NOISE SHIELDING AIRCRAFT CONFIGURATIONS, A COMPARISON BETWEEN PREDICTED AND EXPERIMENTAL RESULTS

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Abstract

By a suitable engine position above a wing or tailplane, shielding of forward and rear arc noise by these surfaces might be obtained below the flight path during flyover.

Ground tests have been performed to evaluate these shielding effects. A small full scale turbofan engine was mounted well above the ground and the influence of shields of various geometry and positions on the noise radiation was measured. Shielding of intake and exhaust noise sources were investigated separately.

The purpose of the tests has been to verify an existing prediction method, mainly applicable to internal noise sources characteristic of high bypass fan engines.

Significant noise attenuation due to shielding has been measured and the results show good agreement with prediction.

I. Introduction

The trend towards high bypass turbofan engines for civil aircraft gives a considerable relief of noise disturbance to the community. The jet mixing noise which was dominating at earlier generations of engines is now reduced to a comparatively low level. Turbomachinery noise sources can be attenuated without great performance losses by proper engine component design and duct treatment with sound absorbing material. The fact that these sources also are concentrated to the intake and exhaust nozzle regions gives the possibility to appreciable further flyover noise attenuation for aircraft configurations, where the engine is located over a shielding wing or tailplane surface. Figure 1 shows some examples.

Because of the length of the engine compared to the wing chord it is usually not possible to get efficient shielding of both intake and exhaust noise. In figure 1a and b the wing surface shields forward and rear arc noise respectively. The possible attenuation in perceived noise level depends upon the difference between intake and exhaust noise radiation. In the case that these are equally strong, the benefit of shielding will be a reduction in noise duration during a flyover. However it is of course possible to use the shielding technique as an alternative or complement to intake and exhaust duct treatment with sound absorbing material. In a more extreme aircraft configuration (fig 1c), the wing and tailplane might be used as shields for forward and rear arc noise respectively.

In several NASA-reports (1,2,3) acoustic investigations of engine - over - the - wing configurations (like fig. 1b) both with attached and unattached jet flow are published. Partly these reports also deal with noise shielding effectiveness. However no study directly concentrated to shielding of engine internal noise sources and no prediction method applied to this problem is yet published, known to the author.

In this paper the results of a systematic experimental study of shielding effectiveness of internal noise sources of a small full scale turbofan engine under static condition are presented. A main objective is to verify a prediction method.

II. Prediction model

The noise attenuation by a screen is treated in a number of studies. Analytical approaches to the problem are based on optical - diffraction theory, assuming that only the incident wavefield at the top edge of the screen contributes to the wavefield that is diffracted over the screen. Most of the published investigations concern semi-infinite screens. In figure 2 the excess attenuation under free field conditions for a point source is shown (4). Measurements by Maekawa (5) show good agreement. Further experimental data by Fleisher (6) give lower attenuation, specially in the high frequency range, where the upper limit is about 24 dB. In a transition zone outside the screen edge, there is also a shielding effect, which ranges from 4-5 dB in the line of sight down to zero.

For the actual case with a screen of finite size few studies are published. Maekawa (7) suggests that the diffracted sound energy over each edge of the screen is summed, neglecting their phases to get the resulting noise level for a receiver position in the shadow zone. The attenuation of the diffracted sound over each edge is obtained from data for semi-infinite screens.

For the present problem the same approach for prediction as that of Maekawa is used. For a shielding surface approximately rectangular, like a wing, this seems to be logical. For comparison with the test results, alternatively the Beranek - Maekawa and the Fleisher curve in figure 2 for excess attenuation has been studied.

Although this approach is quite simple, many problems still remain. The total noise radiation from a turbofan engine consists of several sources - fan, turbine, tailpipe and jet mixing noise. All of these have different spectra and field

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shapes and might also radiate from different positions with respect to the engine. A lot of information is needed and the numerical procedures are quite comprehensive. In the present prediction model, the noise radiation is represented by point sources located on the engine centreline (fig. 3). The point source representing forward fan noise is assumed to be located at entrance of intake duct. For the exhaust internal noise sources, although they are quite strongly concentrated close to the nozzle exit, the experimental results show that a separation into axial positions with respect to frequency range is necessary. This will further be discussed when presenting the test results. With this approach it is not necessary to separate the various component sources, except for the case when the fan flow exit is located upstream of the gasgenerator exit (short fan cowl).

For engines with dominating jet mixing noise the necessity of separated sources due to frequency range is much more pronounced. The well known fact that the jet mixing process and noise radiation goes on several exit diameters downstream of the nozzle, will increase the problem to get a satisfactory source representation. This is not further dealt with in this paper, since the main interest concern shielding of internal sources. However some experiences from the test results regarding jet noise shielding were obtained and are discussed in the following.

In figure 3 the calculating procedures for the point source representing intake noise is illustrated. The shortest pathway to the receiver over each of the three shield edges giving minimum of Fresnel number is defined. The noise levels (1/3 octave spectra) in these directions are corrected by using the data of figure 2 and summed at the point of receiver. The contributions of the exhaust noise sources are treated in the same way and added.

III. Apparatus

For the tests the Turboméca Aubisque, which powers one version of the SAAB 105 trainer aircraft, was chosen (fig. 4). Aubisque has a single stage geared fan with variable inlet guide vanes and two rows of fixed outlet guide vanes. The fan and gasgenerator flow is separated and the nozzle configuration is coplanar. At maximum rating the bypass ratio is about 2.0 and the thrust level about 7000 N. By running the engine at low thrust settings, noise characteristics as of a high bypass turbofan, with dominating internal sources, were obtained.

The engine was mounted with the centreline 1.5 m above the ground. The bellmouth intake had double walls with sound absorbing material in between. The external surface of the engine was covered with a sound absorbing rug to avoid noise leakage (fig. 5). Fan and gasgenerator exhaust temperatures and pressures and fan rpm were measured at all tests. These data were taken in order to control the thrust setting of the engine and to be able to predict the jet mixing noise level.

Shielding of intake and exhaust noise was investigated separately and therefore special silencers were developed. For attenuation of the exhaust noise, when measuring intake noise shielding, an ejector silencer with thick concrete walls and with a curved outlet, directed opposite the microphones, was used (fig. 5). To avoid noise leakage at the engine exhaust a secondary annular intake was fitted close to the nozzle external surface. The walls were built up of internal perforated plates and with absorbing material. A semi-cylindrical shield is connected to the intake so that the secondary air is sucked into the ejector only at the side opposite to the microphones.

