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NOISE OF MODEL TARGET TYPE THRUST REVERSERS FOR ENGINE-OVER-THE-WING APPLICATIONS

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FOR ENGINE-OVER-THE-WING APPLICATIONS

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ABSTRACT

Target-type thrust reversers have been suggested for use with engine-over-the-wing (OTW) powered-lift aircraft for short haul applications. This paper presents the results of experiments on the noise generated by V-gutter and semicylindrical target reversers with circular and short-aspect-ratio slot nozzles having equivalent diameters of about 5 cm. It is assumed that the ground sideline effects of the wing on reverser noise (i.e., shielding or additional interaction noise) are small enough that these data obtained without a wing are pertinent to the OTW reverser noise problem. The experiments were conducted with cold-flow jets at jet velocities ranging at least from about 190 to 290 m/sec. At subsonic jet velocities of interest for OTW powered-lift aircraft, the reversers were noisier than the nozzles alone and also had a more uniform directional distribution and more high-frequency noise. The reverser shape was much more important than the nozzle shape in determining the reverser noise characteristics. The maximum sideline OASPL varied with the sixth power of the jet velocity over the range tested. The experimental data were correlated in terms of normalized SPL spectra as a function of Strouhal number for various angles along the sideline. The possible effects of aircraft motion were also considered. Using these relations, an estimate was made of the perceived noise level along the 152-m sideline for a hypothetical OTW powered-lift airplane.

INTRODUCTION

Because the ability to land on short runways is an important requirement for powered-lift, short-haul jet aircraft, it is obvious that thrust reversers are potentially useful. At the same time because of the required capability to operate from airports in heavily-populated areas, such aircraft will have to meet much stricter noise limitations than conventional aircraft. Thus, the ability to predict the noise generated by thrust reversers is required. The thrust reverser noise problem for the augmentor-wing-type powered-lift airplane is discussed in references 1 to 4 for target-type reversers. References 5 and 6 present results for cascade-type reversers, which are applicable to many cases, including powered-lift aircraft.

For externally-blown-flap powered-lift configurations, a possible solution to the noise problem is to locate the engine above the wing (refs. 7-12). By placing the engine over the wing, wing shielding can reduce the flyover noise. However, in order to obtain lift augmentation it is necessary that the exhaust flow be attached to the upper surface of the wings and flaps, which requires either a specially shaped nozzle or an exhaust deflector. Such a deflector, or a portion of the nozzle, might also be converted to a target thrust reverser upon landing. A reverser for this application would probably be of the V-gutter type (fig. 1(a)), but the semicylindrical type (fig. 1(b)) is considered also, since if it is sufficiently quieter than the V-gutter, it might merit consideration, even though a practical design would be more complicated than the V-gutter. This report presents data from references 1 and 3 applicable to engine-over-the-wing (OTW) configurations, as well as new data on a semicylindrical target reverser with a 4.76:1 aspect-ratio slot nozzle. Data are presented and correlated for the reverser configurations illustrated in figure 1 with the slot nozzle and with a circular nozzle. Both of these nozzles have been used in model OTW system noise tests (refs. 7-10). The possible effects of aircraft motion on reverser noise are considered on the basis of data obtained on noise source location in reference 3, but no relative velocity experiments were performed. Based on correlations obtained herein, the sideline perceived noise level is estimated for thrust reversal on a hypothetical OTW powered lift airplane.

APPARATUS AND PROCEDURE

Test Rig

The new data presented herein and the data of reference 3 were taken on an acoustic rig designed to minimize internal noise and instrumented to obtain detailed acoustic data. This rig is shown schematically in figure 2 and is described in more detail in reference 3. The microphone circle was at a 3.05-m radius centered on the nozzle exit and was at 1.63 m above the smooth asphalt surface, nominally the same as the nozzle centerline. The test rig of references 1 and 2 was similar to that except that the nozzle centerline and microphone height was 1.22 m.

Nozzles and Reversers

Nozzles. - The slot nozzle used in these studies and in references 3 and 7 to 10 is sketched in figure 3. The dimensions of this nozzle and of the circular nozzle used in references 1 and 2 are shown. The slot nozzle was mounted with its long exit-plane dimension parallel to the ground.

Reversers. - The small-scale thrust reversers used in the experiments are sketched in figure 4, with the V-gutter type shown in figure 4(a) and the semicylindrical type in figure 4(b). The reversers had frontal width W and height H. The leading edge of the side plates was at an axial distance X from the nozzle exit. In some cases the centerline of the reverser frontal area was offset a distance Y from the nozzle centerline. These offset configurations shown in figure 4 best simulate the OTW application, since only a small fraction of the airflow exhausted through the small-clearance side, and that fraction of the airflow had a much lower velocity than the main reversed flow stream. However, as will be shown herein, the offset had no significant effect on noise. The reverser-nozzle configurations tested are listed in table I along with the jet velocity range for each configuration.

Procedure

The experimental procedure is described in reference 3, which also gives more details of the data reduction procedures. The 1/3-octave-band analyzer determined the sound pressure level SPL in each band from 50 to 20 000 Hz. These data were corrected for atmospheric absorption, and the overall sound pressure level OASPL was computed for each microphone. All SPL's and OASPL's are corrected to the FAR-36 standard day (ref. 12) and converted to a sideline distance equal to the microphone radius, as follows:

$$SPL_s = SPL_{meas} - 10 \log\left[\left(\frac{\rho_a}{\rho_{std}}\right)^2\left(\frac{c_a}{c_{std}}\right)^4\right] - 20 \log\left[\cos\left(90^\circ - \theta\right)\right] \quad (1)$$

Where SPL_s is the sound pressure level which would be observed on the 3.05-m sideline at the angle θ on a standard day, and SPL_{meas} is the value measured on the actual day on a 3.05-m radius at the angle θ. The second term on the right-hand side corrects the measurement to the standard day, and the final term accounts for the conversion from the 3.05-m radius to the 3.05-m sideline. To compare individual experimental data points that deviate somewhat from a given nominal jet velocity a term, $10\, n \log\left[(U_j/c_a)/(U_{j,nom}/c_{std})\right]$, was subtracted from each SPL_s or $OASPL_s$, where $n = 6$ for the reversers and 8 for the nozzle alone.

