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ACOUSTIC RESULTS OBTAINED WITH UPPER-SURFACE-BLOWING LIFT-AUGMENTATION SYSTEMS

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ABSTRACT

The noise caused by the interaction of the jet exhaust and a wing was measured under static conditions for several versions of a small-scale STOL engine-over-the-wing configuration. Three basic nozzles were used in the tests; a circular nozzle, a 5:1 aspect ratio slot nozzle and a 10:1 aspect ratio slot nozzle. Various flow attachment devices were included in the study. The wing included a flap that could be positioned for nominal takeoff or approach flap settings. Far field noise data are presented for the flyover mode. The data are discussed in terms of sound power and sound pressure spectra. Implications of extending the small-scale-model acoustic data to full-scale aircraft are discussed briefly and indicate a sizeable flyover noise attenuation may be achieved due to shielding by the wing.

INTRODUCTION

In order to provide high speed transportation to city centers and relieve congestion at existing airports, the use of STOL aircraft operating from short runways and producing small noise footprints has been proposed. Such aircraft require more thrust per pound of weight and lift augmentation. Both means can generate additional noise (refs. 1 to 4).

The conventional methods used to reduce aircraft propulsion noise are to lower the jet exhaust velocity (refs. 5 to 8) and acoustically treat the engine inlet and exhaust ducts. Additional noise reduction can be obtained by placing the engine over the wing (OTW) as shown in Fig. 1. The wing-flap system acts as an acoustic shield below the aircraft for the noise produced by the propulsion and lift augmentation (refs. 9 to 13).

This report summarizes the results of some of the initial acoustic studies of the engine-over-the-wing concept. The tests were conducted at the NASA Lewis Research Center with a small wing-section model of 32-cm chord with a single flap. Two flap positions were studied: (1) to simulate an approach condition, the geometric departure angle between the flap upper surface at the trailing edge and the airfoil chordline was 75°, and (2) to simulate a takeoff condition, the geometric departure angle between the flap upper surface at the trailing edge and airfoil chord line was 35°. The engine exhaust jet was simulated by a cold air jet from three nozzle types: a convergent circular nozzle (20.4 cm^2 area), a 5:1 aspect ratio slot nozzle (22.8 cm^2 area) and a 10:1 aspect ratio slot nozzle (13.5 cm^2 area).

In order to evaluate acoustic benefits associated with the engine-over-the-wing concept, the measured noise data, discussed later herein, are compared with the noise of the nozzle alone. Both sound power spectra and sound pressure spectra are presented. The latter data are presented for angular positions that are located nearly under the wing at the takeoff and approach attitude (100° and 80° from the engine inlet respectively) and therefore are of particular interest to shielding the community from noise.

BACKGROUND

The engine-over-the-wing concept (also referred to as upper surface blowing) makes use of the Coanda effect (refs. 14 and 15) to cause the exhaust jet to attach to the upper surface of the wing and large-chord trailing-edge flap (fig. 1). The jet, when attached, follows the curvature of the upper surface thereby turning and causing an increase in the circulation and lift associated with the airfoil. In addition, because the jet is turned, a vertical lift component is obtained.

Experience has shown that the thin exhaust jet from high aspect ratio slot nozzles can remain attached to surfaces having large turning angles.

The exhaust jets of short aspect ratio slot nozzles and circular nozzles usually require additional mechanical devices to form thin exhaust sheets as well as to promote and maintain jet attachment for large turning angles. With slot nozzles, boundary-layer blowing at the leading edge or knee of the deflected flap (ref. 15) can also promote flow attachment. Mechanical devices to aid jet flow attachment include retractable deflectors mounted on top of the engine nacelle, sideplates to provide a channel over the wing surface for the exhaust jet and finally the use of canted or rotatable exhaust slot nozzles. This latter concept generally requires mounting the engines somewhat farther above the wing in order to avoid back-pressuring of the engine by the jet impingement on the wing surface.