When investigating shielding of exhaust noise an intake silencer was mounted (fig. 6). This had the form of a cylinder with a forward vertical wall, giving an annular intake to the engine, similiar to the secondary ejector intake. By adjusting the axial distance between the front plane of the bellmouth intake and the inner vertical wall of the silencer a throat section was obtained, which increased the attenuation.

Four different shields, roughly sized to represent chord length and span of a wing or tailplane, were tested (fig. 6). The shield design was simplified to a wooden structure of ribs with both sides covered by hard plywood and with a rectangular constant section. The shield position relative the intake and the exhaust nozzle respectively was varied both axially and laterally.

Sound data were taken simultaneously by microphones located on a semi-circle each 15°, at a radius of 15 m from alternatively the intake or the exhaust nozzle (fig. 7). The microphones are mounted at the same height (1.5 m) as the engine centreline. To get consistent measurements the grass ground was covered with a fibermaterial within the 15 m radius.

The sound data were analyzed by a narrow band (64 Hz) spectrum analyzer, which determined sound pressure level spectra referenced to 2×10^{-5} N/m^2. These spectra were then transformed to 1/3 octave spectra. The level for each frequency band represent the average value during one minute of engine running time. The OverAll Sound Pressure Levels (OASPL) and Perceived Noise Levels (PNL) were obtained from special computer programs. A block diagram of the measuring and analyzing equipment is shown in figure 8.

IV. Results and Discussion

Shielding of intake noise

From the intake shielding tests only the results for the receiver positions up to $\Theta=45^{\circ}$ above frequencies of 300 Hz are considered. The reason is that at higher angles to intake axis, the shielding effectiveness was so high that exhaust noise dominated and limited possible attenuation. Also the frequency range below about 300 Hz was influenced by exhaust noise radiation for all receiver positions. The silencer was not efficient enough. However true results of measured shielding were obtained for several configurations. The correlation to predicted data in these cases should be valid for all receiver positions.

In figure 9 typical results of measured and predicted 1/3 octave spectra for intake noise shielding are shown. The configurations (a),

(b) and (c) have all the same shield geometry and fixed lateral distance to engine centreline. The axial position is defined by the angles into shadow (α°, β°). The configurations (d) and (e) have smaller shield width. The configuration (f) finally, has the larger shield but increased lateral distance to engine centreline, so that the angles into shadow are equal to configuration (e).

The general impression of the results in figure 9 is the good agreement between measured and predicted spectra. The maximum difference in attenuation given in OASPL or PNL is 1 dB. The Fleisher curve for attenuation in figure 2 is used. The Beranek - Maekawa data would have given about 2 dB increased shielding effectiveness and somewhat less agreement. Also for the reason not to overestimate predicted attenuation the Fleisher data are consequently used in the following.

Going into some details of the results in figure 9 it is seen that maximum attenuation is 8,0 PNdB (configuration b). However this should not be regarded as a limit. In fact higher attenuation is calculated for increased angles to the receiver. But due to the previously mentioned influence of exhaust noise, no true correlation with measurements was possible. Also the type of field shape of the source will set the amount of attenuation. With stronger concentrated peak levels the shielding effectiveness increases.

For configuration (c) the receiver is just in line of sight to the source and the measured attenuation is 4.5 PNdB. This is in agreement with the basic data given in figure 2.

Although the configurations (e) and (f) have identical angles into shadow, the wider shield (f) gives somewhat higher attenuation due to increased pathway to receiver.

Also a lower shield height, 1.3 compared to 4.2 intake diameters above the engine centreline, was tested. No noticeable difference in the results was obtained.

Shielding of exhaust noise

The prediction of shielding effectiveness for exhaust noise involves more factors to be considered than for intake noise. In the present study the widest shield is 5.9 primary nozzle diameters, which is too small to get efficient shielding of the jet mixing noise. This is illustrated in figure 10. For a fixed configuration, a comparison of measured attenuation at a high and low jet noise level, corresponding to 100 % and 80 % engine rpm respectively, is shown. While an appreciable shielding effectiveness is measured for the lower thrust setting, practically no effect is obtained for the higher level. This result is confirmed from several other configurations and receiver positions. In fact no measured shielded spectra were noticeable below predicted jet noise levels. To get attenuation of jet noise an increased width of the shield is necessary. More realistic is however a modified nozzle configuration, which shortens the jet/freestream mixing process.

In the present study only the lower thrust setting (80 % rpm) is considered. In the prediction model the jet noise is assumed to be a point source located 5 primary nozzle diameters downstream of the exit, but with no effect of shielding. This rough assumption is satisfactory, since the jet noise levels are appreciable below the total unshielded levels.

In the prediction model of intake noise shielding was assumed, that the total radiated noise spectra were concentrated to one single point. Figure 11 illustrates the results if the same assumption is applied to exhaust noise. The point source is alternatively located at the nozzle exit and one or two primary nozzle diameters downstream. For the configuration in figure 11 (a) the shield completely covers the radiated rear arc noise. The shielding effectiveness is very high and increases at higher frequencies. The predicted spectra for the three alternative point source positions show comparatively small differences. If the shield is moved one primary nozzle diameter downstream, the measured attenuation now decreases at higher frequencies (fig. 11b). Although the measured shielded spectrum falls within the predicted levels for the assumed point source positions, the agreement in each separate case is poor. Obviously a separation in source position due to frequency range will increase the accuracy of predicted shielding effectiveness.

In figure 12 a comparison of measured and predicted spectra for a series of configurations is shown. The unshielded noise spectra are divided into three ranges, which are represented by point sources at different positions. The frequency range above 2000 Hz is assumed to be concentrated half a primary nozzle diameter downstream of the exit. The corresponding point source positions for the frequency ranges 1000-2000 Hz and below 1000 Hz are one and two diameters respectively. All the configurations in figure 12 have fixed shields, which are moved in steps from a forward to a rear axial position at a constant distance to the engine centreline. The receiver position is fixed (120°) and the angles into shadow for each source are given for all configurations.