Low-frequency background noise was found to be a problem at the test site of this study and reference 3. No data falling within 5 dB of the upper limit of the background noise at a given frequency were included herein. For low jet velocities, this put the low-frequency limit of the data as high as 400 Hz. Ray acoustics calculations according to reference 14 indicated that the strongest discrete ground reflection effects occur at relatively low frequency. The first (and strongest) cancellation and reinforcement each occurred in the bands generally affected by background noise, 125 and 250 Hz, respectively. Since reverser noise generally peaked in the 2000 to 8000 Hz range, the high frequency, asymptotic ground reflection correction is applied to all frequencies. (This correction is -1.7 dB for the new data herein and in ref. 3, and -2.2 dB for the data of ref. 1.)

RESULTS AND DISCUSSION

The noise data considered most significant in this investigation are presented herein in graphical form. For those requiring more detailed data on the semicylindrical reverser with slot nozzle, complete tables of 1/3-octave-band spectra are available, on request, from the authors. Detailed data for the other configurations were reported in references 1 and 3.

The vertical offset configurations illustrated in figure 4 best simulate the OTW application, since only a small fraction of the airflow exhausted through the small-clearance side and that fraction of the airflow had a much lower velocity than the main reversed flow stream. However, as will be shown herein, the offset had no effect on noise. Therefore, the noise data obtained with symmetrically oriented reversers are considered applicable to the OTW reverser noise problem.

Typical Effects of Thrust Reversal on Noise

When a jet flow is reversed by a target-type thrust reverser, the noise field is significantly changed. Typical effects of thrust reversal on noise are presented in terms of sideline overall sound pressure level ($OASPL_s$) directivity in figure 5 and SPL_s spectra at θ_{max} (the angle of maximum $OASPL_s$) in figure 6. The data are given for the slot nozzle alone and for the nozzle with both V-gutter and semicylindrical reversers. In figures 5(a) and 6(a) both reversers were offset from the slot nozzle centerline, simulating the OTW reverser case. However, the jet velocity of 290 m/sec is somewhat high for powered-lift OTW applications. In figures 5(b) and 6(b) the reversers were not offset, but the jet velocity is in the OTW range of interest. These figures are only intended to show general trends; the specific effects of offset and jet velocity will be discussed in a later section of this paper.

Directivity. - Figure 5 shows $OASPL_S$ as a function of angular position θ measured from the inlet axis. The peak $OASPL_S$ for the slot nozzle alone occurs at $\theta = 120^o$ for both jet velocities of 190 and 290 m/sec. In contrast, the peak $OASPL_S$ occurs at $\theta = 60^o$ for both V-gutter and semicylindrical reversers, except for the offset V-gutter configuration (fig. 5(a)), but even there the $OASPL_S$ at $\theta = 60^o$ is within 0.2 dB of the peak. The peak $OASPL_S$ with reversers exceeds that of the slot nozzle alone by at least 10 dB and by as much as 17 dB at the lower jet velocity (in the OTW range) for the V-gutter reverser. Furthermore, in all cases the reversers are louder than the nozzle alone at all angles.

Spectra. - Figure 6 shows the effect of thrust reversal on the noise spectrum at the angle of maximum $OASPL_S$, θ_{max}. All the reverser configurations are higher than the slot nozzle alone over the entire frequency range except for the offset V-gutter reverser at high U_j for $f_c \leq 315$ Hz. The increase relative to the nozzle alone was greatest at frequencies in the 2000 to 8000 Hz range.

Effect of Jet Velocity and Geometric Variables on Thrust Reverser Noise

Maximum sideline OASPL. - In figure 7 the dependence of the normalized maximum OASPL on jet velocity (where jet velocity is ratioed to ambient sonic velocity) is shown for the various reversers tested. Data for the V-gutter reversers are shown in figure 7(a), and data for semicylindrical reversers are shown in figure 7(b). For both reverser types the normalized maximum sideline OASPL is seen to increase with the sixth power of jet velocity, as first suggested by Curle (ref. 14) for the effect of solid boundaries on aerodynamic noise. The effects of nozzle shape and reverser-nozzle offset are seen to be insignificant over the range tested; only one data point falls outside the ±1.5 dB scatter from the faired sixth-power curves for each reverser type.

To summarize these results, the maximum sideline OASPL for target reversers with circular or short-aspect-ratio slot nozzles can be correlated as follows:

$$OASPL_{s,max} = K + 10 \log\left(\frac{A_n \rho_a^2 U_j^6}{L^2 \rho_{std}^2 c_{std}^4 c_a^2}\right) \qquad (2)$$

Where K = 155.2 for V-gutter reversers and 151.7 for semicylindrical reversers. Since jet noise typically varies with the eighth power of jet velocity, it is apparent that decreasing the jet velocity increases the thrust reversal noise relative to the jet noise at a given jet velocity.

<u>SPL spectra at angle of maximum sideline OASPL</u>. - Figures 8 and 9 show plots of sound pressure level normalized to the OASPL at θ_{max}, SPL-OASPL, against the logarithm of the Strouhal number based on nozzle equivalent diameter ($f_c D_e / U_j$) for the various reverser configurations. The V-gutter reverser data are shown in figure 8 for the circular nozzle (fig. 8(a)), the slot nozzle (fig. 8(b)) and the slot nozzle offset by 1.27 cm (0.23 D_e or 0.56 nozzle slot heights, fig. 8(c)). The semicylindrical reverser data are shown in figure 9 for the circular nozzle (fig. 9(a)), the slot nozzle (fig. 9(b)) and the slot nozzle offset by 2.46 cm (0.44 D_e or 1.09 nozzle slot heights, fig. 9(c)).

Also shown for comparison in each case is the same faired average curve. This curve is based on an approximate average of all the data except that for the V-gutter reverser with the circular nozzle. The deviations observed for the V-gutter-circular nozzle configuration appear to be due to a sharp peak (not a tone) of unknown origin at 1250 Hz. Otherwise, there appear to be no significant effects of geometric variables, even reverser shape, on the normalized spectra.

