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16. Abstract

The results of a test program conducted in the NASA Ames 40- by 80-Foot Wind Tunnel to determine the effect of forward speed on the noise levels emanating from a conical ejector nozzle, a 32-spoke suppressor nozzle, and a 104-elliptical-tube suppressor nozzle are reported. It is shown that noise levels are reduced as forward speed is increased and that, for one suppressor configuration, forward speed enhances suppression. Comparisons of noise measurements made in the wind tunnel with those obtained in flight tests show good agreement. It is concluded that wind tunnels provide an effective means of measuring the effect of forward speed on aircraft noise.

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Abstract

The results of a test program conducted in the NASA Ames 40- by 80-Foot Wind Tunnel to determine the effect of forward speed on the noise levels emanating from a conical ejector nozzle, a 32-spoke suppressor nozzle, and a 104-elliptical-tube suppressor nozzle are reported. It is shown that noise levels are reduced as forward speed is increased and that, for one suppressor configuration, forward speed enhances suppression. Comparisons of noise measurements made in the wind tunnel with those obtained in flight tests show good agreement. It is concluded that wind tunnels provide an effective means of measuring the effect of forward speed on aircraft noise.

Nomenclature

Hz	cycles per second
OASPL	over all sound pressure level, dB
SPL	sound pressure level, dB
V_j	jet exit velocity, m/sec (ft/sec)
V_o	wind tunnel velocity, m/sec (ft/sec)
V_R	$V_j - V_o$, m/sec (ft/sec)
θ_I	acoustic angle measured from inlet axis

Introduction

Use of a wind tunnel facility to measure the effect of forward speed on aircraft noise offers several advantages over flight tests in terms of costs, test condition control, model configuration control, and data sample time. The staff of NASA Ames Research Center has used Ames 40- by 80-Foot Wind Tunnel to study such effects on propeller aircraft, large scale STOL models, and jet engines.[1-3] This paper summarizes a test program conducted in the 40- by 80-Foot Wind Tunnel to determine the effect of forward speed on noise from a conical ejector nozzle, a 32-spoke suppressor nozzle, and a 104-elliptical-tube suppressor nozzle with and without a treated ejector shroud. Wind tunnel data showing the effect of forward speed on noise for each nozzle are presented and comparisons of wind tunnel data with flight test data from NASA Lewis Research Center F106B fly-over tests[4] are shown for the conical ejector and the 104-elliptical-tube nozzles. Wind tunnel data corrections and flight test data corrections necessary to make comparisons are summarized.

Model Description and Test Setup

The suppressor nozzles and base line conical ejector nozzles were tested with a GE J 85 turbojet engine mounted in a flight nacelle identical to that used during the F106B flight tests at Lewis Research Center. The nacelle was mounted in two ways, first isolated as shown in Fig. 1 and then under the right wing of an aircraft research model as shown in Fig. 2. Both arrangements were used for studies on the static test stand and in the wind tunnel. The nozzles studied were the baseline conical ejector nozzle, a 32-spoke nozzle, and a 104-elliptical-tube nozzle with an acoustically treated shroud. The nozzles are shown in Figs. 3 through 5.

The static portion of the testing was done at the Ames Static Test Facility. The model was mounted on a test stand so that the centerline of the engine axis was 6.1 m (20 ft) above the ground surface. Microphones were placed to duplicate the wind tunnel positions and were also placed on a 30.5 m (100 ft) arc, referenced to the nozzle exit centerline, to make far-field measurements. The wind tunnel microphone positions were 1.8 m (6 ft) above the surface while the far-field microphone height was 6.1 m (20 ft). The microphone setup was similar for both of the nacelle mounting arrangements. Schematics of the microphone setup are shown in Fig. 6. The installation in the wind tunnel for both the isolated nacelle and nacelle mounted to the model was with the centerline of the nozzle exit 6.1 m (20 ft) above the tunnel floor. Figure 7 shows the isolated nacelle installed in the wind tunnel.

Data Acquisition and Corrections

Data from the static test facility were obtained for several jet velocities; wind tunnel noise measurements were obtained at several combinations of forward speed and jet velocity. The static tests provided data to establish: (1) near-field to far-field directivity difference for data measured in the wind tunnel and extrapolated to flight distances; (2) a comparison of data for the isolated nacelle and the nacelle under a wing; (3) far-field directivity for each nozzle; and (4) free-field data for wind tunnel microphone positions to determine the reverberation corrections for wind tunnel data.

The reverberation corrections[5,6] were established on a 1/3-octave band SPL spectrum basis by comparing the outdoor data (corrected for ground reflections) to similar spectrums measured in the wind tunnel at zero forward speed. The differences between the wind tunnel data and free-field outdoor data, at each 1/3-octave center frequency, were used as the reverberation corrections. It was found that the reverberation corrections established were independent of nozzle type and power setting of the engine. Additional details are given in Ref. 7.