For the most forward position of the shield (configuration a) only a close region downstream of the nozzle is shielded and the attenuation is largest at higher frequencies. Moving the shield rearwards (configurations b and c) gives an increased attenuation for all frequencies up to a position where the forward edge of the shield is located at the nozzle exit (configuration c). The maximum overall attenuation is as large as 12 dB in OASPL and 16 dB in PNL. A further movement of the shield behind the nozzle exit (configurations d, e and f) will rapidly decrease the shielding effectiveness specially of the high frequency noise.

The agreement between measured and predicted spectra are quite good. It is seen that high frequency noise radiates close to the exit and lower frequencies somewhat further downstream.

Further results from exhaust noise shielding tests with comparison of predicted data are shown in figure 13 and 14.

In figure 13 the effect of lateral distance of the shield to the engine centreline is shown for a fixed axial location and receiver position (120°). Increased distance gives larger attenuation in the high frequency range. The region closest to the nozzle exit where this noise is concentrated, is more efficiently shielded. This is the same observation as from the results of figure 12.

Figure 14 finally, shows the shielding effectiveness in three receiver positions (105, 120 and 135°) for the tested configuration, which gives the largest attenuation. Again the predicted spectra are in good agreement with measurements.

V. Concluding Remarks

The results of the present investigation show that an appreciable reduction of turbomachinery noise during flyover might be obtained by a suitable engine position above a wing or tailplane. Predicted shielding effectiveness is in good agreement with measurements.

The prediction model for intake noise shielding is quite simple, since the total noise radiation can be represented by one single point source located at the entrance of the intake. For exhaust noise shielding, the measurements showed that the turbomachinery noise is radiated within a region about two primary nozzle diameters downstream of the nozzle exit. High frequency noise is concentrated to the forward part of this region and low frequency noise to the rear part. For shields, which efficiently cover this region, a quite true representation of source positions is not critical. However if this is not the case, it was found that a separation into three point sources representing the high, middle and low frequency ranges gave satisfactory results.

An interesting question is of course to what degree the prediction model have general validity. Regarding intake noise shielding it is believed that the present approach is generally applicable. For exhaust noise shielding it seems logical with a separation into point sources due to frequency range. The radiation of the internal sources should also be concentrated close to the nozzle exit. However the jet velocity level might have some effect on the source positions. An increased velocity may move the internal noise radiation downstream. On the other hand, high jet velocities also mean increased jet mixing noise and this source was not noticeable found to be shielded for a conventional nozzle configuration and a realistic chord length of the wing. In this respect the convection effect on internal sources is in practice limited.

The investigation performed concerns static conditions without free stream effects. Temperature and velocity gradients in the proximity of the wing may diffract the sound waves from the source. If the directivety characteristics of the noise radiation have a relatively even distribution, the effect is expected to be small. However a study of freestream effects is planned to be performed.

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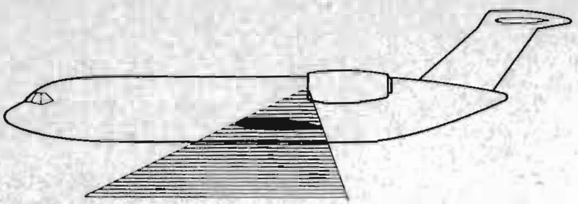
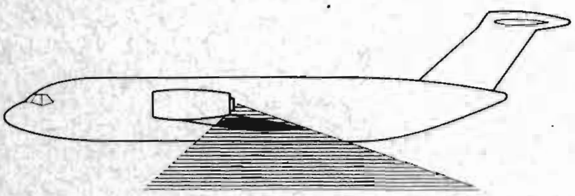
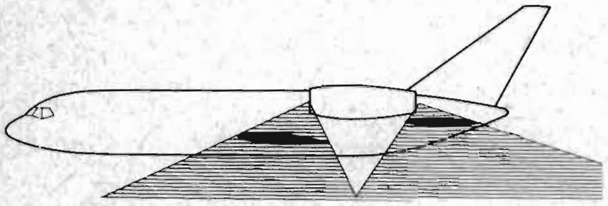


a. Forward arc shielding



b. Rear arc shielding



c. Forward and rear arc shielding

Figure 1. Noise shielding aircraft configurations.