Spectral directivity. - Thrust reversal noise directivity at various Strouhal numbers is illustrated in figures 10 through 12. Plots are shown of SPL_s referred to that at θ_{max}, $SPL_s - SPL_s(\theta_{max})$, against θ at constant Strouhal number for the various reverser configurations. In each case the same curve is shown for comparison. This curve is based on the average $OASPL_s$ directivity (not shown), which was essentially the same for all configurations and jet velocities. At a Strouhal number of ~ 1.0, which corresponds essentially to the peak SPL at all angles (fig. 10), the directivity is approximately the same for all configurations and jet velocities and is in agreement with the OASPL curves. Since this is essentially the peak SPL (except for the V-gutter reverser with the circular nozzle), the agreement with the $OASPL_s$ directivity is not surprising. At higher frequencies (e.g., Strouhal number of ~ 3.2, fig. 11), the agreement with the OASPL directivity is reasonably good (with some slight effects of configuration and jet velocity appearing). The $OASPL_s$ curve, however, still gives a reasonable approximation to the directivity at high frequencies. At lower frequencies (e.g., Strouhal number of ~ 0.25, fig. 12), SPL_s generally varies less with angle than at the higher frequencies and $OASPL_s$, especially for $\theta > \theta_{max}$. However, in estimating the noise for full scale reversers, frequencies corresponding to a Strouhal number of 0.25 would not be very important in calculating perceived noise. However, these low frequencies may have significant effects on aircraft structures and the human body. Therefore, the $OASPL_s$ directivity can be applied to all frequencies as a reasonable approximation for full scale noise prediction.

Discussion of Relative Velocity Effects

All of the thrust reverser noise experiments reported in the literature were conducted under static conditions with no relative velocity of the surrounding airstream. In operation, OTW airplane thrust reversers would be used at airplane velocities as high as 53 m/sec (100 knots), so the effects of airplane motion relative to a stationary observer and ambient airstream motion relative to the reverser must be considered.

The dominant noise source with target reversers appears to be of dipole type caused by the interaction of the jet and the reversing surface (ref. 3), so that it may not be effected much by the relative airflow. It should be noted, however, that reference 15 reported some decrease in dipole-type internally-generated noise in a nozzle exhaust with forward velocity, but it is questionable whether such an effect would be obtained with thrust reversers. However, jet noise may be important relative to reverser noise at very low frequencies (fig. 6(a)), and since the jet flow is reversed, the relative jet velocity of the flow leaving the reverser would be increased, which would increase the very low frequency noise. Since the relatively high frequencies dominate in the perceived noise level (PNL) calculations, any increase in the low frequency noise would probably not effect the PNL. However, this increase in low frequency noise might have other significant effects, as mentioned in the previous section.

If the dominant noise source is considered to be moving with the airplane velocity, U_o, a Doppler-type frequency shift would be observed. The frequency heard by a stationary observer, f, would be related to the frequency relative to the moving source, f_s, by

$$\frac{f}{f_s} = 1 + \left(\frac{U_o}{c_a}\right) \cos \theta \tag{3}$$

Thus, directly ahead of the airplane the frequency would be shifted by a factor of 1.15 (less than one 1/3-octave band) for $U_o = 53$ m/sec, and would decrease to zero at $\theta = 90^o$. The frequency shift would decrease as the plane slows down. Assuming a dipole noise source, the corresponding increase in amplitude would be a maximum of 2.4 dB at $\theta = 0^o$ and a minimum of -2.4 dB at $\theta = 180^o$, according to reference 16. At

$\theta = 60^{O}$ (generally the angle of peak PNL), the corresponding amplification would be +1.3 dB. It can be assumed then that the Doppler shift, though having a significant effect on the directivity, would not have much effect on the peak PNL. It can then be concluded that relative velocity effects should not be significant for target-type thrust reversers.

Estimation of Perceived Noise at Airplane Scale

The empirical relations presented herein are used to estimate the 152-m (500-ft)-sideline perceived noise for target-type thrust reversers on a hypothetical four-engine, powered-lift OTW airplane. The nozzle equivalent diameter for each engine is 2 m, and the jet velocity is 200 m/sec; these values are in the range of interest for full-power operation of powered-lift OTW engines. The FAR 36 standard day conditions are assumed.

The maximum sideline OASPL (free-field, no atmospheric absorption) is computed for a single engine from equation (2) for both V-gutter and semicylindrical reversers. The spectra at 20^{O} angular increments are then obtained from the reference spectrum curve (figs. 8-9) and the $OASPL_S$ directivity (figs. 10-12). These spectra are then corrected for atmospheric absorption according to reference 17. Then 3dB are added to account for ground reflections. Another 3 dB are added to roughly account for multiple-engine and shielding effects. (This 3 dB would result in an idealized case where there is no wing shielding and only two engines are heard due to fuselage shielding. However, the same result would also be obtained if additional noise from the engines on the far side of the plane exactly cancelled any wing shielding benefit.) The perceived noise is then calculated according to reference 18. No correction is made for extra ground attenuation or for Doppler effects. Procedures for scaling thrust reverser noise have not been verified by full-scale tests, but it is believed that these predictions are of sufficient accuracy to indicate the gross magnitude of the OTW reverser noise problem.

The calculated noise levels are plotted in figure 13 against distance along the 152-m sideline on the ground. For the specific case of a 200-m/sec jet velocity, the quieter semicylindrical reverser maximum PNL is more than 105 PNdB. With a V-gutter reverser, the peak PNL might be as much as 110 PNdB. Such noise levels might well be a serious obstacle to obtaining an environmentally acceptable airplane, if the engines are required to operate at a power setting producing the example value of jet velocity (near full power range according to current studies of engines for OTW powered-lift aircraft).

Operating at reduced power during thrust reversal would reduce the thrust-reverser noise; for example, to reduce the noise by 5 dB would require a 21 percent reduction in jet velocity. If the reverser has a high enough thrust-reversal efficiency, such a procedure might be feasible for dry runway conditions. A detailed consideration of the tradeoffs in this approach to reducing the reverser noise is beyond the scope of this paper. Such considerations are discussed in reference 6 for cascade type thrust reversers.

Small shields, near the reverser, but outside the flow stream shown in reference 3 to have some potential for reducing the sidel ne noise for reversers of this type. The shields could be an integral part of the nacelle or wing surface, retracting for flight (or conversely, extending during reverser operation).

SUMMARY OF RESULTS

The results of this investigation of the noise generated by target-type reversers applicable to powered-lift OTW engines may be summarized as follows:

1. The reversers generated more noise than the unreversed jet at the subsonic jet velocities of interest for powered-lift OTW airplanes. The reverser noise exceeded that of the jet (unreversed) at all angles and peaked at slightly higher frequency.

