# Over-the-Wing Target-Type Thrust Reverse Aeroacoustic Characteristics

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**A static test of a large-scale, over-the-wing (OTW) powered-lift model was performed. The OTW propulsion system had been modified to incorporate a simple target-type thrust reverser as well as the normal rectangular OTW exhaust nozzle. Tests were performed in both the reverse thrust and approach configurations. The thrust reverser noise created by jet turbulence mixing and the OTW approach noise were both low-frequency and broadband. When scaled to a 45,400-kg (100,000-lb) aircraft, the thrust reverser and approach configurations produced peak 152-m (500-ft) sideline perceived noise levels of 110 and 105 PNdB, respectively. The aerodynamic performance of the model showed that 50% or greater reverser effectiveness can be achieved without experiencing ingestion of exhaust gas or ground debris into the engine inlets.**

## Nomenclature

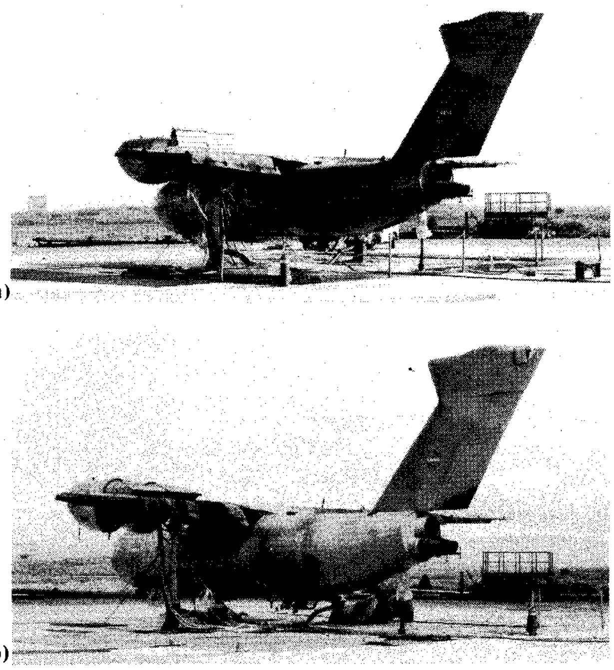
| | |
|---|---|
| $A_N$ | = nozzle area at primary nozzle exit plane, $m^2$ ($ft^2$) |
| $D_N$ | = nozzle diameter or equivalent nozzle diameter $= [4(A_N)/\pi]^{1/2}$, m(ft) |
| $f$ | = one-third octave band center frequency, Hz |
| mac | = mean aerodynamic chord, m(ft) |
| $N_f$ | = fan speed, percent of maximum rpm |
| OASPL | = overall sound pressure level, dB re 20 $\mu N/m^2$ |
| PNL | = perceived noise level, PNdB |
| $P_T$ | = exhaust gas total pressure, $N/m^2$ (psia) |
| $P_o$ | = ambient pressure, $N/m^2$(psia) |
| $S_n$ | = Strouhal number, $f(D_N)/V_J$ |
| SPL | = sound pressure level, dB re 20 $\mu N/m^2$ |
| $V_J$ | = isentropic jet velocity, m/sec (ft/sec) |
| $\theta$ | = microphone or acoustic angle reference to upstream, deg |
| $\delta_f$ | = flap deflection, deg |

## I. Introduction

THE takeoff and approach noise of commercial turbofan-powered transport aircraft is regulated by the federal government under FAR 36. Transport aircraft also operate in a reverse thrust mode of limit ground roll. Regulations for thrust reverser noise have been proposed and may be enacted in the future. It has been suggested that new criteria be established for the reverser noise because of its impact in the immediate vicinity of the airport rather than on the surrounding community. Whatever the criteria, to design a quiet, effective thrust reverser, the designer needs the capability of predicting and suppressing its noise. This necessitates a more complete understanding of the acoustic process than now exists.

This paper presents the results of an investigation of the acoustic and aerodynamic characteristics of an application of a target-type thrust reverser to a large-scale model of an over-the-wing (OTW) short-haul transport powered by JT15D-1 turbofan engines. The OTW concept has received attention as a possible candidate for a commercial short-haul transport because of its relatively simple and efficient design, in which the exhaust from high bypass-ratio turbofan engines blows over the wing surface. High-lift forces are realized by turning the exhaust flow with a wing trailing edge coanda flap, which also serves to shield the ground from the high-frequency aft fan and core engine noise.