Results

Static Tests

Figure 8 shows the noise measured at the static test facility at several microphone locations with the conical nozzle on the isolated nacelle. Data from the near-microphone positions were corrected

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for ground reflection and extrapolated to the far-field positions on the 30.5 m (100-ft) arc. Comparison of the data for different microphone locations indicates that for the close-in microphones there appears to be a shift in the directivity pattern when compared with far-field. However, for the maximum noise angle, the near-field and far-field sound pressure levels were in good agreement. Figure 9 compares the far-field directivity with the isolated nacelle to the directivity with the nacelle mounted under the wing of a model, as measured at the static test facility. There was a change in directivity in the far-field for each of the nozzles. The 32-spoke nozzle shows a slight increase in noise in the forward quadrant and little or no change in the aft quadrant when the engine is mounted on the model. The conical ejector nozzle showed an increase in forward quadrant noise of from 1 to 3 PNdB when the engine was mounted on the model, and a decrease of 1 to 2 PNdB for most of the aft quadrant noise. The effect observed for the 104-tube nozzle is that the model caused forward quadrant noise to increase 1 PNdB and the peak noise to decrease by 2 to 3 PNdB. This suggests that installation effects can alter the observed effectiveness of suppressors.

Wind Tunnel Tests

The effect of forward speed on noise was observed in the wind tunnel for the various nozzles studied. In general, the effect of forward speed, for a given jet velocity, was a reduction in noise with increasing forward speed. The effect for the conical nozzle was similar to that observed statically when the jet velocity was reduced by changing engine power. Figure 10 shows OASPL as a function of relative velocity ($V_j - V_o$) at the peak noise angle. The wind tunnel data for the conical nozzle at various forward speeds all fall on the static (zero forward speed) line; thus relative jet velocity adequately defines the variation of peak angle noise with forward speed for the conical nozzle. Similar data are shown for the 104-tube-mixer suppressor nozzle in Figs. 11 and 12. The figures show that as forward speed is increased the noise at the peak angle both with and without the acoustic shroud is reduced more than would be predicted by relative velocity alone. This is especially true for a tunnel speed of 91 m/sec (300 ft/sec). The reason for this excess attenuation is unknown. Also shown in Fig. 12 are the peak angle noise levels at zero wind tunnel speed for the conical ejector nozzle and for the 104-tube nozzle without the acoustic shroud. The figure shows that for the zero speed case, the noise from the 104-tube nozzle without the shroud is 4-5 dB higher over the range of relative velocities shown and that the conical ejector is from 9 dB to 16 dB higher in noise level than the 104-tube nozzle with the acoustic shroud.

The effect of forward speed on the directivity of the conical nozzle is shown in Fig. 13. There was a reduction in noise at all angles for increasing forward speed. The amount of reduction for each forward speed change, however, is different for different angles. Recently obtained data from fly over tests conducted in England[8,9] have shown a measured increase in noise in the forward quadrant angles (reference to inlet) and little or no change at 90°; these effects were not observed in the data presented here. However, as is shown in the next section, comparisons of wind tunnel data with F106B flight data show good agreement.

Figure 14 shows the relative velocity effect on a 1/3 octave spectrum basis for the nozzles tested. The effect in all cases is a reduction in the spectrum levels for increasing forward speed.

Flight Comparison

Wind tunnel data for the conical nozzle and for the 104-tube nozzle were compared with test data obtained in flight tests of an F106B aircraft. The comparison of flight data with wind tunnel data requires that both sets of data be free-field, that the same distance be used for the comparison, and that flight test data and wind tunnel data be compared at the noise angle at the time of noise emission. The flight data were reduced and the emission angle was accounted for by using retarded time. The emission angles in the wind tunnel were corrected for flow convection. The flight test data were corrected to free-field by first correcting for ground reflections using the procedures outlined in Ref. 10. These procedures are similar to those of Refs. 5 and 6 except for modifications to make the suppressor nozzle correction more realistic. The flight data were also corrected for Doppler shift and to standard day conditions (59°F and 70% relative humidity). The wind tunnel data were corrected to free-field by applying the reverberation corrections determined from the static tests and were then extrapolated to the flight measurement distances by using spherical attenuation and applying the near-field to far-field corrections established from the static tests. The wind tunnel data were also corrected for standard day atmospheric attenuation by using Ref. 11. Slight differences in relative velocity between fly-over data and wind tunnel data were accounted for by correcting the wind tunnel data to the same relative velocity as flight by using Figs. 10, 11, and 12. The actual corrections from this source were less than 1.5 dB.