NOISE SOURCES

The noise characteristics associated with the engine-over-the-wing concept depend on which of the several noise sources predominate. In Fig. 2 the various noise sources for the concept are shown schematically. As expected, one of the main sources is the engine-alone noise made up primarily of high frequency internal noise from the turbomachinery and jet exhaust mixing noise. A second significant high frequency noise source is the deflector, when used, that contributes jet-deflector interaction noise similar to that observed in under-the-wing blown flap studies (refs. 9 to 12). A third noise source, generating low frequency noise, is the scrubbing noise caused by the jet flow over the upper surfaces of the wing-flap system. The final noise source, also low frequency, is that associated with the exhaust jet flow over the trailing edge of the flap. In the event that a multiple flap system with open slots between flaps were used, additional flap leading and trailing edge noise sources and noise leakage through the slots would have to be included (refs. 9 and 10). For most STOL engine-over-the-wing concepts, however, a plain flap is used to promote jet flow attachment and reduce the weight of the flap and its operating mechanisms.

APPARATUS AND PROCEDURE

Aerodynamic Test Stand

Aerodynamic data consisting of lift and thrust components were obtained using the test stand shown in Fig. 3. In this rig (ref. 8) pressurized air at about 289 K was supplied to 15.25-cm diameter plenum by twin diametrically opposed supply lines. Flexible couplings in each of the twin supply lines isolate the supply system from a force measuring system. The plenum is free to move axially through an overhead cable suspension system. The test nozzles were attached to a flange at the downstream end of the plenum. A load cell at the upstream end of the plenum is used to measure thrust. A second load cell near the nozzle is mounted to measure horizontal side loads. The wing-flap section was mounted in a vertical plane so that lift forces were measured by this side-mounted load cell. Thrust and lift forces were obtained at nominal nozzle pressure ratios of 1.25, 1.4, and 1.7 which yielded nominal jet velocities of 180, 225 and 280 m/sec, respectively.

Airflow through the overhead supply line was measured with a calibrated orifice. The nozzle inlet total pressure was measured with a single probe near the plenum exit flange. Pressure data were recorded from suitable multitube manometers.

Acoustic Test Stand

The acoustic test stand used in these studies is shown in Fig. 4 and consisted of a flow control valve, perforated plate, a four chamber baffled muffler, 10 cm diameter inlet pipe and finally the test model. The mufflers removed sufficient internal noise so that it was not significant in the measured noise levels.

Pressurized air was supplied at a temperature of about 278 K. Data were obtained at nominal jet velocities within a range of 180 to 280 m/sec (nominal pressure ratios of 1.25 to 1.7, respectively).

Sound data were taken with 1.27-cm condenser microphones placed on a 3.05 m radius centered at the nozzle exit. The microphone horizontal plane and jet centerline were located 1.5 m above the ground. The sound data were analyzed by a 1/3 octave band spectrum analyzer. The analyzer determined sound pressure level (SPL) spectra referenced to 2×10^{-5} N/m^2 (0.0002 microbar). Overall sound pressure levels (OASPL) were computed from the SPL data. The noise was measured with the wing-flap system making a 90^o angle with the microphone plane, which was horizontal (fig. 4).

Herein, no corrections are made in the SPL data for ground reflections. Most of the cancellations and reinforcements in the data occur at lower frequencies than the peak noise and are not pertinent to the present discussion or to scaling the data to a full-sized aircraft.

Models

Details of the basic wing and flap system (32-cm chord) are given in Ref. 4. For the present study, however, the slots on the multiflap system of Ref. 4 were covered with either tape or a curved metal sheet thereby simulating a single plain flap.

Two flap positions were tested: (1) to simulate an approach condition, the geometric turning angle between the flap upper surface at the trailing edge and the airfoil chordline was 75^o and (2) to simulate a takeoff condition, the geometric turning angle was 35^o. These angles were equivalent to 60^o and 20^o, respectively, for the standard airfoil chord line reference system used to measure flap deflection angles in Ref. 4.

Three nozzles were used in these studies; a circular nozzle with a nominal 5.1-cm diameter (20.4 cm^2 area), a 5:1 aspect ratio slot nozzle (22.8 cm^2 area) and a 10:1 aspect ratio slot nozzle (13.5 cm^2 area).

In order to promote flow attachment on the upper surfaces of the wing-flap system, several mechanical devices were used. These include canted nozzles, deflectors, and sideplates. Schematic sketches are shown in Fig. 5. A close up of a typical configuration using a circular nozzle with deflector in place over the wing is shown in Fig. 6. All tests except those with canted nozzles were conducted with the wing at a 5° angle of attack with respect to the nozzle centerline (refs. 9 and 10). When the sideplates were used, a 12.7-cm flow channel was formed extending from the wing leading edge to the trailing edge of the flap.