The need for thrust reversers on short-haul STOL and CTOL aircraft is well established, including special constraints and requirements for powered lift concepts.[1] The OTW powered-lift concept lends itself to the integration of a simple target reverser system that would minimize ground debris and exhaust gas ingestion, aircraft surface overheating, and engine performance degradation. Several investigations of OTW target-type reverser models have been completed[2-5] using small-scale models blown by isolated high-pressure air systems. Although these tests did not precisely simulate an aircraft installation, they did establish thrust reversers as a potential source of noise. The present study is the first of an actual engine thrust reverser installation where both the noise and aerodynamics are reported.



a)

b)

**Fig. 1 Three-quarter rear view of installation of OTW model at the Ames Static Test Facility: a) thrust reverser configuration; b) OTW powered-lift configuration.**

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## II. Model Description

The thrust reverser investigation was conducted at the NASA Ames Static Test Facility using a large-scale, swept-wing OTW model mounted with the wing at a height of 1.5 wing chords to simulate ground roll (see Fig. 1). The model was powered by two JT15D-1 turbofan engines mounted on the left wing only to simplify installation and operation. The overall model geometric details are shown in Fig. 2.

The model was tested in both approach and reverse thrust configurations. The propulsion system details for the approach configuration are presented in Fig. 3. The engines were equipped with rectangular (aspect ratio = 5) exhaust nozzles that produced a maximum thrust of 8900 N (2000 lb) at a pressure ratio of approximately 1.4. The complete thrust and exhaust flow characteristics of this engine assembly were measured during an earlier experiment.[6] The exhaust from the rectangular nozzle was turned by a 70% span coanda flap deflected to 55°.

The target-type thrust reverser installation and geometric details are shown in Fig. 4. To simplify the experimental apparatus, the reversers were not designed as an integral part of the exhaust system, as would be the case in a production aircraft, but were fixed assembly that replaced the OTW exhaust system. Three lip geometries with various lengths and angles were tested.

## III. Tests

The aerodynamic tests were performed before the noise tests to assure adequate thrust reversal and the absence of adverse operational effects. The inboard nacelle was operated both alone and with the outboard nacelle to investigate interference effects. Static force and reverser inflow measurements were made for each reverser lip geometry over a fan speed range of 50-90% of maximum rpm. The force measurements were made with two-axis load cells mounted on each strut tip. The reverser inflow measurments were made with a pressure/temperature rake mounted at the reverser entrance. The inlet exhaust gas ingestion was monitored with thermocouples installed in each nacelle inlet (see Fig. 4a).

Upon completion of the force runs, the rakes were removed and the test runs repeated for noise measurements. These measurements were made with twelve 1.27 cm (0.5 in.) condenser microphones mounted on 1.83 m (6 ft) stands. The microphones were arranged in a 27.4 m (90 ft) radius semicircle centered between the nacelles.

Following the thrust reverser noise tests, the reverser assemblies were replaced by the OTW exhaust nozzle, and force and noise measurements were repeated at the same fan speeds. The pressure rake data showed the thrust reverser and OTW exhaust system to have the same total pressure ratio for a given fan speed.

Upon completion of the tests, the analog acoustic data were reduced to one-third octave band frequency specta. These data were corrected for recording system reponse and non-standard-day atmospheric conditions but not for ground reflections. Because fan noise interference was present at high frequencies, any acoustic energy above 5000 Hz was neglected in computing the OASPL from the corrected specta. PNL was computed by estimating the higher frequency noise from a constant slope extrapolation of the lower frequency data. The full-scale aircraft noise levels were computed assuming a 45,400-kg (100,000-lb) aircraft at a thrust-to-weight ratio of 0.3 for approach using the method described in Ref. 5.

## IV. Results and Discussion

### Aerodynamic Performance

The performance of a thrust reverser system is defined by its effectiveness; the ratio of reversed thrust to the engine forward thrust for the same power setting. Studies of short-haul stopping systems have shown a 50% effective reverser is necessary to stop the aircraft in adverse landing conditions.[1] Small-scale models achieved this level of performance without difficulty.[2,3] The question remained whether they could be applied to an actual turbofan installation without significantly effecting the engine functions.