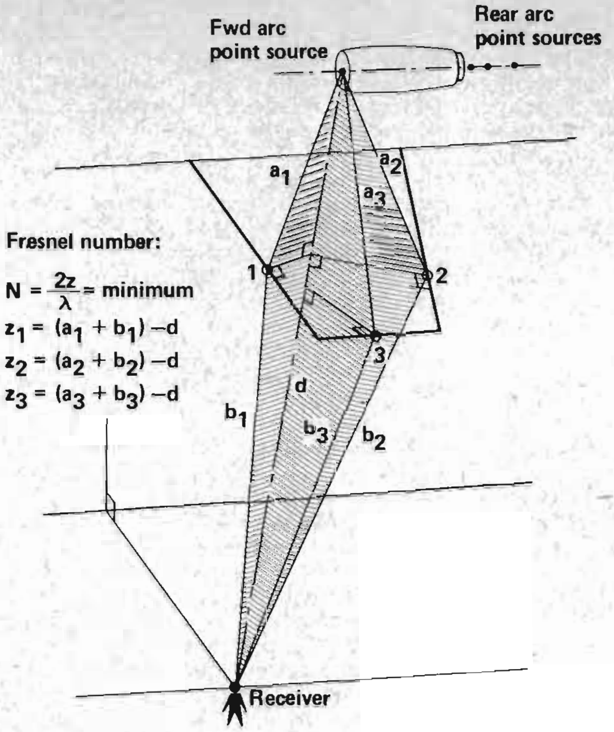


Figure 3. Prediction model

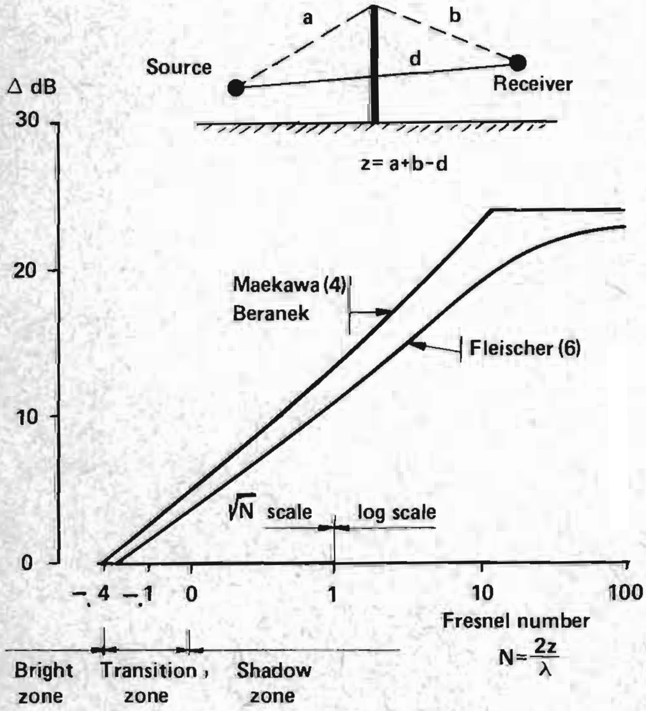
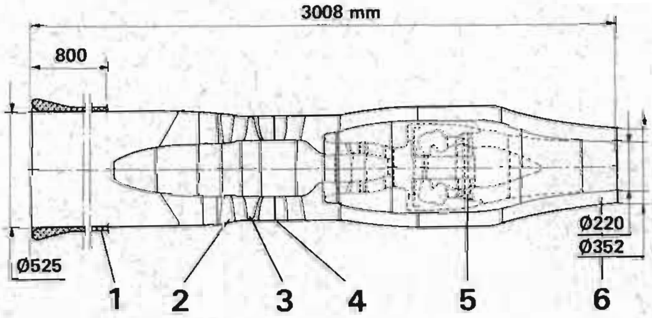
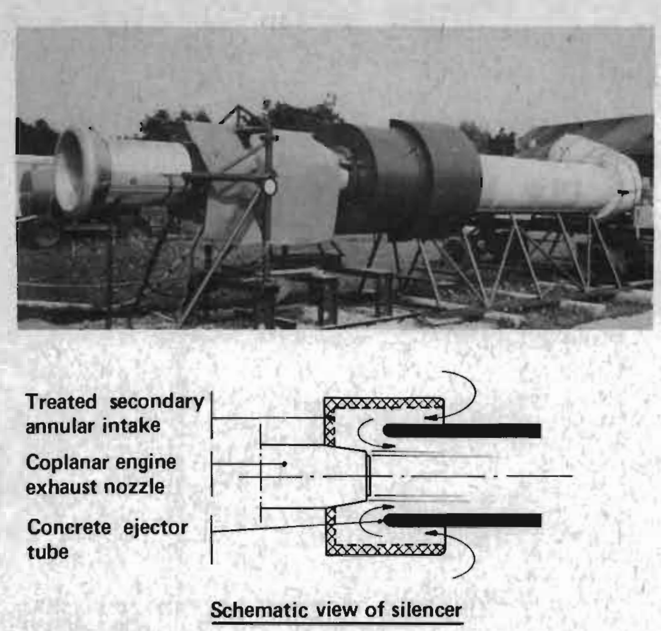


Figure 2. Attenuation by a screen vs. Fresnel number for point source



1. Bellmouth intake
2. Variable inlet guide vanes
3. Single stage geared fan
4. Two rows of fixed outlet guide vanes
5. Two stage turbine
6. Coplanar nozzle

Figure 4. Test engine-Turboméca "Aubisque"



Schematic view of silencer

Figure 5. Front view of test rig with exhaust silencer

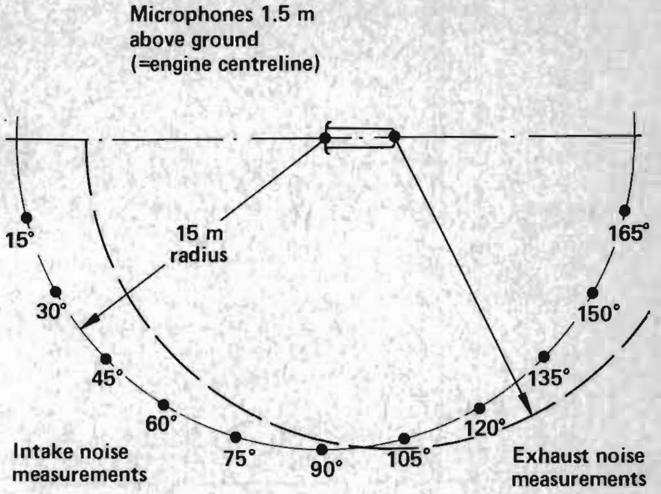
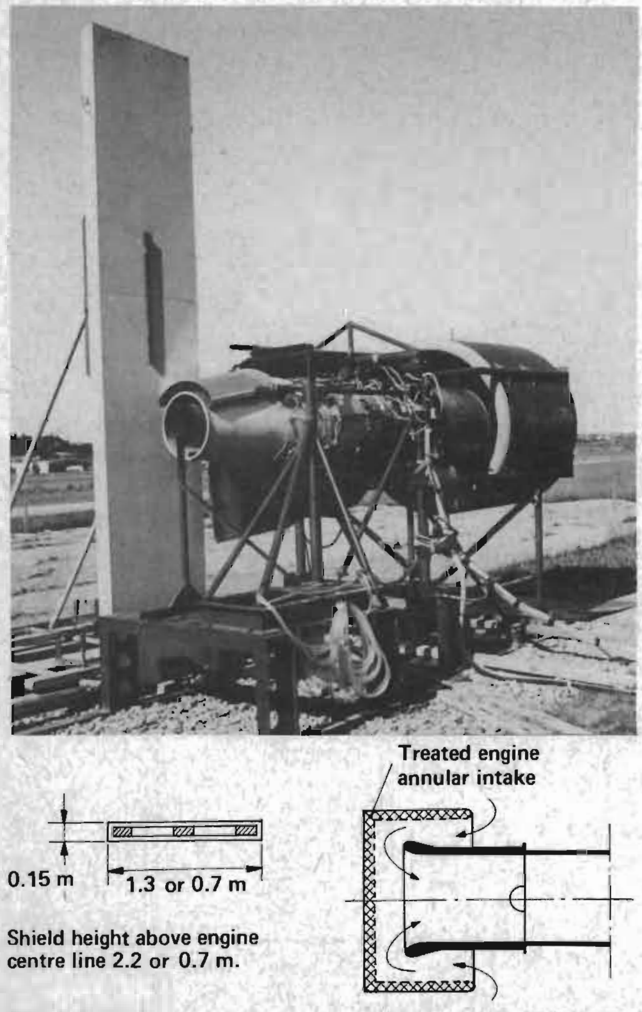


Figure 7. Location of microphones



Shield height above engine centre line 2.2 or 0.7 m.