2. The thrust reverser maximum sideline OASPL increased with the sixth power of exhaust jet velocity. Nozzle type and reverser-nozzle offset had no significant effect, but the V-gutter reversers were consistently louder than the semicylindrical type.

3. The SPL spectra for these reversers at the angle of maximum sideline OASPL were normalized as a function of Strouhal number based on nozzle equivalent circular diameter and jet velocity. Reverser and nozzle geometry had no significant effect on these spectral shapes, except for the V-gutter reverser with the circular nozzle, which had more low-frequency noise.

4. The sideline OASPL directivity was essentially independent of jet velocity and geometry. The SPL directivities at the peak SPL and higher frequencies agreed reasonably well with the OASPL directivity. At lower frequencies, the geometry and jet velocity had some effect on directivity, but not enough to affect the perceived noise calculation.

5. Using the relations obtained from the data, the perceived noise level on the 152-m sideline was estimated for a hypothetical powered-lift OTW airplane. Peak perceived noise levels in excess of 105 PNdB were estimated, indicating that thrust reversal noise may be a serious obstacle to obtaining an environmentally acceptable airplane for an engine jet velocity of 200 m/sec. Solutions to the problem may be possible by shielding techniques and by operating at reduced power during thrust reversal if sufficient reverse thrust can still be obtained.

SYMBOLS

A_n nozzle exit area, m^2

c sonic velocity, m/sec

D_e equivalent circular nozzle diameter, $\sqrt{4A_n/\pi}$, m

f frequency heard by stationary observer, Hz

f_c 1/3-octave-band center frequency, Hz

f_s	frequency emitted by a moving source, Hz
H	reverser height, m
K	constant in equation (1), dB re 20 μ N/m^2
L	distance from source to arbitrary sideline, m
n	exponent defined in text, dimensionless
OASPL	overall sound pressure level, dB re 20 μ N/m^2
PNL	perceived noise level, PNdB
R	distance from source to observer, m
SPL	1/3-octave-band sound pressure level, dB re 20 μ N/m^2
U_j	isentropic ideal jet velocity, m/sec
U_o	airplane forward velocity, m/sec
W	reverser width, m
X	reverser-nozzle spacing, m
Y	reverser-nozzle offset, m
ρ	density, kg/m^3
θ	angle from inlet axis, deg
θ_{max}	angle of maximum sideline OASPL, deg

Subscripts:

a	ambient
max	maximum
meas	measured value
nom	nominal value
s	sideline
std	FAR 36 standard day

REFERENCES

1. O. A. Gutierrez, and J. R. Stone, "Preliminary Experiments on the Noise Generated by Target-Type Thrust Reverser Models," NASA TM X-2553, (May 1972).

2. J. R. Stone, and O. A. Gutierrez, "Target-Type Thrust Reverser Noise," J. Aircraft, 10, 283-288 (1973).

3. J. R. Stone, and O. A. Gutierrez, "Small-Scale Noise Tests of a Slot Nozzle with V-Gutter Target Thrust Reverser," NASA TM X-2758, (Apr. 1973).

4. J. R. Stone, and O. A. Gutierrez, "Noise Tests of a High-Aspect-Ratio Slot Nozzle with Various V-Gutter Target Thrust Reversers," Paper presented at the 86th Meeting of the Acoustical Society of America, (1973); also NASA TM X-71470.

5. O. A. Gutierrez, J. R. Stone, and R Friedman, "Results from Cascade Thrust Reverser Noise and Suppression Experiments," AIAA Paper No. 74-46 (1974).

6. D. A. Dietrich, and O. A. Gutierrez, "Model Tests of Cascade Thrust Reverser Performance for Short Haul Application," AIAA Paper No. 74-1171 (1974).

7. M. Reshotko, W. A. Olsen, and R. G. Dorsch, "Preliminary Noise Tests of the Engine-Over-the-Wing Concept. I: 30°-60° Flap Position," NASA TM X-68032 (Mar. 1972).

8. M. Reshotko, W. A. Olsen, and R. G. Dorsch, "Preliminary Noise Tests of the Engine-Over-the-Wing Concept. II: 10°-20° Flap Position," NASA TM X-68104, (June 1972).

9. R. G. Dorsch, M. Reshotko, and W. A. Olsen, "Flap Noise Measurements for STOL Configurations Using External Upper Surface Blowing," AIAA Paper 72-1203 (1972).

10. U. von Glahn, M. Reshotko, and R. G. Dorsch, "Acoustic Results Obtained with Upper-Surface-Blowing Lift Augmentation Systems," NASA TM X-68159 (Nov. 1972).

11. M. Reshotko, J. H. Goodykoontz, and R. G. Dorsch, "Engine-Over-the-Wing Noise Research," AIAA Paper No. 73-631 (1973); also J. Aircraft, 11, pp. 195-196 (1974).

12. U. von Glahn, J. Goodykoontz, and J. Wagner. "Nozzle Geometry and Forward Velocity Effects on Noise for CTOL Engine-Over-the-Wing Concept," Paper presented at the 86th Meeting of the Acoustical Society of America, (1973); also NASA TM X-71453.

13. Federal Aviation Regulations, "Noise Standards: Aircraft Type Certification," 3, Pt. 36 (1969).

14. W. L. Howes, "Ground Reflection of Jet Noise," NASA TR-R-35 (1959).

15. N. Curle, "The Influence of Solid Boundaries Upon Aerodynamic Sound," Proc. Royal Soc. (London) A231, 505-514 (1955).

16. U. von Glahn, and J. Goodykoontz, "Forward Velocity Effects on Jet Noise with Dominant Internal Noise Source," Paper presented at the 86th Meeting of the Acoustical Society of America (1973); also NASA TM X-71438.

17. R. G. Dorsch, "Externally Blown Flap Noise Research," SAE Paper No. 740468, (1974).

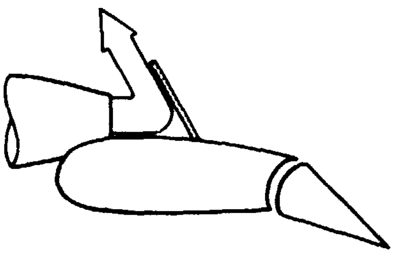
18. Aerospace Recommended Practice, "Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity for Use in Evaluating Aircraft Flyover Noise," ARP 866, Society of Automotive Engineers (Aug. 31, 1969).