| ITEM | WING |
|---|---|
| AREA | 21.37 m² (230 ft²) |
| ASPECT RATIO | 8.0 |
| TAPER RATIO | 0.30 |
| SPAN | 13.08 (42.9) |
| ROOT CHORD | 2.51 (8.25) |
| TIP CHORD | 0.75 (2.475) |
| MAC | 1.79 (5.881) |
| SWEEP (C/4) deg | 27.5 |
| AIRFOIL SECTION | 65A-42 |

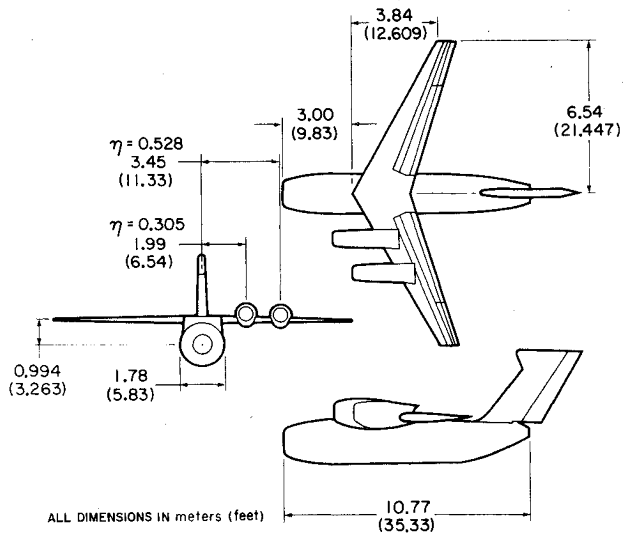


Fig. 2 General model arrangement for OTW/thrust reverser.

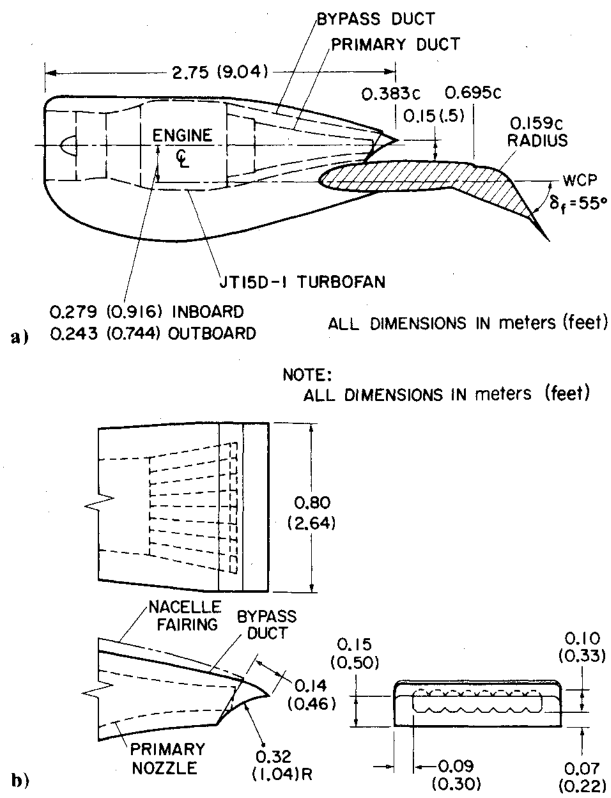


Fig. 3 OTW approach configuration geometric details: a) general arrangement-outboard nacelle; b) exhaust nozzle details.