Data Normalization

In order to provide data comparisons between the three nozzles used, a data normalization procedure was established. All geometric dimensions herein were scaled to that for the circular-nozzle-wing configuration. Since the 5:1 slot nozzle had an exhaust area only slightly larger than that for the circular nozzle, the effect on the acoustic parameters amounted to less than 1/4-dB. For the 10:1 slot nozzle, the area was sufficiently smaller than that of the circular nozzle so that data adjustments were required in order to obtain normalization with that for the circular nozzle. The adjustment consisted of a 2-dB increase in the SPL and PWL' values for the 10:1 slot nozzle-alone data while the frequencies were reduced by one 1/3-octave band (a factor of 1.26 for Strouhal scaling). A further correction was made to the 10:1 slot nozzle-wing configurations in order to obtain the correct scaling of the wing chord with respect to the normalized nozzle area. Based on unpublished NASA data in which the effect of increasing the airfoil chord relative to a fixed nozzle size was evaluated, measured noise data for the 10:1 slot nozzle-wing configurations, when scaled to the circular nozzle configuration, required a two 1/3-octave band shift of the data toward higher frequency bands together with a 2-dB increase in SPL values below the wing and a 1-dB increase in PWL' values. Finally, the acoustic parameters were normalized to an ambient air temperature of 298 K.

RESULTS AND DISCUSSION

Aerodynamic

The results of jet turning angle and turning efficiency for the nozzle-wing configurations for which acoustic data were obtained are shown in

Fig. 7 (ref. 12). The data are presented in terms of the ratio of the normal force (nominal lift) to total thrust, F_N/T, plotted as a function of net axial force to thrust, F_A/T. Such a plot yields both jet turning angle and turning efficiency.

At the takeoff condition (fig. 7(a)) with an upper surface turning angle of 35^o, all the slot nozzles were reasonably good aerodynamically with turning efficiencies of 86- to 95 percent and effective turning angles of 28^o to 32^o. The circular nozzle with deflector showed a somewhat lower turning efficiency (75 percent), however, it is believed that its efficiency can be improved substantially with minor changes in the deflector geometry (such as deflector angle and location of the deflector from the jet exhaust plane).

At the approach condition (fig. 7(b)), the effective upper surface turning angle of 75^o was not achieved by the nozzles tested. The largest turning angle obtained was about 60^o with the circular nozzle with deflector. This was accompanied by a 69-percent turning efficiency. The 10:1 slot nozzle without any flow attachment device achieved a turning angle of about 40^o with a turning efficiency of about 83 percent.

Although no acoustic data are yet available, aerodynamic tests of other slot nozzle configurations with sideplates or canted nozzles have achieved turning angles up to 60^o with turning efficiencies between 80- and 90-percent. Improvements in both turning efficiency and angle can also be achieved by boundary-layer blowing at the leading edge or knee of the flap (ref. 15).

Acoustic Shielding by Wing With Unattached Flow

The wing-flap system with the engine-over-the-wing concept acts as an acoustic shield between the jet exhaust noise and an observer on the ground below the aircraft. When the jet exhaust flow is not significantly attached to the wing surface, as in the case of a circular nozzle, the sound power spectrum is substantially that of the exhaust jet or nozzle-alone case. No significant additional sound power is generated by the wing since the surface is not scrubbed by the jet flow and there is no wake noise at the flap trailing edge.

The directivity and local magnitude of the sound pressure level, however, is affected by the proximity of the wing to the nozzle jet flow. Above the wing the SPL values are increased, while below the wing the SPL values at certain frequencies are reduced due to the acoustic shielding provided by the wing. A typical sound pressure level spectrum for essentially unattached flow with a circular nozzle and a wing is shown in Fig. 8 at the 100^{o} angular position below the wing. Also shown, for comparison, is the spectrum for the nozzle-alone. Because of the proximity of the circular nozzle to the wing surface, a small amount of scrubbing and wake noise occurs; however, the flow was not significantly turned by the wing (δ_f, 35^{o}). It is apparent that the decrease in SPL caused by the acoustic shielding is significant in the middle and high frequency bands. The SPL values at these frequencies are of prime importance when scaling model data to full scale aircraft because they are shifted to frequency bands that are heavily weighted in the calculation of perceived noise levels.