19. Aerospace Recommended Practice, "Definitions and Procedures for Computing the Perceived Noise Level of Aircraft Noise," ARP 865A, Society of Automotive Engineers (Aug. 15, 1969).

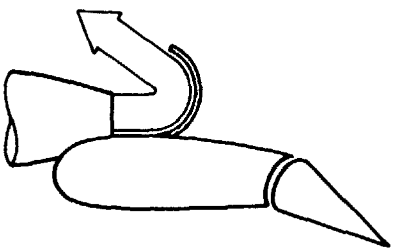
TABLE I. - SUMMARY OF TEST CONDITIONS

Nozzle	Reverser			Orientation		Jet velocity range, U_j, m/sec	Data source
	Type	Height, H, cm	Width, W, cm	Spacing, X, cm	Offset, Y, cm		
Circular	Semicylindrical	8.80	17.20	0	0	193, 296	Ref. 1
Circular	V-gutter	7.94	6.60	4.45	0	296	Ref. 1
Slot	Semicylindrical	8.80	17.20	-2.48	0	195-372	Herein
Slot	Semicylindrical	8.80	17.20	-2.48	2.46	237, 295	Herein
Slot	Semicylindrical	8.80	17.20	0	0	239-370	(a)
Slot	V-gutter	8.33	13.97	-.45	0	190-390	Ref. 3
Slot	V-gutter	8.33	13.97	-.45	1.27	286, 363	Ref. 3

[a]Not presented; available on request.

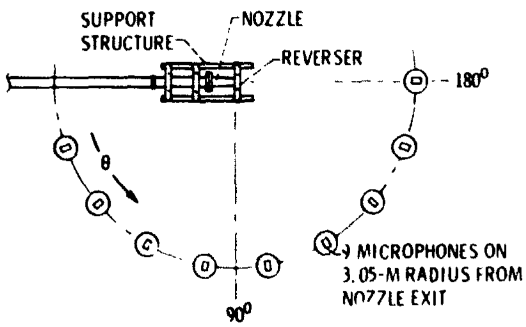


(a) V-GUTTER REVERSER.

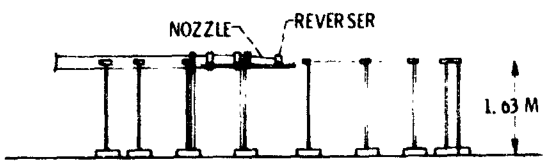


(b) SEMICYLINDRICAL REVERSER

Figure 1. - Thrust reverser configurations applicable for engine-over-the-wing (OTW), powered lift aircraft.

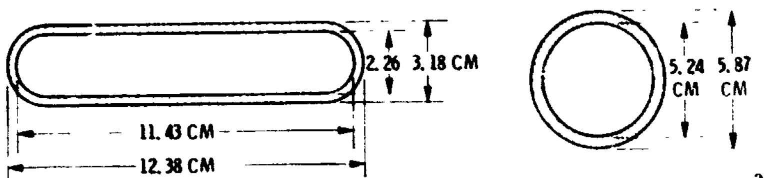


(a) PLAN VIEW.



(b) ELEVATION.

Figure 2. - Schematic diagram of acoustic rig.



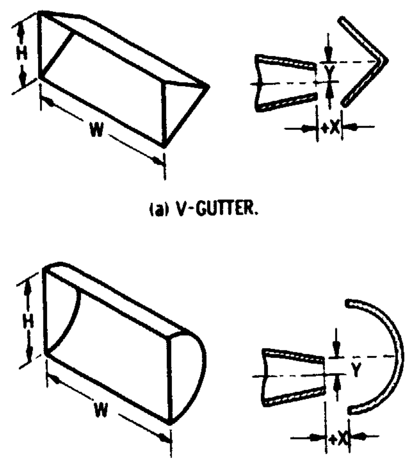
AVERAGE SLOT WIDTH, 10.77 CM
EQUIVALENT CIRCULAR DIAMETER, D_e, 5.56 CM
ASPECT RATIO, 4.76
EXIT AREA, A_n - 24.3 CM^2
UPSTREAM (PIPE) AREA, 79 CM^2

(a) SLOT NOZZLE.

EXIT AREA, A_n 21.6 CM^2
UPSTREAM (PIPE) AREA, 79 CM^2

(b) CIRCULAR NOZZLE.

Figure 3. - Nozzle geometries.



(a) V-GUTTER.

(b) SEMICYLINDRICAL.

Figure 4. - Thrust reverser geometries.

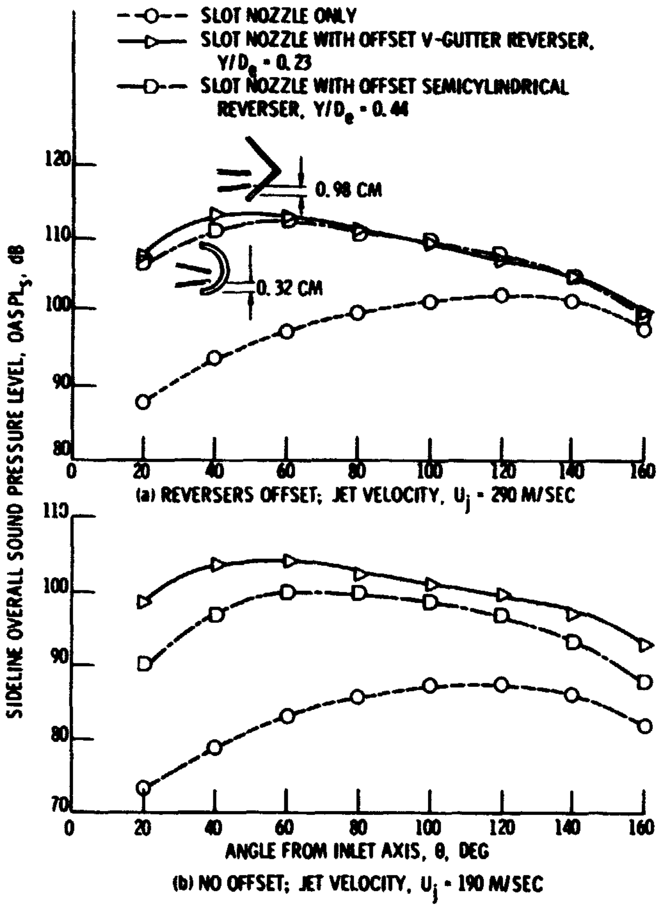


Figure 5. - Typical effect of thrust reversal on 3.05-m sideline OASPL directivity; corrected to FAR 36 standard day; nozzle exit area, 24.3 cm^2.