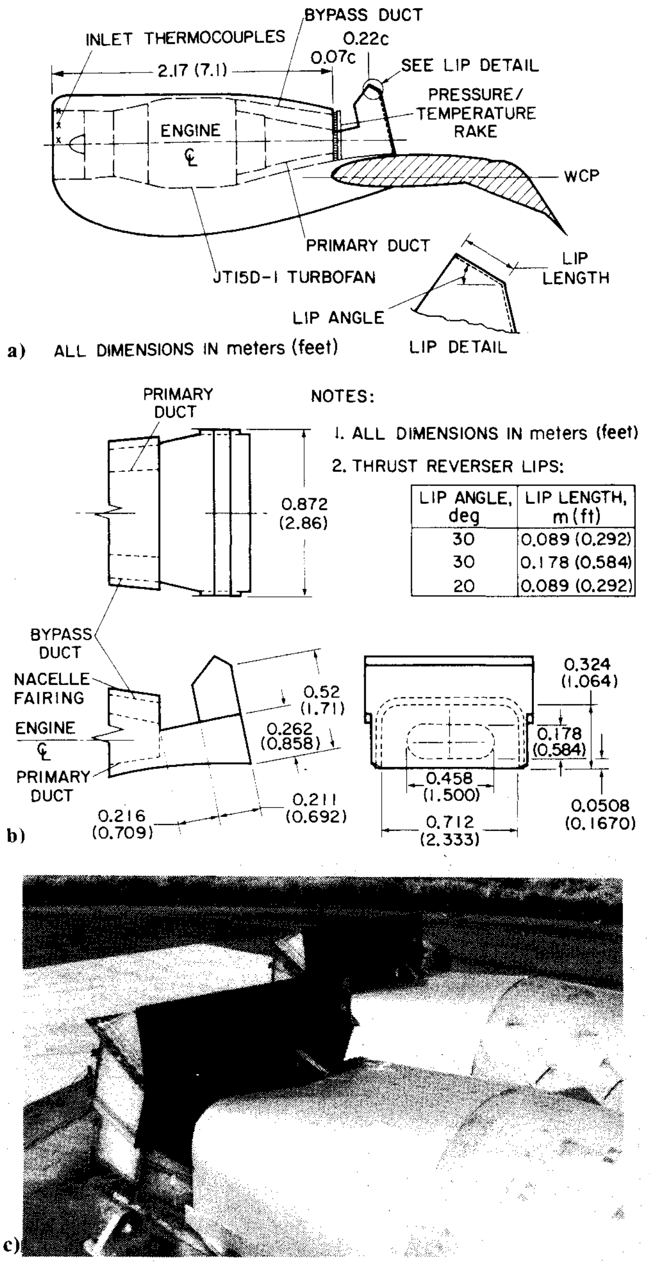


Fig. 4 Thrust reverser geometric details: a) reverser/model integration details; b) reverser assembly details; c) thrust reverser installation.

The static aerodynamic characteristics of the subject model as presented in Fig. 5 show that two reverser configurations (17.8 cm-30° and 8.9 cm-20°) produced an effectiveness of 50% or greater. The reverser efficiency (ratio of resultant force to engine forward thrust) indicates that even though the reversers were simple flat plate designs, the reversing process was accomplished with only a 10-15% loss in available thrust. It should also be noted from the performance data that the effectiveness was relatively insensitive to power setting.

The operation of thrust reversers on almost all existing aircraft is restriced to aircraft speeds above a certain minimum velocity. Below this velocity, the engines are subjected to inlet exhaust gas and/or ground debris ingestion. For the present model, it was thought the exhaust ingestion problem would be aggravated by the proximity and stagger of the nacelles.

In order to investigate this problem, thermocouples were installed in the inlets and smoke studies made of the exhaust plume. The thermocouples indicated no significant exhaust gas ingestion even at the highest pressure ratio with the most

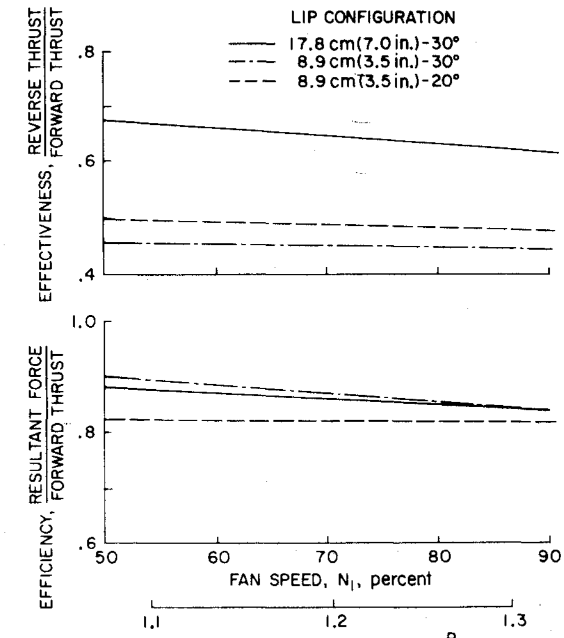


Fig. 5 Thrust reverser aerodynamic characteristics.