The resulting comparisons of data are shown in Figs. 15 through 19. Two different nozzle comparisons are shown: a comparison of data for the conical ejector nozzle and a comparison of data for the 104-elliptical-tube nozzle, both with and without the treated ejector shroud. Figures 15, 16, and 17 show perceived noise level versus acoustic angle from the inlet. The flight data are from PNL time histories of fly-overs with the same relative velocities as the wind tunnel data. In Fig. 15, the comparison of data for the conical ejector nozzle shows that the data are within 2 PNdB except at the 150° position where the difference is 6 PNdB. Figure 16 shows the comparison for the 104-elliptical-tube nozzle without the acoustically treated shroud; the data agree within ±1.5 PNdB. The angles not shown for the 104-tube nozzle, but shown for the conical ejector nozzle, were influenced by the high background noise level of the tunnel and model supports at those angles. Figure 17 shows that the wind tunnel and flight data for the 104-elliptical-tube nozzle with the acoustically treated shroud agreed within ±2 PNdB.

Figures 18 and 19 show comparisons of flight data and wind tunnel data on a 1/3-octave spectrum basis. Figure 18 shows a comparison of spectral data for the conical ejector nozzle. The flight data are from Ref. 12, which included only peak noise angle 1/3-octave spectrums for the flight data. The actual correspondence of data from flight and wind tunnel tests is not exact but within 6° of acoustic angle. The wind tunnel data have been extrapolated to the flight distance and corrected for atmospheric attenuation, Doppler shift, and near-field to far-field difference. The difference in acoustic angle and large atmospheric attenuation corrections probably accounts for the difference in the spectrums at high frequencies.

Figure 19 shows 1/3-octave spectrum comparisons for the 104-elliptical-tube nozzle, both with and without the acoustic shroud. The flight data were supplied by Lewis Research Center and are within 3° of acoustic angle of the wind tunnel data. The wind tunnel data were extrapolated to the flight distance and corrections applied as before; there is good agreement over most of the spectrums. The disagreements in the lower frequencies are due primarily to the inexact corrections for reflections in both the wind tunnel and flight data. The reason for high frequency disagreement in the spectrums is not known. The agreement of the spectrums is considered good considering the magnitude and accuracy of the corrections applied to the data.

Conclusions

From the data presented in this paper, the following conclusions can be made:

1. The forward speed effect observed in the wind tunnel shows a decrease in noise level as forward speed is increased for the nozzles tested.
   a) Noise measured from the conical nozzle at the peak noise angle showed the classical relative velocity effect with a predictable attenuation with forward speed.
   b) For the 104-tube nozzle, with and without the acoustically treated shroud, the decrease in noise with increased forward speed at the peak noise angle is not predictable from the relative velocity; instead, at the higher forward speeds, more attenuation than would be predicted was observed.
2. Wind tunnel data compare favorably with flight test data when appropriate corrections are made to both sets of data.
3. Measurements made in the near-field, as required in the wind tunnel, of the jet noise source show some differences when compared to measurements made in the far-field for the same acoustic angle. These differences should be accounted for when comparing wind tunnel data to flight data.
4. The presence of the model changes the directivity of the noise source in the far-field as compared to the isolated nacelle. The directivity change varies with nozzle configurations.

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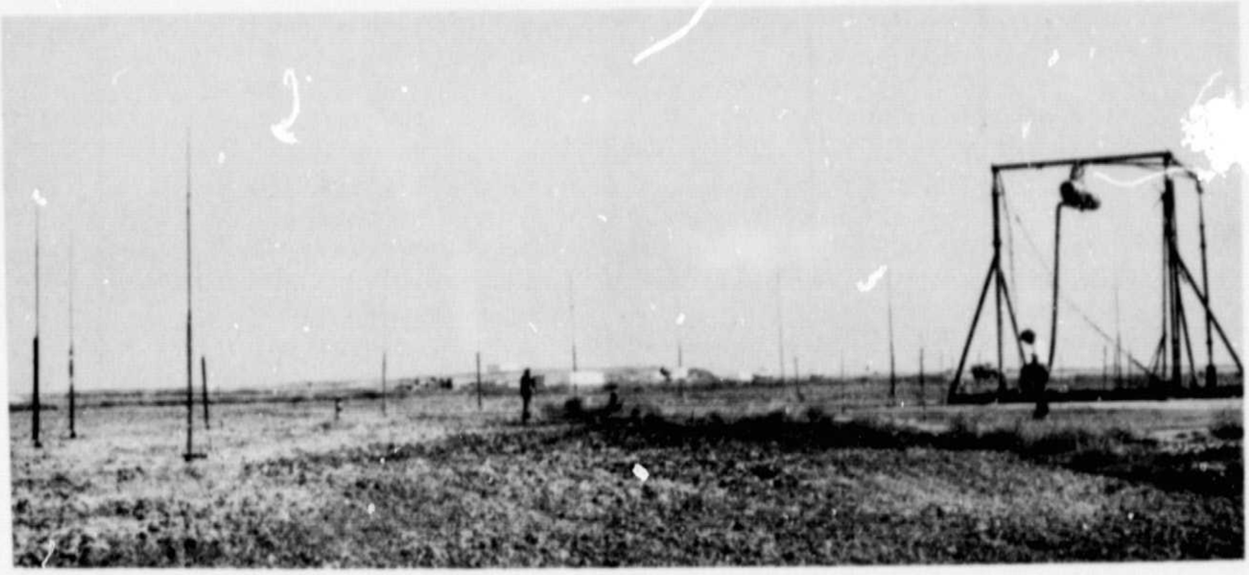


Fig. 1 Isolated nacelle — static test installation.