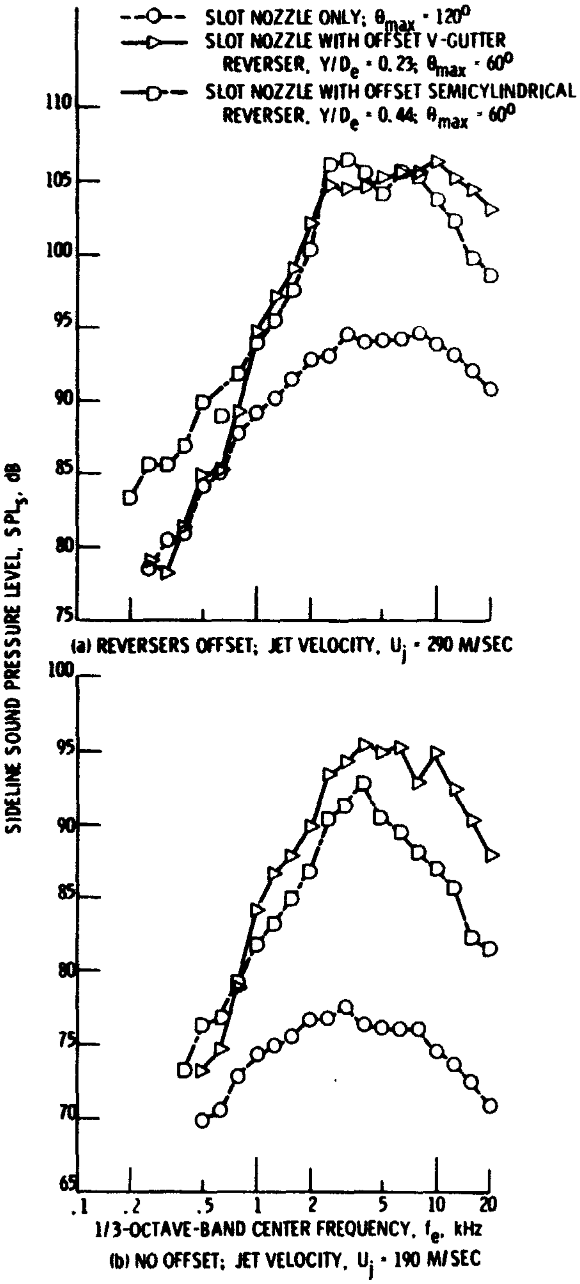


Figure 6. - Typical effect of thrust reversal on SPL spectrum at angle of maximum 3.05-m sideline OASPL, θ_{max}. Corrected to FAR 36 standard day; nozzle exit area, 24.3 cm^2.

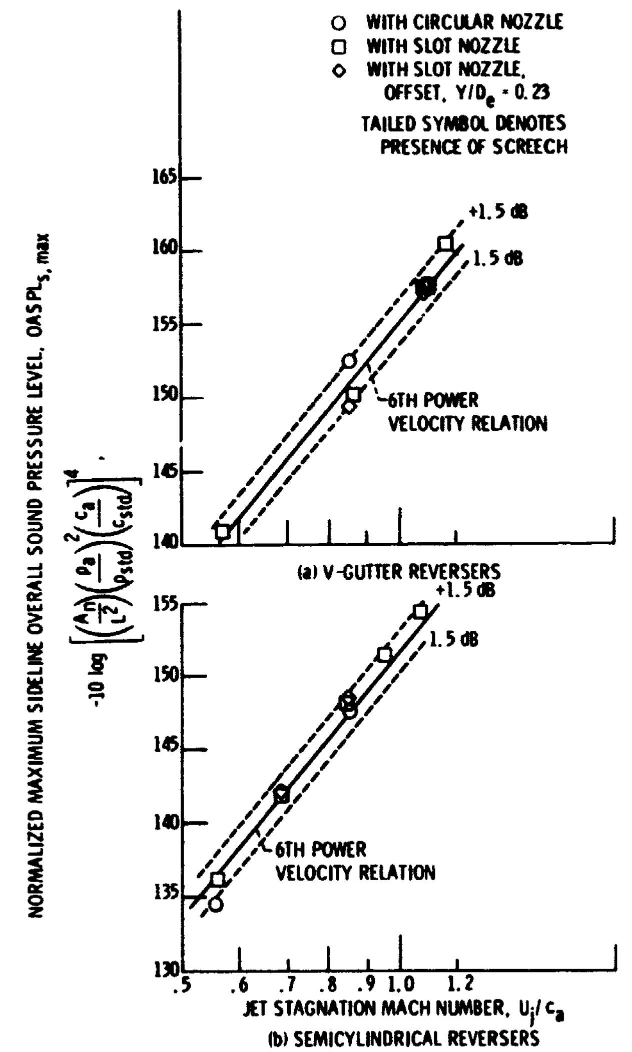


Figure 7. - Effects of jet velocity and reverser geometric variables on maximum sideline OASPL.