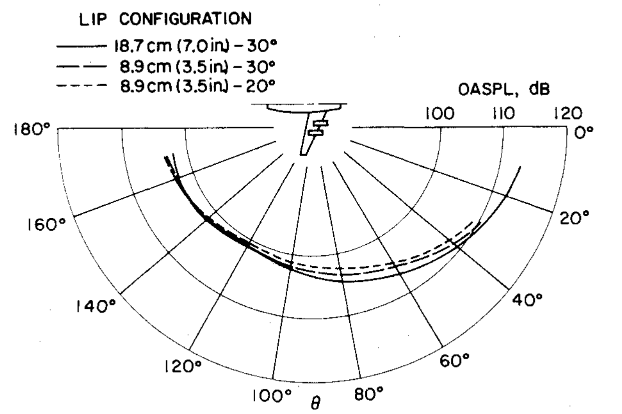


Fig. 6 Effect of lip configuration on acoustic directivity $P_T/P_o = 1.34$.

effective configuration. The plume smoke studies showed a compact flow path without excessive lateral spreading. A stagnation point was observed about half way between the inlet and thrust reverser on the nacelle's upper surface. These results demonstrate that a simple effective target-type thrust reverser can be incorporated into the OTW propulsion system, and not adversely alter the engine performance even under static conditions.

When the model was operated in the OTW approach configuration, the 55° coanda flap turned the exhaust flow 41° with an efficiency of 80%. This relatively poor turning performance can be attributed to the close ground proximity and the absence of flap BLC.

#### Thrust Reverser Acoustic Characteristics

In commercial applications of OTW to short-haul transport aircraft, the acoustic and aerodynamic performance are of equal concern because either could make the aircraft unacceptable. The acoustic performance of the model is presented in Figs. 6 and 7. The curves of OASPL directivity in Fig. 6 show that peak noise occurs in the forward quadrant and that changing reverser lip geometry, while significantly altering aerodynamic effectiveness, had little effect on noise. The most effective geometry for thrust reversal (17.8 cm-30°) was

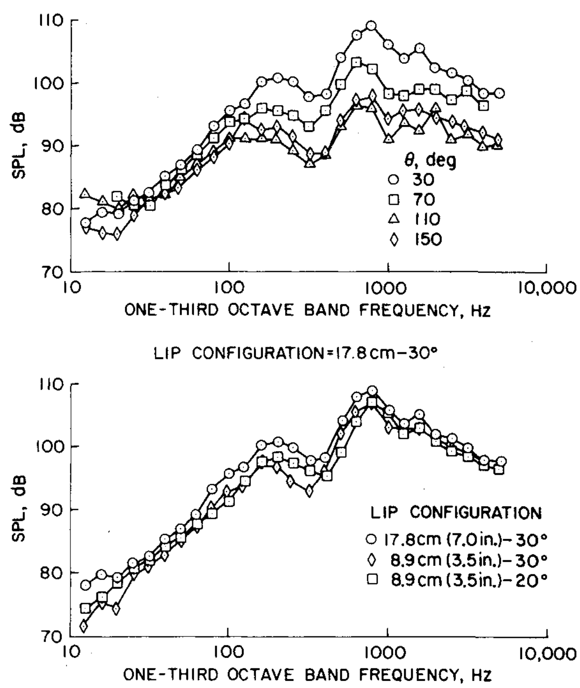


Fig. 7 Thrust reverser spectral characteristics, $P_T/P_o = 1.34$.

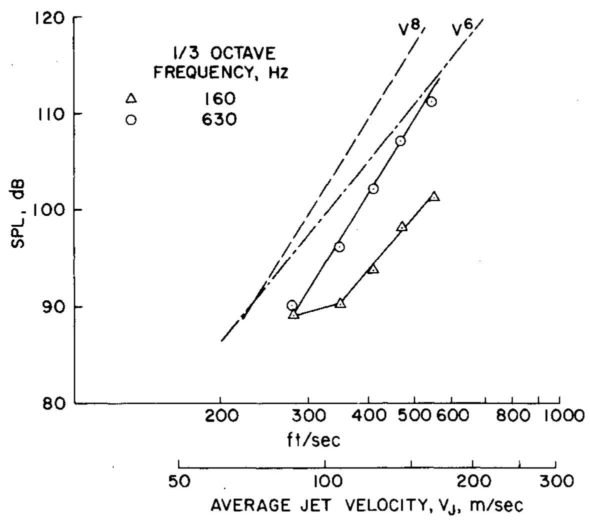


Fig. 8 Variation of thrust reverser noise with jet velocity, $\theta = 10°$, lip = 17.8 cm-30°.

the loudest, but the least effective (8.9 cm-30°) was not the quietest. The largest difference in OASPL was only 2 dB. Examination of the peak noise frequency spectra for the three reverser geometries (Fig. 7) shows them to have the same characteristic shape with a dominant spectral peak at $f = 800$ Hz and a secondary peak at $f = 200$ Hz. The reverser noise had this same characteristic form at all acoustic angles.