The reduction in SPL shown is the maximum that can be achieved for the configuration shown because, as will be discussed later, flow turning by attachment to the surfaces causes an increase in sound power. This results in a decrease net shielding by the wing-flap system with reference to the nozzle-alone noise.

Acoustic Results With Attached Flow

Sound Power Level

Sound power spectral plots are shown in Fig. 9 for typical engine-over-the-wing configurations with and without a jet flow deflector (circular nozzle and 10:1 slot nozzle, respectively). The sound power level plotted is that obtained from acoustic measurements in the flyover plane. Because tests have indicated only a small azimuthal variation in noise, the sound power levels shown approximate the true power spectra. The sound power spectra are independent of any noise intensity reduction caused by shielding or reflection; consequently, they represent total noise generation.

In Fig. 9(a), typical sound power spectra for a configuration with a deflector are shown. These spectral plots shown are for the basic circular nozzle, the nozzle with deflector and finally the nozzle with deflector and wing. It is apparent that the interaction between the jet and the deflector causes a large increase in noise. This increase in noise is similar to that associated with lower surface blowing on a flap (refs. 4 and 11). The addition of the wing causes another increase in noise but only at lower frequencies. This latter increase in noise appears to be caused primarily by two factors: (1) the scrubbing of the attached jet flow over the wing surface and (2) the flap trailing edge noise caused by the jet wake.

A typical sound power spectral plot for the 10:1 slot nozzle with and without a wing is shown in Fig. 9(b). It is apparent that the increase in noise level with the wing in place occurs primarily at low and middle frequencies. This increase in noise is again attributed to the jet flow scrubbing over the wing surface and the jet wake flow at the flap trailing edge. It should be emphasized that the presence of the wing contributes substantially no increase in sound power level at high frequencies. This can become significant when small-scale data are scaled to full-sized aircraft.

Sound power spectra. - The sound power spectra for the circular nozzle configurations are shown in Fig. 10. It is apparent that the complete configuration, consisting of the nozzle, deflector and wing-flap system, has an overall broadband increase in sound power level of about 10 dB over that for the nozzle-alone noise level. This increase appears to be independent of flow turning angle for both the approach and takeoff flap positions.

The nominal sound power spectra for the slot nozzle configurations are shown in Fig. 11 for the takeoff flap position. The data indicate that for slot nozzles the power spectra are substantially independent of the means used to promote flow attachment to the wing-flap system. The power spectra for the 10:1 slot nozzle without any flow attachment device was only slightly lower (1 to 2 dB) than that with an attachment device, such as sideplates, or with a canted nozzle.

Only limited data are available for slot-nozzles in the approach flap position. In Fig. 12 the power spectra for the 10:1 slot nozzle are shown for this flap position and a jet exhaust velocity of 180 m/sec. No flow attachment device was used. These data indicate, when compared to the data at the takeoff flap position and at the same jet exhaust velocity, that the sound power spectra for slot nozzles are not very sensitive to flap position for the angular settings shown.

Effect of jet velocity on scrubbing noise. - The increase in noise caused by the scrubbing of the attached flow over the wing surface and by the wake at the flap trailing edge was illustrated by the cross-hatched region in Fig. 9. The magnitude of this increase in power spectra, $PWL'_C - PWL'_N$, is shown in Fig. 13 for two jet velocities as a function of the frequency. It is apparent that the largest increase in noise (over that of the nozzle-alone) caused by the wing occurs at the lower velocity. It is also evident that, for slot nozzle configurations (fig. 13(b) and (c)), the increase in sound power caused by the scrubbing and wake noise sources extends over a wider frequency range than that for the circular nozzle configuration (fig. 13(a)). For the 10:1 slot nozzle configuration the effect of jet velocity on sound power increase is very slight compared with the other configurations.

At the approach flap position for the circular nozzle configuration (fig. 13(d)), a much greater effect of jet velocity on noise level and frequency range was measured than that for the takeoff flap position (fig. 13(a)). Further basic studies are needed to explain fully the trends shown by the data in Fig. 13.