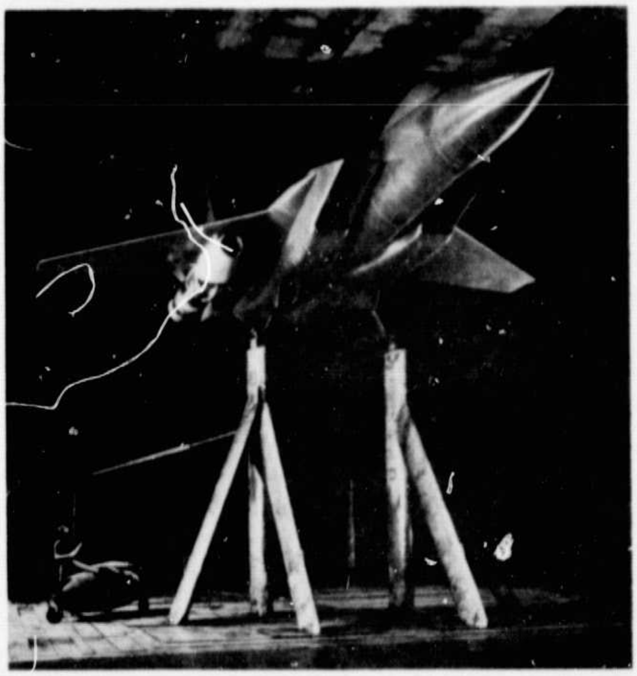
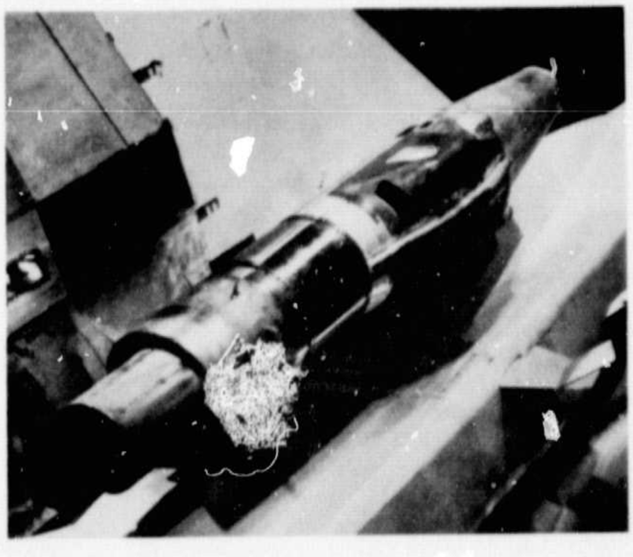


Fig. 2 Nacelle under wing installation in wind tunnel.



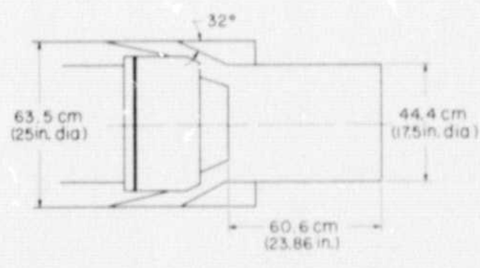


Fig. 3 Conical ejector nozzle.