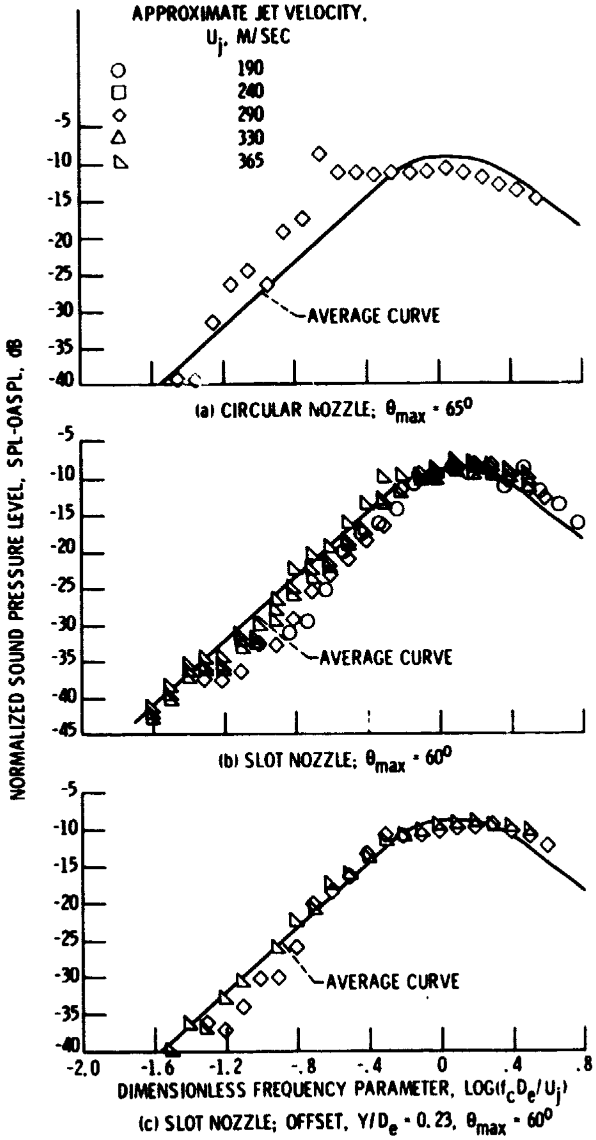


Figure 8. - Normalized sound pressure level spectra at angle of maximum sideline OASPL, θ_{max}, for V-gutter reversers.

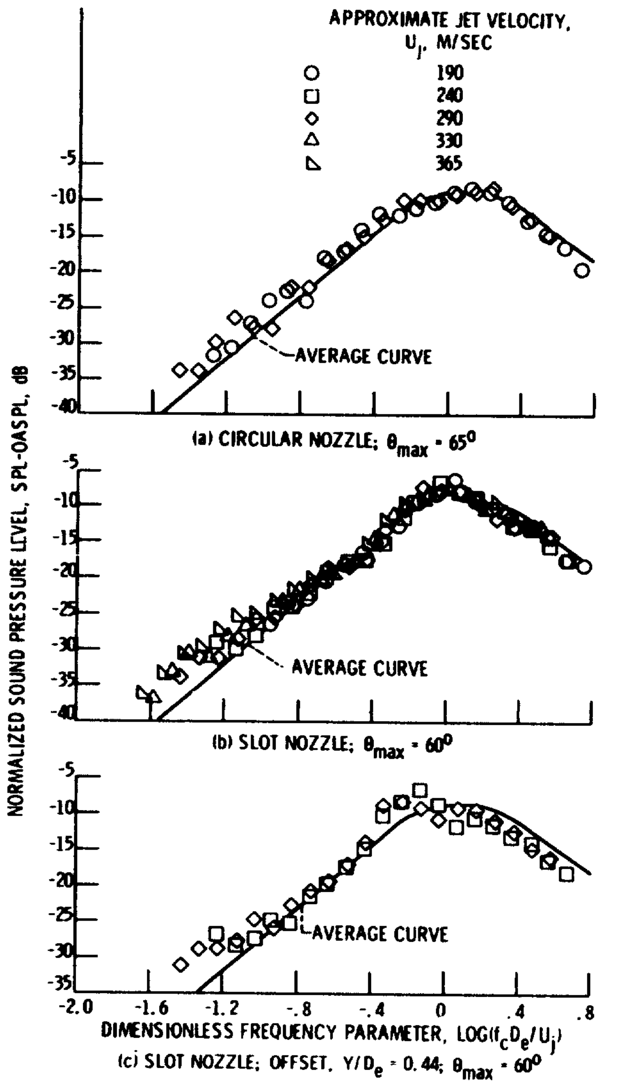


Figure 9. - Normalized sound pressure level spectra at angle of maximum sideline OASPL, θ_{max}, for semicylindrical reversers.

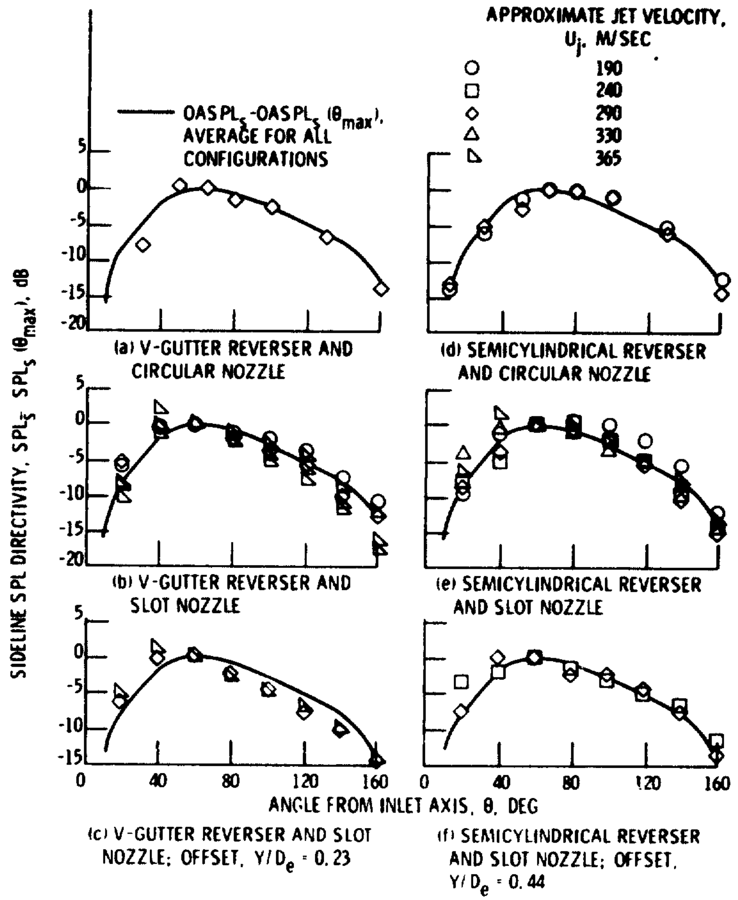


Figure 10. - Sideline SPL directivity for Strouhal number, $fD_e/U_j = 1.0$.