Shield geometries

Schematic view of silencer

Figure 6. Rear view of test rig with intake silencer and shield configurations.

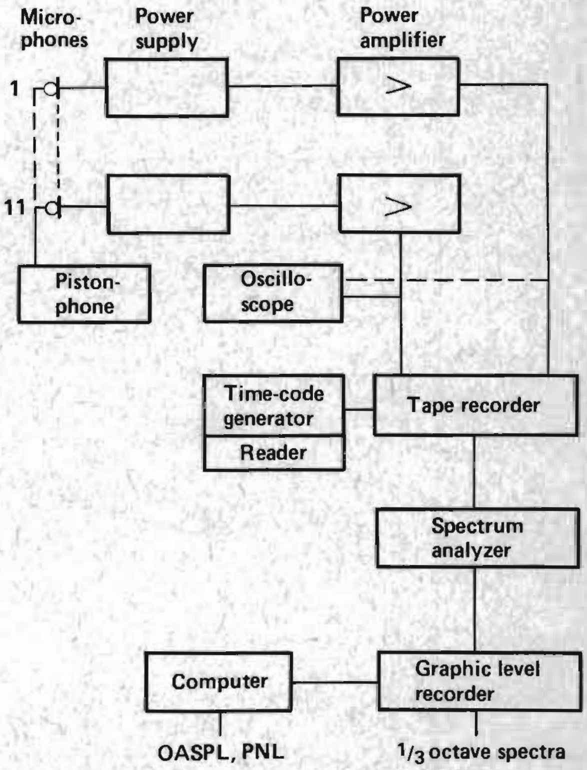


Figure 8. Block diagram of measuring and analyzing equipment.

