet transport aircraft has been evaluated using a simple expression for powerplant noise level. The parameters varied were the bypass ratio, field length, climb out and descent angle, installed thrust, standard of engine acoustic treatment and the rate of noise attenuation. Curves are presented for typical ranges of the variables.

It was concluded that the bypass ratio is the most important influence on the footprint area. The attenuation rate also has a very significant effect but it is outside the control of the designer. Field length has only secondary effect.
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1. INTRODUCTION

Some of the earlier investigations into the operating characteristics of STOL and RTOL aircraft suggested that reduction in field length requirements is accompanied by a reduction in noise nuisance to the surrounding environment. More recent work, such as Ref. 1, has shown that this is not necessarily the case. Whilst there may be some slight reduction in noise nuisance with reduced field length the effect does not appear to be very large for the high bypass ratio powerplants envisaged for use in the next generation of subsonic jet transport aircraft. Indeed there appears to be little doubt that the noise nuisance becomes more severe when the reduction of field length is accompanied by the use of some form of powered lift.

The purpose of the present study is to investigate the relative importance of the main parameters governing the noise nuisance of aircraft which do not use powered lift, and to reconcile the apparent discrepancies between the earlier and more recent work on short and reduced field length designs.

2. BASIC CONSIDERATIONS

2.1 Noise nuisance criteria

A number of criteria have been established to compare the noise nuisance of aircraft. Basically these can be divided into two categories:

a) Evaluation of noise index contours, such as NNI, which are derived by weighting the noise levels of a given aircraft by the number of operations in a given time. Refinements of this approach, such as that suggested by Richards and Ollerhead (Ref. 2) enable an assessment to be made on an overall basis so that the conditions at different airports may be compared.

b) Establishing the ground noise footprint area outside of which the noise level falls below that of the general environment and there is thus no nuisance. In this case the frequency of operations has no relevance.

It is not intended to discuss all the relative advantages and disadvantages of the two approaches. The first is directly related to current certification procedures and operations. However the second is used for purposes of this comparative study because of its relative simplicity, independence of a particular airport and operational pattern, and especially because it is likely that it will be the ultimate requirement.
The acceptable background noise level in a given environment varies according to circumstances and has not yet been completely defined. In the case of an urban environment the level is probably in the 66 dBA to 70 dBA range (Ref.3,4) although recent work by Lilley (Ref.5) suggests a somewhat lower figure of 55 to 65 dBA. Aircraft noise subjectively adds from 10 to 14 dB and therefore the higher of the above suggestions implies that the 80 PNdB noise footprint is a suitable basis for comparison. Although this may be somewhat high on the basis of Lilley's findings it is convenient to use and is the criteria adopted for comparison in this investigation. In the past the 90 PNdB footprint area was frequently used for comparison purposes.

2.2 Aircraft noise source

There is some evidence to suggest that airframe noise may be significant in those cases when an aircraft is powered by very quiet fan engines (Ref.1). This effect is very dependent upon the forward speed and whilst it may become the dominating factor in some cases, for simplicity it is neglected in the present comparison. The noise of a turbojet results from three basic elements and the interactions between them, namely the fan/compressor turbine and exhaust. A very important parameter is the specific thrust,(Ref.6) that is the ratio of the static thrust to the total mass flow through the unit. Taken with the core engine thermodynamic cycle it defines the bypass ratio. Published data for engines designed at the current level of technology and with typical core cycles suggests (Ref. 1):

\[
\text{PNdB} = 10 \log \left[ \text{Antilog}(8.8 + \log R) + \text{Antilog}(11.5 - 1.7 \log R) + \text{Antilog}(12.8 - 3 \log R) \right] + 10 \log \left( \frac{T}{80000} \right) - \Delta \ldots (1)
\]

at 500 ft distance from the aircraft.

where 
- \( R \) is the bypass ratio
- \( T \) is the static thrust in lbs
- \( \Delta \) is a correction which allows for the standard of acoustic treatment employed, extent of noise shielding achieved, etc. Present evidence suggests that \( \Delta \) may eventually exceed 10 dB for engines of high bypass ratio.

A simple formula such as Eq.(1) can only be regarded as being very approximate since it makes no allowance for directional and other important effects. It cannot be used to predict the effective perceived noise level (EPNdB).
When the powerplants are operated at less than the static design thrust it can be assumed that the noise is reduced by:

\[ 15 \left( \frac{T_R - T}{T} \right) \text{ dB} \quad \ldots (2) \]

where \( T_R \) is the reduced thrust level.