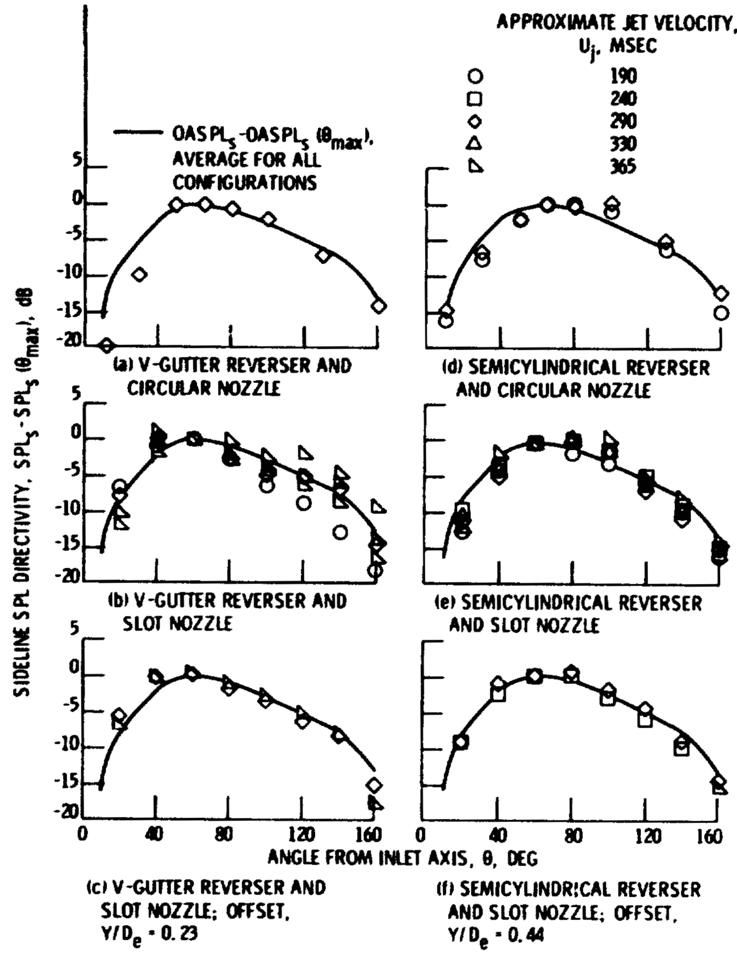


Figure 11. - Sideline SPL directivity for Strouhal number, $fD_e/U_j \approx 3.2$.

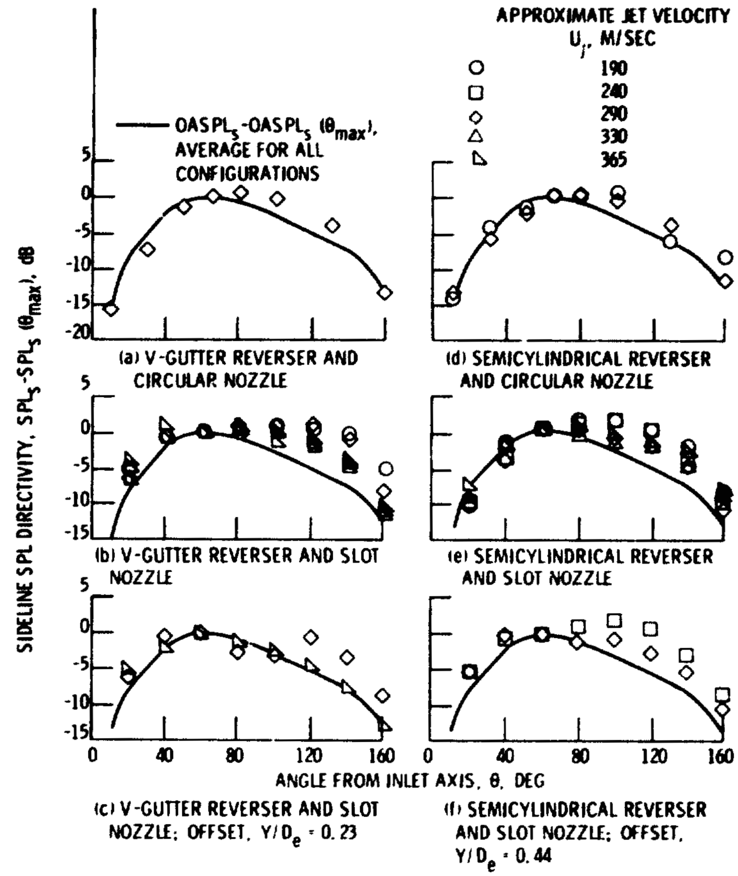


Figure 12. - Sideline SPL directivity for Strouhal number, $fD_e/U_j \approx 0.25$.

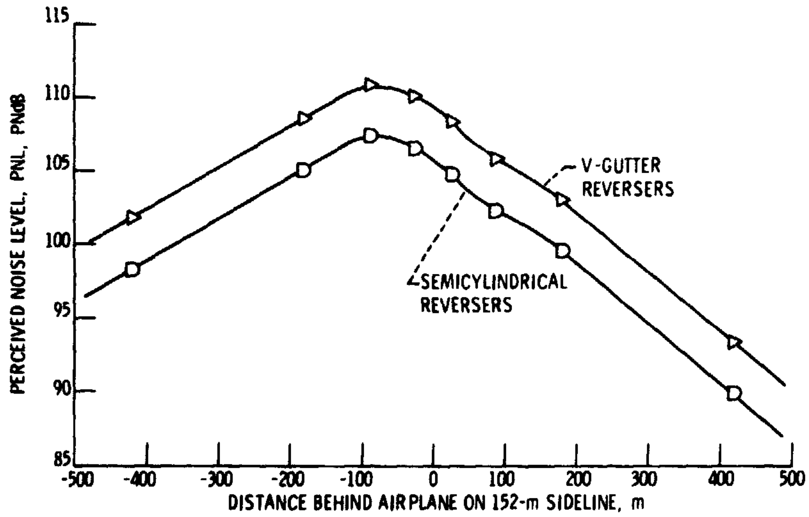


Figure 13. - Perceived noise level on 152-m sideline for thrust reversal on a hypothetical OTW powered-lift airplane; four 2-m equivalent-nozzle-diameter engines and 200-m/sec jet velocity.