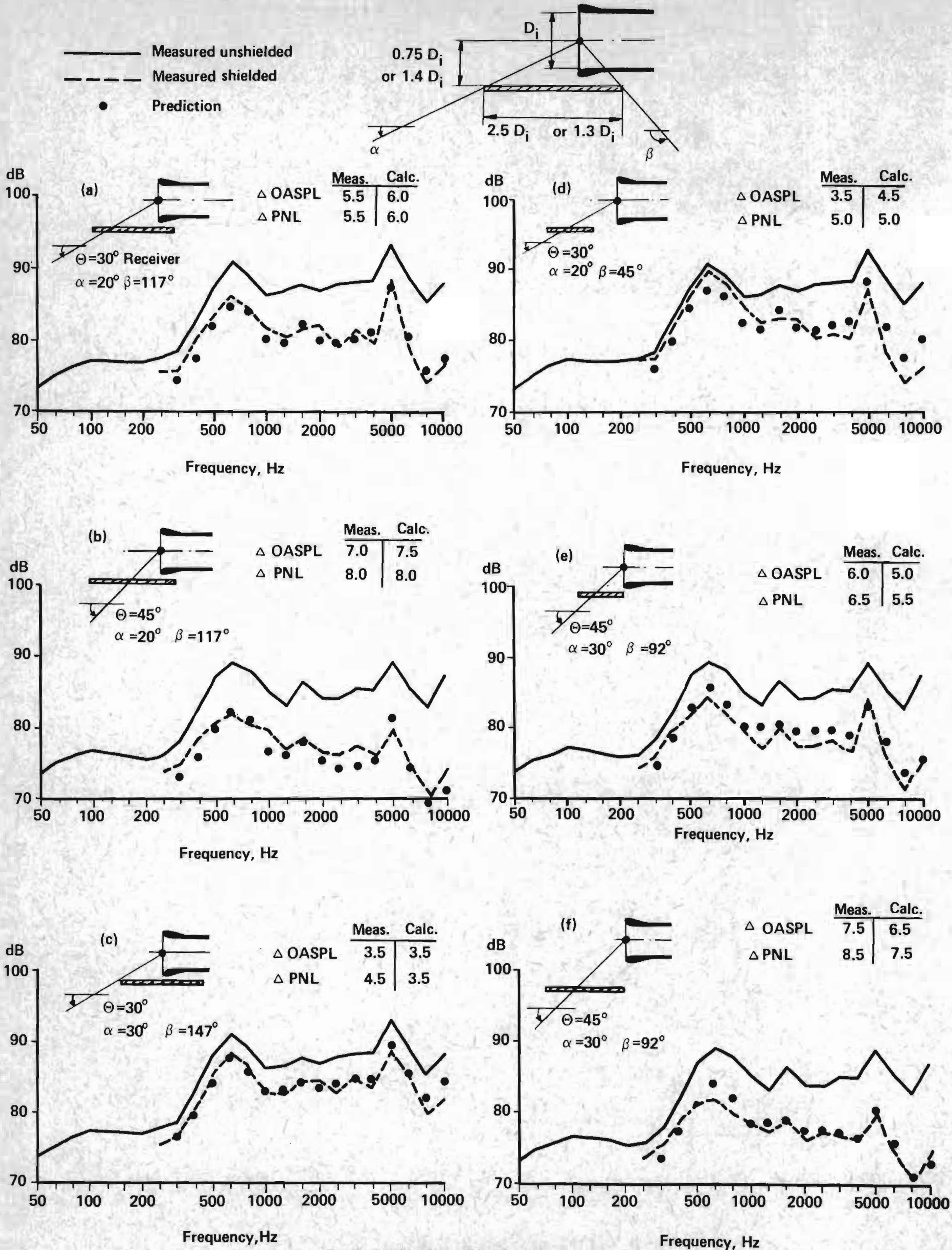


Figure 9 Shielding of intake noise
Measured and predicted 1/3 octave spectra

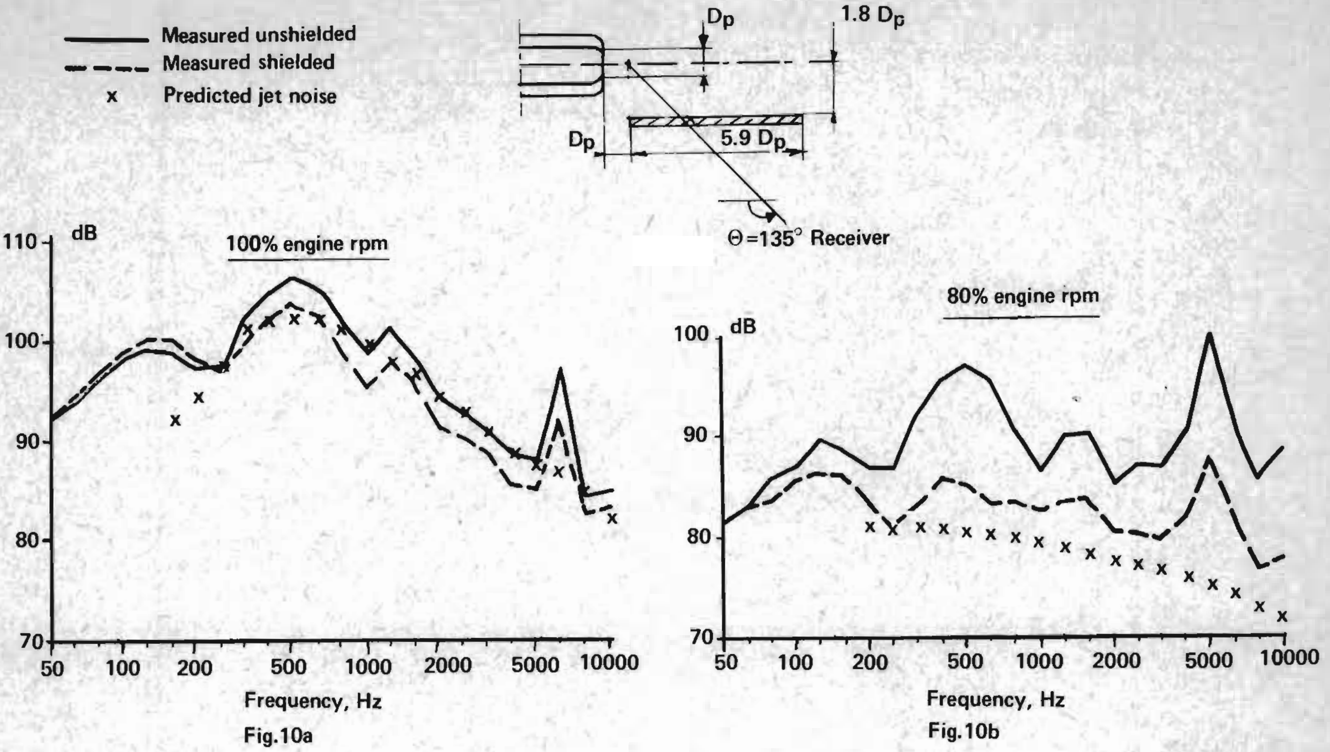
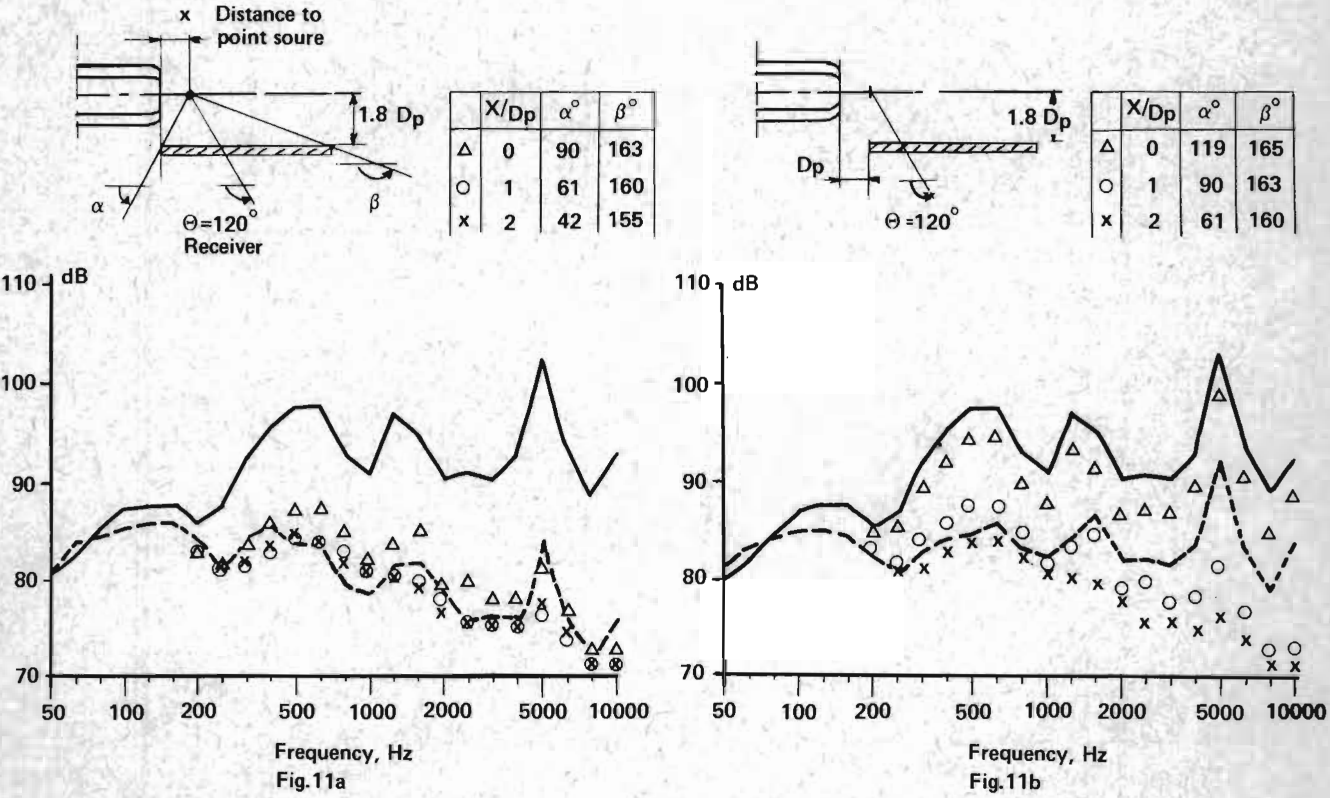


Fig.10a

Fig.10b

Figure 10 Comparison of measured shielding effectiveness at high and low jet noise level



	X/Dp	α°	β°
△	0	90	163
○	1	61	160
x	2	42	155

	X/Dp	α°	β°
△	0	119	165
○	1	90	163
x	2	61	160

Fig.11a

Fig.11b

Figure 11 Effect of point source position on predicted 1/3 octave spectra.
Total exhaust noise radiation is assumed concentrated to one single point.