Some insight into the acoustic mechanisms involved in the generation of far-field noise can be gained by examining noise as a function of jet velocity. It has been shown in numerous studies that the peak noise of turbulent jet mixing varies with the eighth power of jet velocity, while noise created by the interaction of jet turbulence with surfaces and edges displays a fifth or sixth power dependence. Examination of the thrust-reverser noise variation as a function of inflow velocity shows both types of mechanism to be involved (Fig. 8). The 800-Hz peak noise that dominates the overall noise varies with the eighth power, whereas the 200-Hz secondary peak varies with the sixth power. The dominant reverser acoustic mechanism for this model is, therefore, probably the mixing of the exhaust with ambient air.

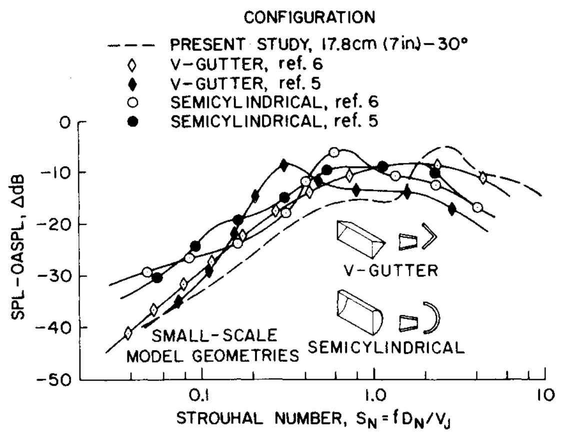


Fig. 9 Comparison of large- and small-scale model normalized peak noise spectra.

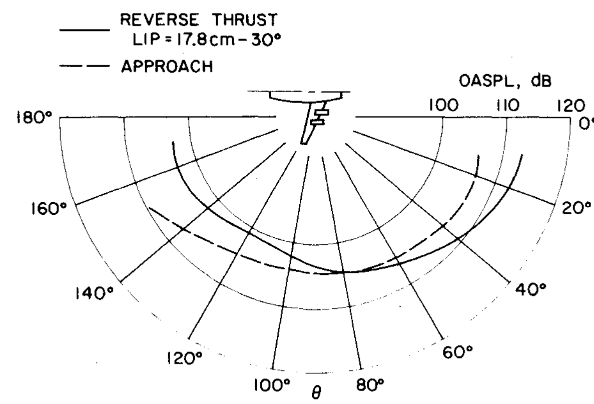


Fig. 10 Comparison of OASPL directivity for reverse thrust and approach configurations, $P_T/P_o = 1.26$.

### Comparison of the Noise of Large- and Small-Scale Models

Several acoustic investigations of OTW target-type thrust reversers have used small-scale models blown by high-pressure air from an isolated compressor system.[6,7] The principal difference between these small models and the present test configuration is that the presence of the wing in the large model prohibited any lower surface flow. To allow direct comparison of the noise results, the frequency spectra were normalized against OASPL and Strouhal Number. These normalized data are presented in Fig. 9 for the peak overall noise of each model. There are up to 10 dB differences between the results of the various models, although the general character of the curves are similar. The principal dissimilarities in the normalized spectra are the existence of and the frequency of a well-defined spectral peak. There is no apparent consistent trend even in the small-scale results. In one study, the V-gutter shows the peak, whereas, in the other, the semicylindrical reverser displays the peak. The present study data shows a peak but at a much higher Strouhal number than exhibited by the other models.

The small- and large-scale noise data also showed different variations with jet velocity. As discussed previously, the large-scale reverser noise varied with the eighth power of velocity. This was not the case for the small-scale model data, which displayed a sixth-power dependence. The noise generation mechanisms seem to be different, although examination of the test results does not seem to provide a cause of the different mechanisms. Closer simulation between the large- and small-scale experiments is apparently required for closer agreement in noise data.