2.3 Attenuation

The rate of noise attenuation is a very important parameter in the establishing of the footprint area. The theoretical inverse square law gives a 6 dB reduction in noise level for each doubling of the distance from the source. In free air conditions the rate of attenuation is normally taken as 6.3 dB/doubling of distance. Near to the ground the situation is more complex and is inevitably dependent upon local conditions. Measurements on rotorcraft noise suggest that the decay rate may be as high as 8 dB for air to air and 10 dB for ground to ground conditions (Ref.7). Such high attenuation rates cannot be relied upon in practice and it is probable that absolute distance influences the situation as well as relative values. Near to the ground an attenuation of about 7 dB/doubling of distance is probably realistic.

An indication of the importance of this parameter in determining footprint area can be seen by reference to Figure 13. This shows the ratio of the 80 PNdB to 90 PNdB footprint areas as a function of the attenuation rate beyond the 500 ft datum distance assumed in Eq.(1). The area ratio is about 9 for the 6.3 dB decay rate but it falls to about 7 for a 7 dB decay rate and 4 for the 10 dB rate.

2.4 Evaluation of Footprint Area

The footprint area can be evaluated using Eqs.(1) and (2) in conjunction with an assumed attenuation rate. In the present case a very simple representation of the aircraft flight path was assumed.

a) The take off footprint area was calculated by assuming a rectangular shape defined in width by Eq.(1) and the attenuation to 80 PNdB and in length by the assumed field length.

b) Climb out footprint area was taken as the elliptical shape obtained by assuming a given climb angle and the same width as that used for the take off phase. Thus no allowance was made for any noise abatement procedures or change in attenuation rate with increased altitude.

c) The landing footprint area was evaluated in an exactly similar way using the assumed descent angle and a width based on a reduced thrust appropriate to landing conditions. For simplicity this was assumed to be 33% of the static value in all cases which implies a 10 dB reduction in the noise level at 500 ft distance relative to the value given by Eq.(1).
2.5 Parametric Variations

The 80 PNdB footprint area was calculated for the following variations of parameters:-

a) Bypass ratios of 1, 5 and 10.

b) Total static thrust of 40,000 lb, 80,000 lb and 160,000 lb. These values were chosen to be representative of the range likely to be found in transport aircraft varying from the smaller short haul RTOL concepts to long range large subsonic aircraft.

c) Runway field lengths of 4000 ft, 7000 ft and 10,000 ft.

d) Attenuation rates of 6.3 dB, 8 dB and 10 dB per doubling of distance from the 500 ft datum.

e) Two engine acoustic treatment conditions:-
   \[ \Delta = 0 \] to represent a 'standard' powerplant except that a 5 dB reduction was allowed for an exhaust silencer on the take off conditions of the bypass ratio one case only.
   \[ \Delta = 5 \text{ dB} \] to represent a 'quietened' powerplant in all cases.

f) Shallow and steep climb out and approach conditions
   These were defined as:-
   - Shallow climb at 10° and shallow descent at 3°.
   - Steep climb at 20° and steep descent at 6°.

3. RESULTS

The results of the calculations are presented in carpet form in Figures 1 to 8. These give the variation of the 80 PNdB footprint area as a function of two basic parameters, namely the bypass ratio and total static thrust, for the various combinations of the other parameters. It was found to be necessary to use a logarithmic scale for the footprint area to show meaningful values for the higher bypass ratio cases. Figures 1 to 4 are based on the 6.3 dB attenuation rate whilst Figures 5 to 8 cover the 8 dB condition. In each set the first two figures refer to the standard noise condition and the latter two to the quietened powerplant. The first figure of each pair shows the results for the shallow climb and descent pattern whilst the second gives the corresponding information for the steep climb and descent.

Figures 9 and 10 extract the field length data as a function of thrust and climb/descent pattern for the particular cases of standard noise levels and bypass ratios of 5 and 10 respectively.
The effect of attenuation rate on footprint area is shown in Figures 11 and 12 as a function of thrust and runway length for two particular cases. These are a bypass ratio of 5 with shallow climb and descent and a bypass ratio of 10 with steep climb and descent. Standard noise conditions were assumed in both cases.

4. DISCUSSION OF RESULTS

The figures show clearly that the bypass ratio is by far the most important parameter in determining the noise footprint area for a given installed thrust. There is a very large reduction in the footprint area when the bypass ratio is increased in the range of one to five. The rate of reduction is appreciably less for further increase of bypass ratio but up to a value of ten it is nevertheless significant. It should be noted, however, that an increase of bypass ratio implies an increase in installed thrust for a given cruise performance so that the full effect of footprint area reduction may not be achieved in spite of the improved low speed characteristics.

Figures 11 and 12 demonstrate the importance of the rate at which noise is attenuated. This is, of course, outside the control of both the designer and operator. Here the point to be made is that it is essential to know the value assumed in any prediction made, otherwise comparisons are likely to be quite meaningless.