Sound Pressure Level

For STOL aircraft the lift-augmentation noise generated below the wing (between 70^o and 120^o measured from the engine inlet) is of most interest for community noise considerations. Herein, only the sound pressure level spectra at 80^o (approach) and 100^o (takeoff) will be considered; the other angular positions in the indicated range of interest yielding somewhat similar trends and noise orders of magnitude.

Initially, the sound pressure level data are normalized, as a function of frequency, by using the parameter $SPL-OASPL_N$. In terms of this parameter, subsonic jet exhaust noise can be scaled by the use of the Strouhal relationship (product of frequency and characteristic jet dimension divided by jet exhaust velocity). The nozzle-alone acoustic data are correlated to a single curve as shown in Fig. 14. When a wing shields the jet exhaust noise, the shielded portion of the sound pressure level spectrum (fig. 14) when referenced to the $OASPL_N$ of the nozzle, is also correlated.

However, that portion of the spectrum in which the nozzle plus wing noise is greater than the nozzle-alone noise is not correlated by the $SPL-OASPL_N$ parameter (fig. 14). In this unshielded region, the noise due to scrubbing and the wake is the dominant noise source; consequently, correlation in terms of the jet noise characteristics is no longer obtained. In the unshielded noise region Strouhal scaling can be obtained by using the configuration OASPL in place of the $OASPL_N$ in the sound pressure level parameter.

The present study is directed toward the shielding of the jet noise. Therefore, the sound pressure level data herein will be related to the nozzle-alone acoustic values. Because acoustic scaling in terms of the parameters just discussed is possible for the region of interest, the data are presented generally at only one jet exhaust velocity (225 m/sec) and in terms of frequency since only one size of each nozzle-wing configuration was included in the study. In order to permit acoustic scaling, values of $OASPL_N$ are given in table I. Finally, the changes in sound pressure level due to shielding, $SPL-SPL_N$, are examined and related to the components of specific configurations.

<u>Normalized sound pressure level spectra</u>. - The normalized sound pressure level spectra for the circular nozzle configuration are shown in Fig. 15 for the takeoff flap position and an angular position of 100° measured from the inlet. In Fig. 15(a) the normalized sound pressure level spectrum for the nozzle with deflector is compared with that for the nozzle-alone. It is apparent that the data follow a trend similar to the PWL data (fig. 10) in that the noise increase due to the deflector is greatest at the higher frequencies and amounts to about 10 dB.

The normalized sound pressure levels with a wing included are shown in Fig. 15(b) for the takeoff flap position. It is immediately evident that at frequencies above 2500 Hz, shielding of the deflector noise occurs. At the frequencies of greatest interest for full scale aircraft (10 kHz and up), the noise of the deflector is completely shielded. Furthermore, the nozzle jet noise is also shielded in this frequency range, by nearly 2 dB at 20 kHz. At frequencies less than about 2500 Hz, the normalized sound pressure level is greater than that obtained for the nozzle with the deflector. Normally these noise levels in the lower frequency bands are not particularly important for full-sized aircraft effective perceived noise level considerations; however, for OTW configurations, the noise at low frequencies can be important because of the very large increase in sound pressure level (up to 20 dB) over the nozzle SPL values caused by the scrubbing and wake noise. The increase in low frequency noise levels is also very important from structural vibration and material fatigue considerations.

The normalized sound pressure level data for the two slot nozzles are shown in Fig. 16 as a function of frequency for the takeoff flap position. For the 5:1 slot nozzle configurations, shielding of the nozzle noise occurs at about 6000 Hz, while for the 10:1 slot nozzle configuration shielding occurs at about between 6 and 8 Hz. For the 5:1 slot nozzle, little difference in noise level was noted for the cases of canted nozzle or with the use of sideplates. A 3.0 dB spread in the noise levels occurred with the 10:1 slot nozzle depending on the specific flow attachment configuration. The canted 10:1 nozzle had the lowest noise level (most shielding relative to the nozzle-alone noise level), while the 10:1 nozzle with sideplates had the highest noise level.