### Comparison of Reverse Thrust and Approach Noise

The OTW powered-lift noise, which has been documented in numerous studies, is low frequency, broadband in

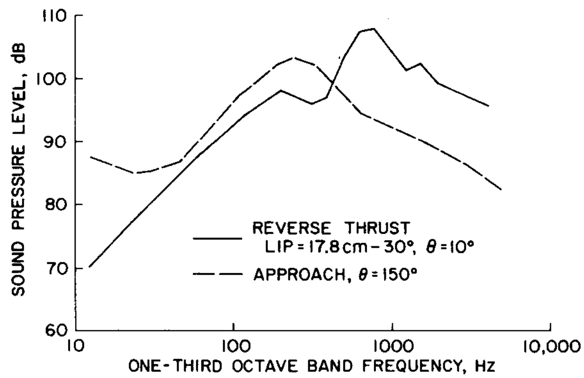


**Fig. 11 Comparison of noise spectra for reverse thrust and approach configurations, $P_T/P_o = 1.26$.**

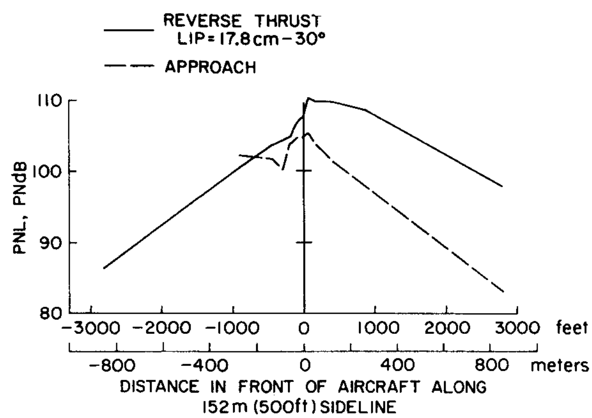


**Fig. 12 Sideline perceived noise level for a 45,400-kg (100,000-lb) aircraft, $P_T/P_o = 1.26$.**

character. The principal source of the noise originated from the interaction of the exhaust turbulence with the flap surface and edges. This can be modeled by an acousic dipole with the noise exhibiting a fifth- or sixth-power dependence on jet velocity. The approach noise of the subject model was measured for comparison with thrust reverser noise. The OASPL directivity patterns of the approach and thrust reverser configurations are compared in Fig. 10. The two geometries display opposite directivity patterns. The reverser peak noise occurs at low acoustic angles ($\theta \leq 30°$), whereas the approach peak occurs in the aft quadrant at high acoustic angles ($\theta \neq 150°$). To the direct sideline ($\theta = 90°$), the OASPL levels are similar. The frequency specta of the two configurations also display some significant differences (Fig. 11), with the thrust reverser peak noise being of higher frequency and the approach noise showing no secondary peak. Even though there are differences, both configurations are low-frequency, broadband noise sources. The dissimilarties probably result from the differences in flow path and source mechanisms.

**Full-Size Aircraft Noise**

In order to evaluate the impact of the thrust reverser noise, the model acoustic data were scaled to a 45,400-kg (100,00-lb) four-engine transport aircraft. The scaled data were projected along a 152-m (500-ft) sideline. The results of this scaling are presented in Fig. 12 for both the approach and reverse thrust configurations. The peak PNL is reached when the aircraft is closest to the observer, even though the peak OASPL does not occur at this location.[4,5] The OTW approach configuration peak PNL was 105 PNdB, whereas, the peak for the thrust reverser was 110 PNdB. Most probably, both configurations will require some type of noise suppression, and the different acoustic generation mechanisms involved will require different suppression techniques to be used.

## V. Concluding Remarks

This investigation has shown that a relatively simple target thrust reverser with an effectiveness of 50% or greater can be applied to the OTW propulsion system without adversely affecting the engine performance. For the model used in this investigation, reverser effectiveness of greater than 50% was measured under static conditions without experiencing any inlet exhaust gas or ground debris ingestion.

The thrust reversers generated low-frequency broadband noise which was not significantly affected by changes in target lip geometry. A comparison of the thrust reverser and approach configuration acoustic characteristic showed them to have opposite OASPL directivity patterns with the reverser peak noise occurring at low acoustic angles. The variation of their peak noise with jet velocity indicates that different acoustic generation mechanisms are involved. The approach mode noise was probably created by the interaction of the exhaust turbulence with the wing surfaces and edges, whereas the reverser noise probably resulted from the mixing of the exhaust turbulence and the ambient air. When scaled to a 45,400-kg (100,000-lb) aircraft, the reverse thrust and approach configurations produced peak 152-m (500-ft) sideline PNL of 110 and 105 PNdB, respectively. Both configurations will require significant suppression.

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