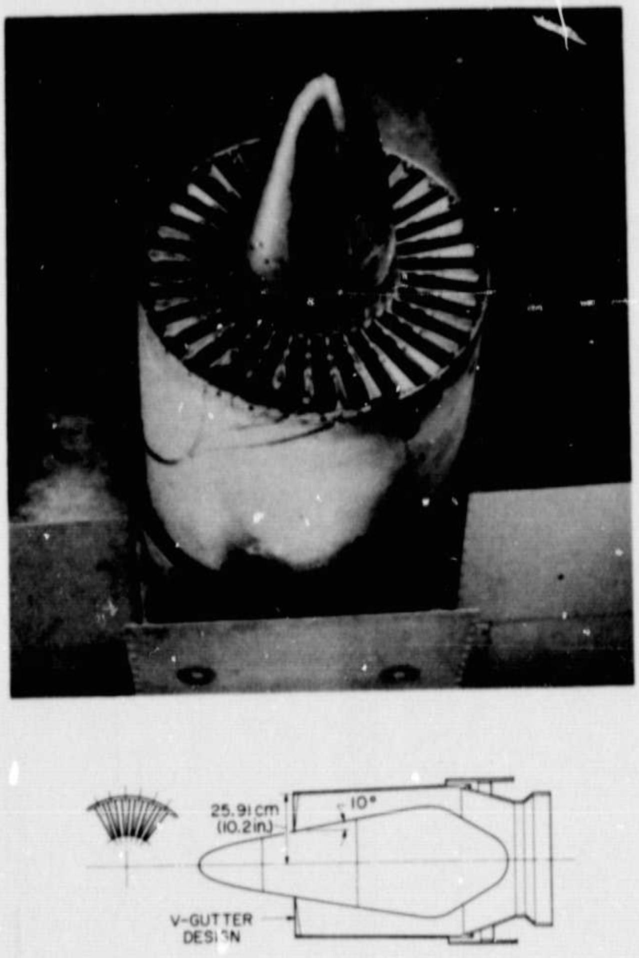


Fig. 4   32 spoke nozzle.

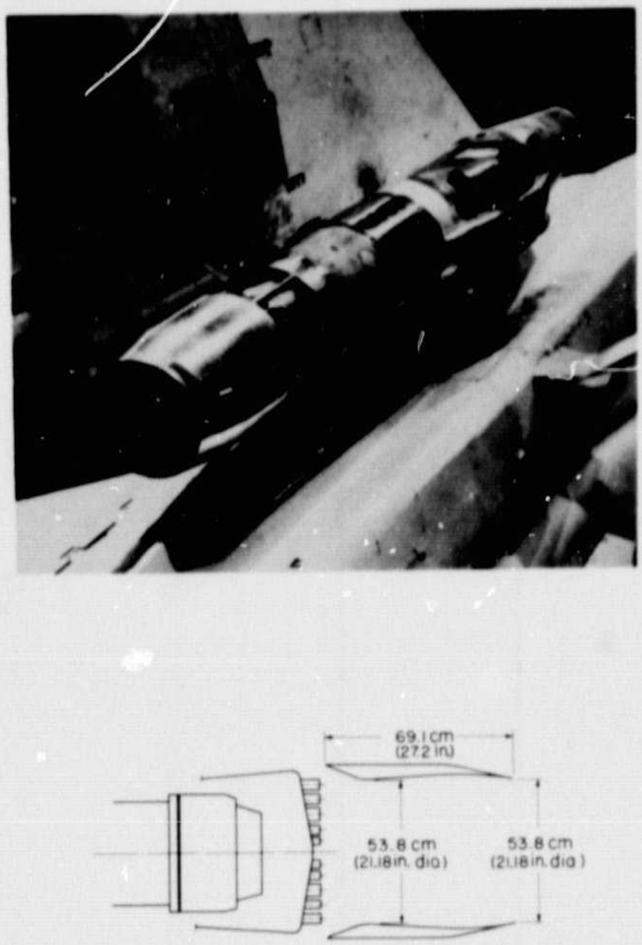


Fig. 5   104 elliptical tube nozzle with acoustically treated shroud.

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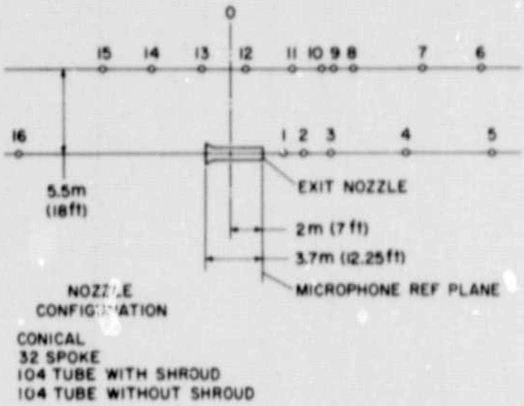


(a) Isolated nacelle microphone locations — wind tunnel set up.

Fig. 6 Microphone locations.