The effect of employing steep climb out and descent techniques can be seen by reference to Figure 9 and 10. A significant reduction in footprint area can be made. For example at the higher bypass ratio the 80 PNdB footprint area is reduced by some 30% for the lower installed thrusts and this increases to about 50% for higher thrust conditions. These reductions are equivalent to a bypass ratio increase of about two in the five to ten range.

These same figures also show that the runway length has only a secondary effect. Whilst there is some reduction in footprint area as field length is reduced the maximum improvement is only about 30% for a reduction from 10,000 ft to 4,000 ft. Since this shorter field length is also likely to imply increased installed thrust the practical gains may be expected to be much less. It would appear that the results obtained from early studies of STOL and RTOL aircraft were incorrect in anticipating significant footprint area reductions due simply to reduction of field length. The effect noted was due primarily to the higher bypass ratio powerplants proposed for these classes of aircraft, and to the steeper climb and descent paths anticipated.
Acoustic treatment of the powerplants to reduce the basic noise level by the datum value of 5 dB assumed for the 'quietened' aircraft has the greatest effect at high bypass ratios and low installed thrust. In this case the reduction of the 80 PNdB footprint area varies from as much as 65% for an attenuation rate of 6.3 dB/doubling of the distance to about 50% when it is 8 dB. At lower bypass ratios and higher installed thrusts the absolute reduction in footprint area is significant even though the relative values are less.

Figures 14 and 15 illustrate the relative importance of the parameters studied in the context of two particular reference conditions. The former of these shows the reduction in the noise footprint area when the parameters are varied over a practical range from a condition representative of that of the first generation of long range jet transport aircraft. As would be expected the bypass ratio change is by far the most significant. The second of these figures uses the current generation of wide body long range transports as the reference with a datum bypass ratio of five. In this case the effect of the parameters is of the same order except for that of field length and to some extent the climb/descent pattern.

5. CONCLUSIONS

5.1 The field length capability of an aircraft has only a secondary effect on the noise footprint area.

5.2 The most important parameter within the control of the designer is the specific thrust of the powerplant. For a given core engine technology this parameter can be identified with bypass ratio. It would appear that bypass ratios in excess of ten yield only relatively small gains.

5.3 Steep climb out and approach techniques can have a significant effect in reducing the footprint area. Doubling the climb and descent angles relative to those typical for conventional aircraft is approximately equivalent to increasing bypass ratio by two in the five to ten range.

5.4 A 5 dB reduction in the basic noise of the powerplant achieved by acoustic treatment has a similar reduction in footprint area as that of doubling the climb and descent angle at low bypass ratio.

5.5 The noise attenuation rate is also of great importance but it is outside the control of the designer.
REFERENCES


5. LILLEY, G.M. Noise - Future targets R.Ae.S. Spring Symposium May 1974


FIG. 1. VARIATION OF 80 PNdB FOOTPRINT WITH THRUST AND BYPASS RATIO. (STANDARD POWERPLANTS – SHALLOW CLIMB AND APPROACH) 6.3 dB ATTENUATION.

FIG. 2. AS FIGURE 1, WITH STEEP CLIMB AND APPROACH.
FIG. 3. VARIATION OF 80 PNdB FOOTPRINT WITH THRUST AND BYPASS RATIO. (QUIETENED POWERPLANTS – SHALLOW CLimb AND APPROACH) 6.3 dB ATTENUATION.
8 dB ATTENUATION/DOUBLING OF DISTANCE.

FIG. 5. AS FIGURE 1, WITH 8 dB ATTENUATION.

FIG. 6. AS FIGURE 2, WITH 8 dB ATTENUATION.
6 dB ATTENUATION/DOUBLING OF DISTANCE.

BYPASS RATIO

TOTAL THRUST - 10000 LB

FIELD LENGTH

10000 FT

4000 FT

FIG. 7. AS FIGURE 3, WITH 8 dB ATTENUATION.

FIG. 8. AS FIGURE 4, WITH 8 dB ATTENUATION.
FIG. 9. EFFECT OF FIELD LENGTH ON FOOTPRINT AREA (STANDARD POWERPLANTS – BYPASS RATIO 5)
FIG. 10. AS FIGURE 9, WITH QUIETENED POWERPLANTS AND BYPASS RATIO 10.
FIG. 11. EFFECT OF ATTENUATION ON FOOTPRINT AREA (STANDARD POWERPLANT · BYPASS RATIO 5 AND SHALLOW CLimb AND APPROACH).
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FIG. 13 EFFECT OF ATTENUATION ON RATIO OF 80 PNdB AND 90 PNdB FOOTPRINT AREAS.
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