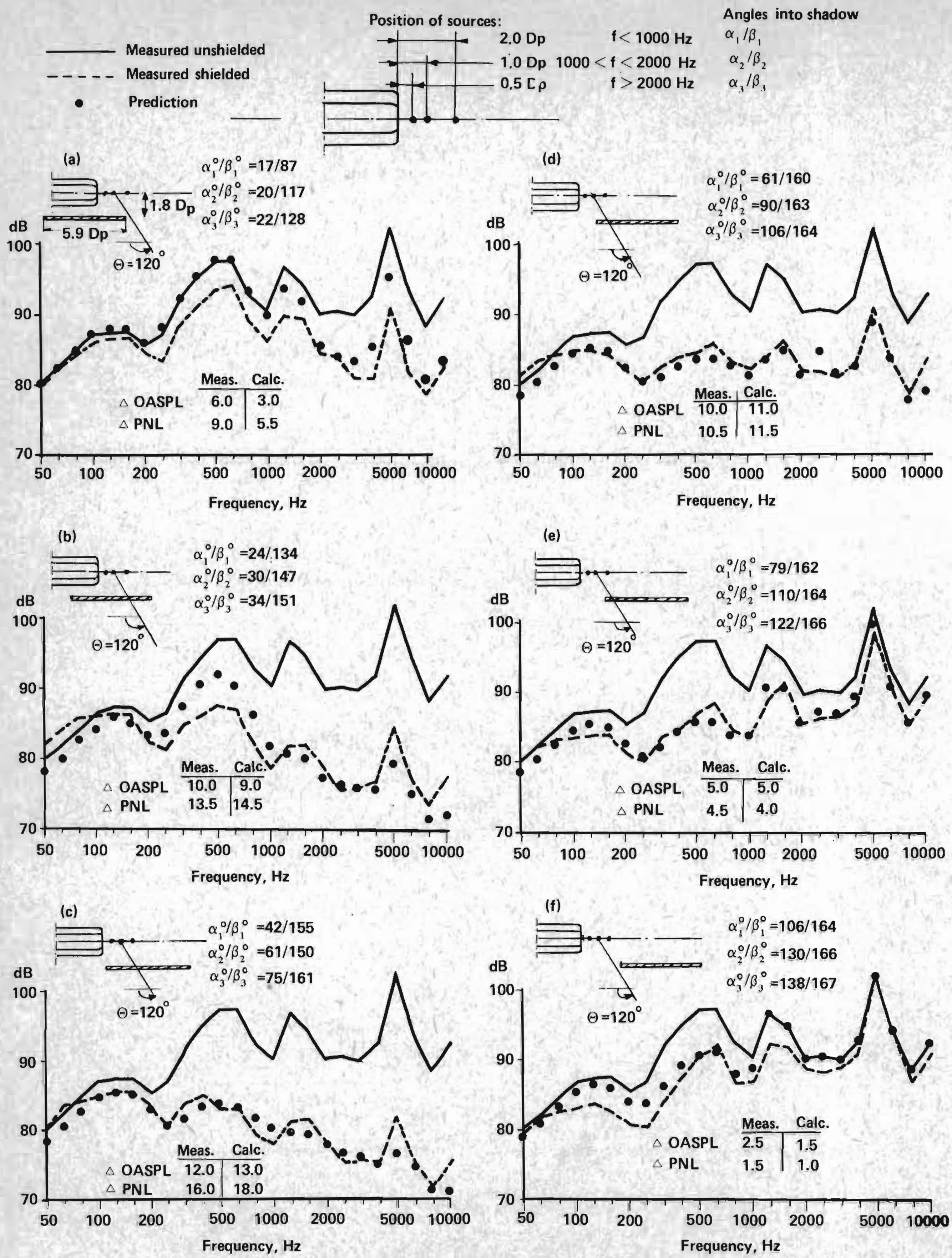


Figure 12 Shielding of exhaust noise. Measured and predicted 1/3 octave spectra for separated positions of point sources. Fixed shield geometry with various axial positions.

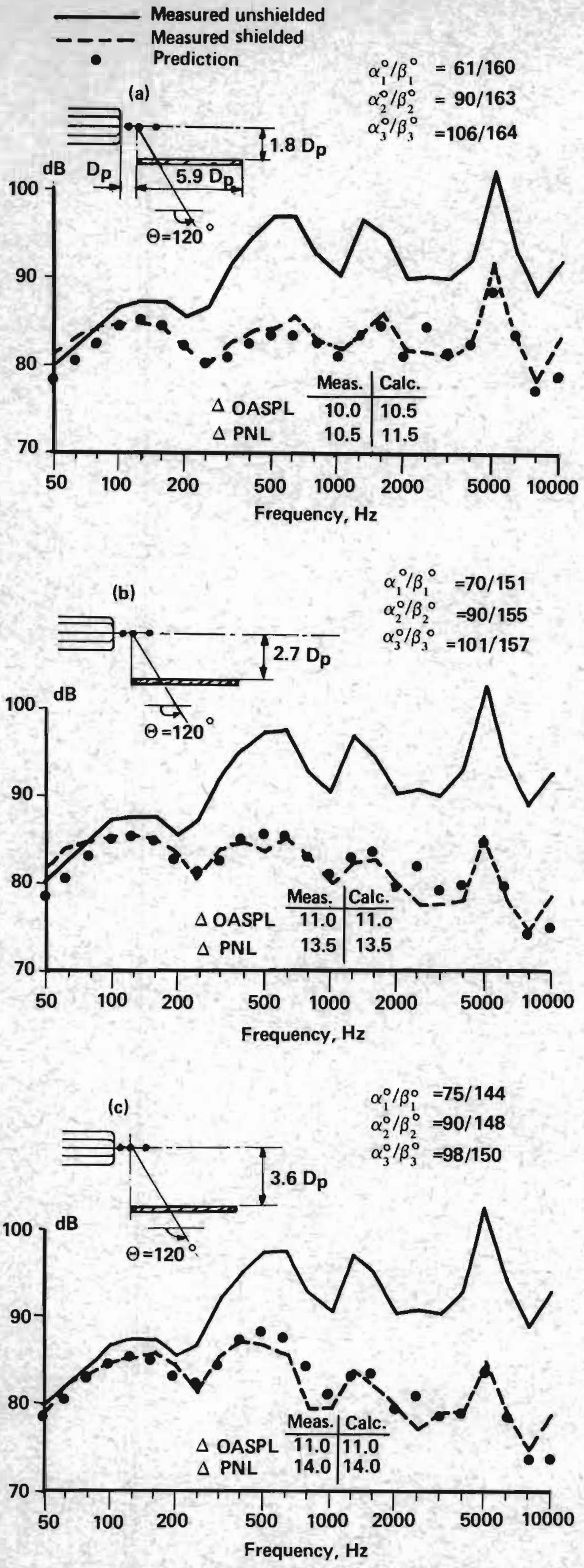


Fig 13. Shielding of exhaust noise.
Various lateral shield positions.