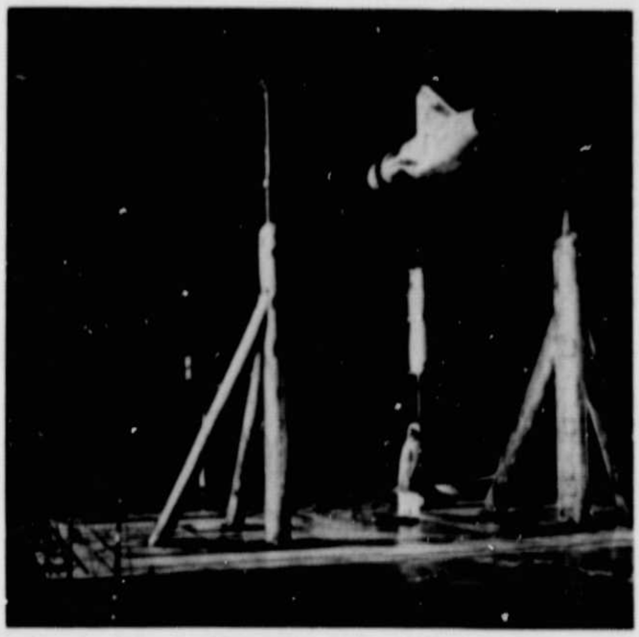
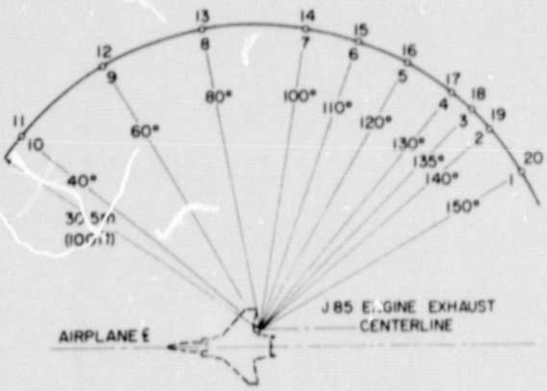


Fig. 7 Isolated nacelle in wind tunnel.



(b) Microphone positions on 30.5 m radius, arc.

Fig. 6 Continued.

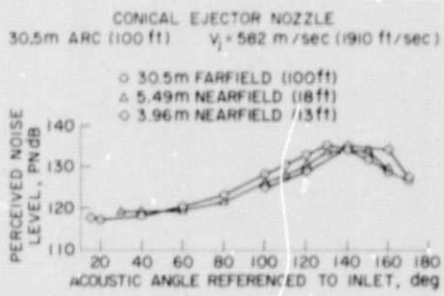
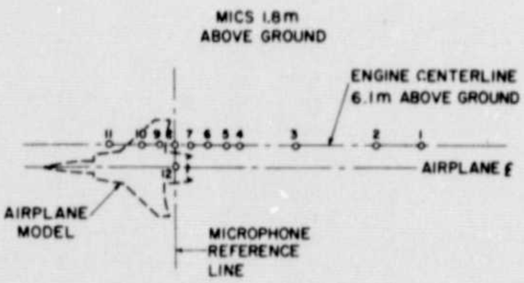


Fig. 8 Isolated nacelle outdoor static test far-field/near-field comparison, PNdB directivity, conical ejector nozzle.



(c) Microphone positions for wing and nacelle.

Fig. 6 Concluded.

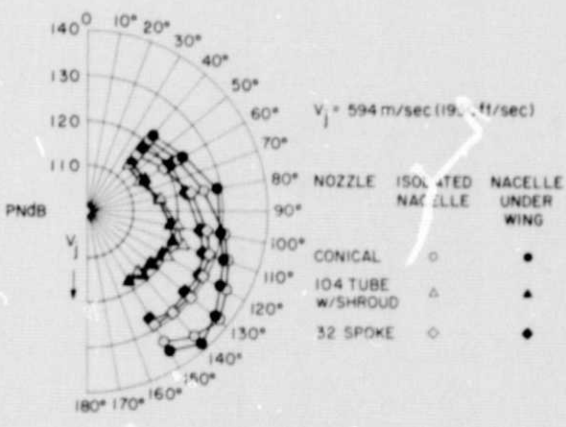


Fig. 9 Far-field directivity for isolated nacelle versus nacelle/wing installation.

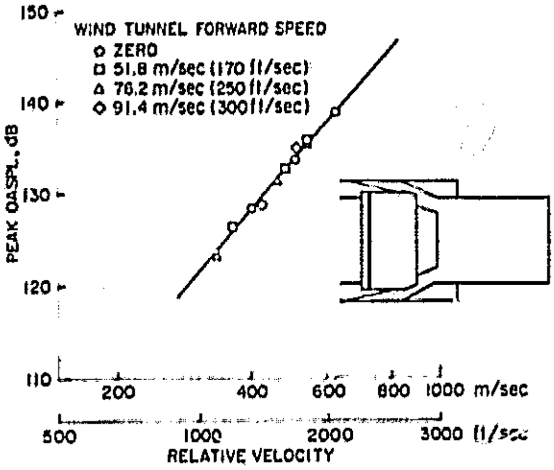


Fig. 10 Static data and wind tunnel forward speed data for conical ejector nozzle (peak noise).

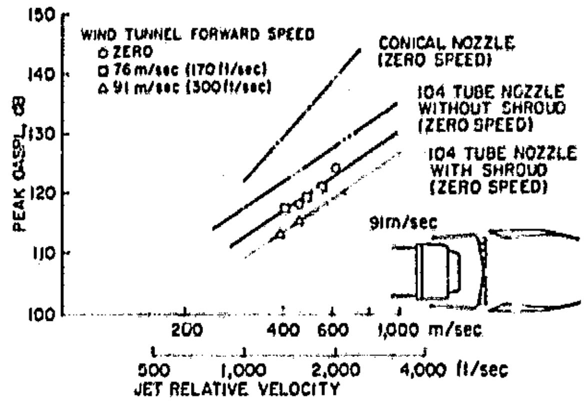


Fig. 12 Static data and wind tunnel forward speed data for the 104-tube nozzle with acoustic shroud (peak noise).

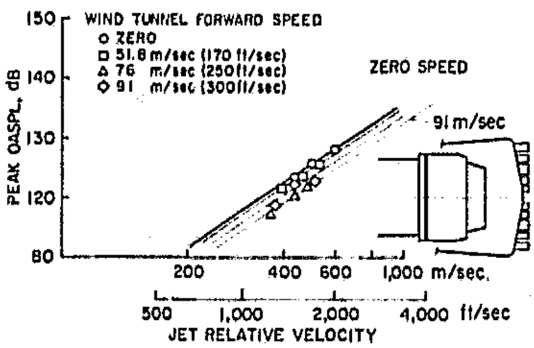


Fig. 11 Static data and wind tunnel forward speed data for the 104-tube nozzle without shroud (peak noise).

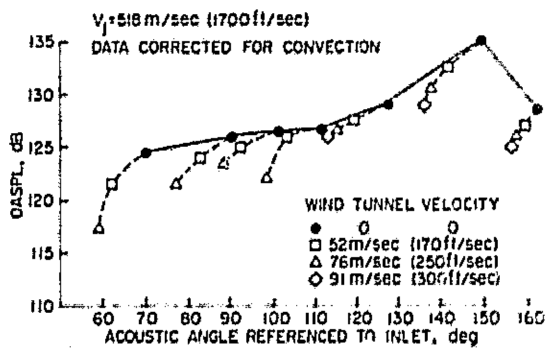
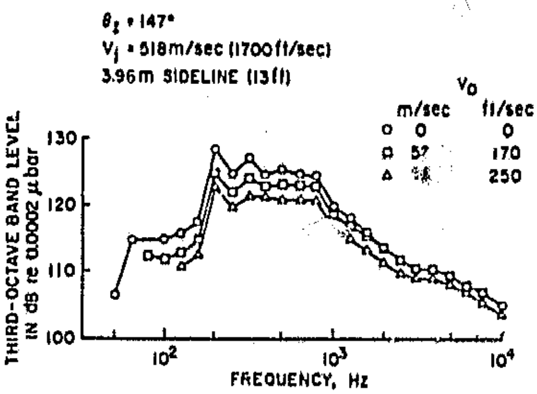


Fig. 13 Wing nacelle wind tunnel test, OASPL directivity, conical ejector nozzle.



(a) Conical ejector nozzle.

Fig. 14 Wing nacelle wind tunnel test, 1/3 octave band spectra.

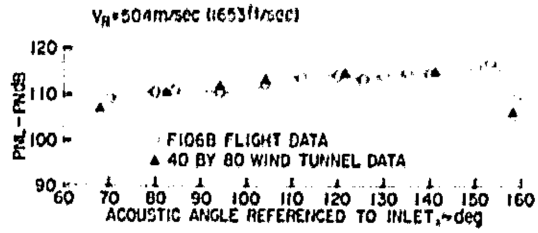
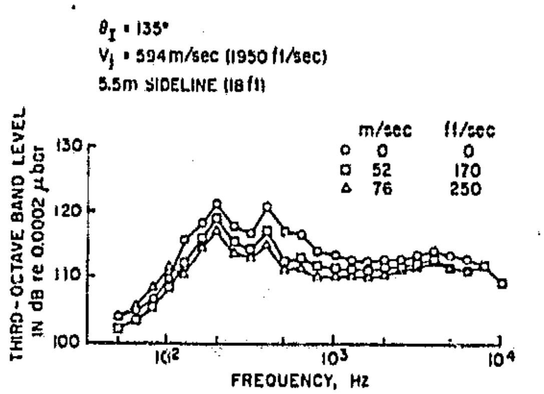


Fig. 15 Comparison of wind tunnel data with flight data for the conical ejector nozzle.



(b) 32-spoke area ratio nozzle.

Fig. 14 Continued.