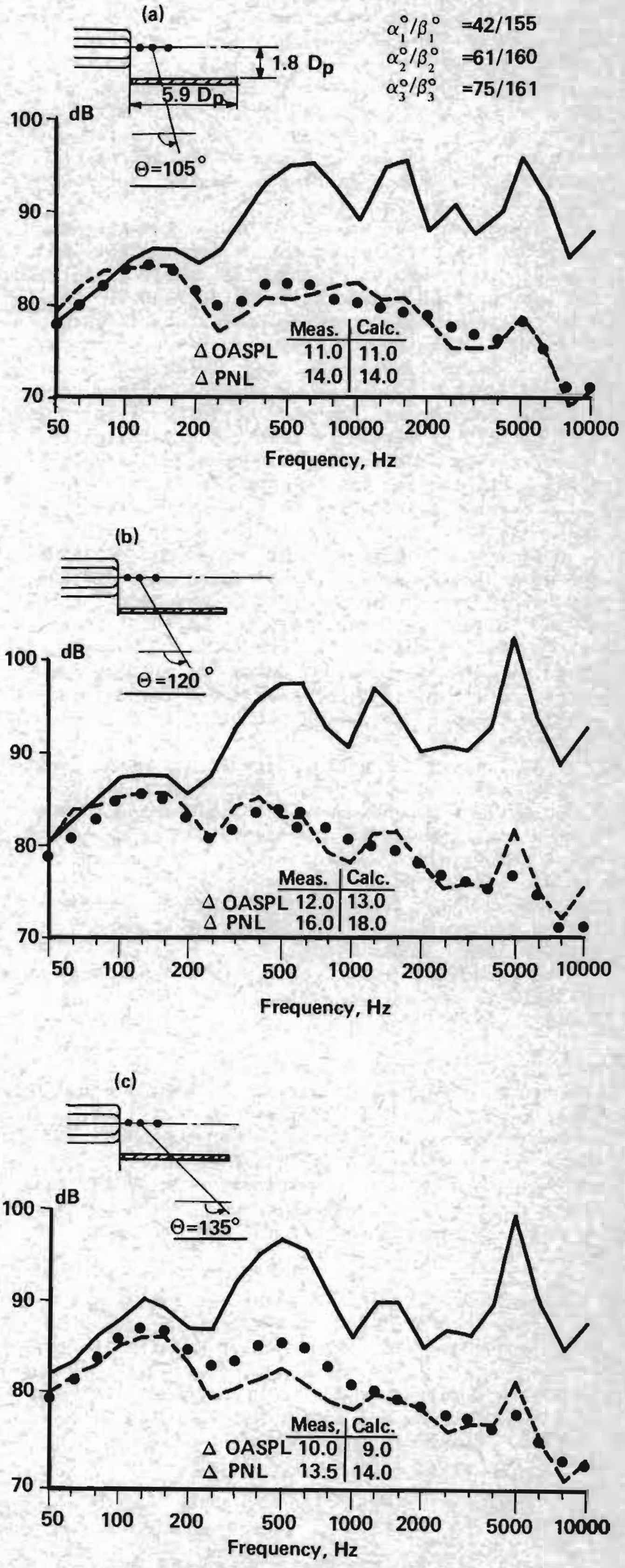


Figure 14. Shielding of exhaust noise.
Fixed shield configuration with
various receiver positions.

DISCUSSION

N. Moses (Acoustic Dept., Israel Aircraft Industries, Ben Gurion Airport, Israel): 1. In flight I expect the noise reduction to be less, as the surface area of the shield should be much greater to take into account the effect of forward speed.
2. In the 1950-1960 the work on reduction on exhaust noise showed that the noise reduction obtained by ejectors etc. just vanished in flight. Hence much more attention should be given to the aspect of forward speed superposition on static test.

F.W. Armstrong (National Gas Turbine Establishment, Pyestock, U.K.): I joined the discussion between the author, Mr. Moses of Israel Aircraft Industries, and the chairman regarding the difference in shielding to the expected between static and flight conditions. I pointed out that the effect of flight on a jet is to lengthen out the mixing region, thus extending the jet noise sources further downstream. This means that the shielding of jet noise will be less effective in flight than statically. If the jet is a dominant noise source in a particular installation, the overall beneficial effect of an exhaust shield will be somewhat reduced.

G. Hellstrom: I agree with Mr. Moses and Mr. Armstrong that a reduction in shielding effectiveness due to free stream speed is to be expected for jet mixing noise. In fact we did not measure any attenuation of this source even statically. However, for internal noise sources, which was of primary concern, the effect of free streamspeed is not necessarily believed to give a reduction in shielding effectiveness.

Velocity and temperature gradients in the proximity of the wing will cause a diffraction of the sound waves. Depending on the field shape of the source and actual wing flow field, an increased or decreased shielding effectiveness might result. In the present investigation the geometry of the shields was simplified to a rectangular section. The actual profile of the wing might also have an influence even statically.

The effect of free stream speed on the location of internal noise sources is not believed to be significant.

V.L. Marshall (British Aircraft Corporation, Weybridge, U.K.): As a general comment, I would like to point out that the Aerodynamicist will not be too happy with proposals for engines mounted close to the wings and tailplane, especially for engines close to and increasingly overlapping the upper surface wing trailing edges. There are considerable interference effects inherent with such layouts.

G. Hellstrom: Aerodynamic interference effects are certainly important and must be considered. However the possibility to overcome these problems is quite realistic. Several existing aircraft have for instance a benefit of intake noise shielding. There is also a freedom for engine location relative to the wing, still keeping strong shielding effects.