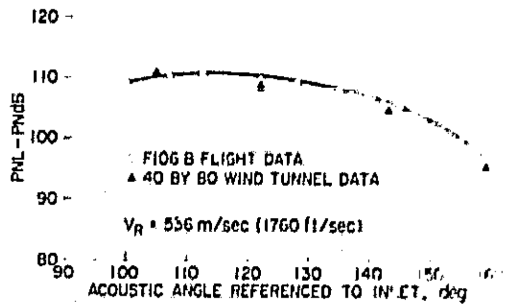
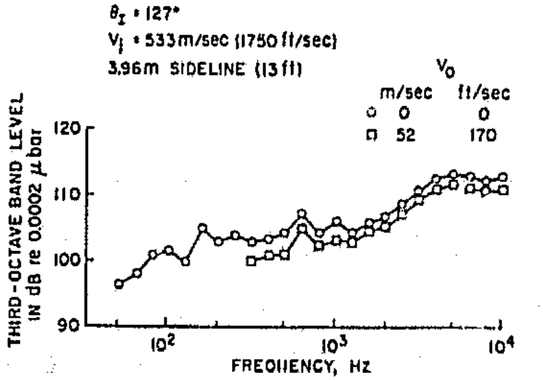


Fig. 16 Comparison of wind tunnel data with flight data for the 104-tube nozzle without acoustic shroud.



(c) 104-tube nozzle without shroud.

Fig. 14 Concluded.

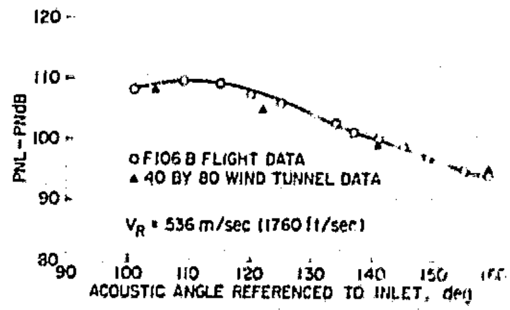


Fig. 17 Comparison of wind tunnel data with flight data for the 104-tube nozzle with acoustic shroud.

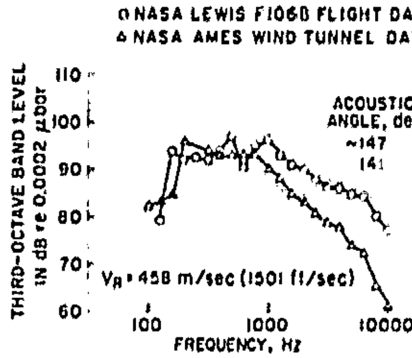
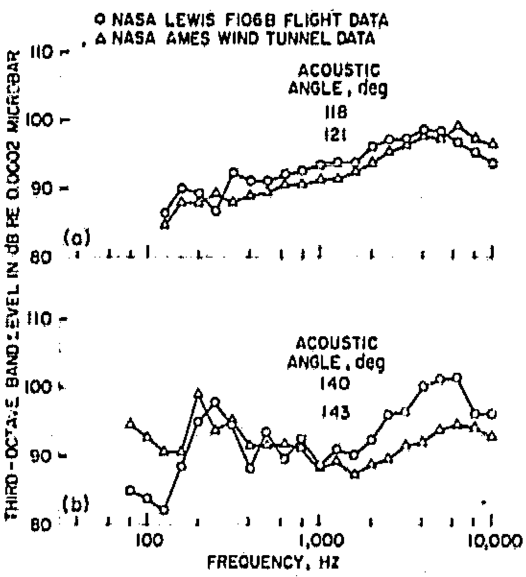


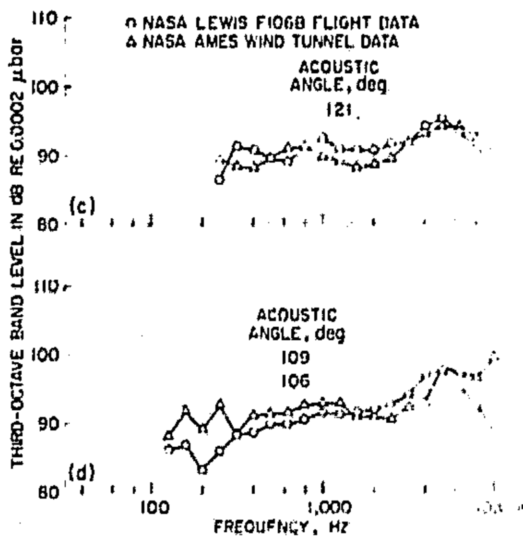
Fig. 18 Comparison of flight data with wind tunnel data, conical ejector nozzle, flight acoustic angle 147°, wind tunnel acoustic 141°.



(a) Without acoustic shroud, flight acoustic angle 118°, wind tunnel acoustic angle 121°.

(b) Without acoustic shroud, flight acoustic angle 140°, wind tunnel acoustic angle 143°.

Fig. 19 Comparison of flight test data with wind tunnel data, 104-elliptical-tube nozzle.



(c) With acoustic shroud, flight acoustic angle 109°, wind tunnel acoustic angle 121°.

(d) With acoustic shroud, flight acoustic angle 109°, wind tunnel acoustic angle 106°.

Fig. 19 Concluded.

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