Normalized sound pressure level spectra at the approach flap position and at an angular position of 80° measurement from the inlet are shown in Fig. 17. The circular nozzle configuration, shown in Fig. 17(a), indicates that the wing does not shield all of the deflector generated noise at this angular position. Data (not shown herein) at angular positions of 60° and 100°, however, indicate about the same degree of shielding as that noted for the data in Fig. 15(b). Furthermore, data obtained with a mixer-nozzle

EOW configuration (ref. 13) indicated that small changes in nozzle position and/or changes in deflector geometry or angle can influence markedly the local shielding effectiveness. Consequently, it is believed that acoustic shielding for the approach condition can be achieved by small configuration changes, without materially affecting the acoustic shielding at other angular positions.

Significant acoustic shielding is obtained with the 10:1 slot nozzle (no flow attachment device) at the approach flap position as shown by the data in Fig. 17(b). Acoustic shielding below the noise level of the nozzle-alone began at about 5 kHz.

Shielding effectiveness. - The shielding effectiveness in terms of SPL-SPL_N values as a function of frequency is shown in Figs. 18 and 19 at the takeoff and approach flap positions, respectively, for the three nozzle configurations and several flow attachment devices. As was evident in the previous section, in which the normalized sound pressure level was discussed, the extent and magnitude of noise reduction was greater for the slot nozzle configurations than for the circular nozzle configuration. The canted slot nozzles gave the greatest noise reductions; however, the other means of promoting flow attachment were not significantly less effective in noise reduction. At the approach condition, Fig. 19, the shielding effectiveness with the 10:1 slot nozzle configurations is nearly the same as that for the takeoff flap position when the differences in jet exhaust velocity are taken into consideration.

For all configurations, sound pressure level increases of about 20 dB were incurred at very low frequencies (of the order of several hundred Hz).

CONCLUDING REMARKS

On the basis of the acoustic studies discussed herein, it is apparent that significant shielding of jet exhaust noise can be achieved by the engine-over-the-wing (OTW) concept. Maximum shielding benefits for a given OTW configuration are obtained when the wing-flap system is not used to turn the exhaust jet, as in a conventional takeoff and landing (CTOL) aircraft application. In all cases, turning the exhaust jet by flow attachment to the wing-flap system caused an increase in low frequency noise and reduced the net shielding effect at high frequencies. Use of high aspect ratio slot nozzles improved the shielding benefits over those obtainable with circular nozzles. It should be emphasized, however, that the OTW configurations discussed herein are not optimized for either aerodynamics or acoustics. Further improvements in both technical areas appear attainable without serious design or structural compromises.

Unpublished NASA-Lewis data in which the airfoil chord was increased by about 25-percent relative to the nozzle dimensions showed significant improvements in both shielding of the nozzle noise and in reductions of the scrubbing and wake noise. This suggests that novel design approaches to the arrangement of the engine pods relative to the aircraft wing could achieve large reductions in flyover and sideline jet exhaust noise.

The importance of the shielding benefits at high frequencies lies in the scaling aspects of the data. For a viable commercial aircraft, the scale factor applied to the data presented herein is of the order of 15 or greater. The shielding of the high frequency bands of the noise spectrum is beneficial with respect to the effective perceived noise levels for full-scale aircraft. However, in terms of human noise annoyance, the noise in the low frequency bands of an OTW configuration can be equally important or even more so than the high frequencies. This is caused by the very large increase in sound power and pressure levels at low frequencies for OTW configurations. Also the increase in low frequency sound pressure levels can cause locally severe structural and vibration problems. In Ref. 16 it is suggested that a reduction of the fluctuating pressure differences at the flap trailing edge by use of porous surfaces could reduce the wake noise component. However, the possible loss in lift augmentation may limit the use of this method.

The present report concerns only noise levels associated with the flyover attitude of an aircraft. In order to meet proposed sideline noise goals

(95 PNdB at 152 m), the azimuthal variation of noise radiated from OTW configurations must also be evaluated. Limited sideline data are given in Refs. 9 and 10 and indicate that the sideline noise levels during flyover are about 3 dB less than the flyover values directly under the wing for the configurations discussed herein.

SYMBOLS

F_A	axial force, N
F_N	normal force (nominal lift), N
PWL'	effective sound power level (re 10^{-13} W), dB
OASPL	overall sound pressure level referenced to 2×10^{-5} N/m^2, dB
SPL	sound pressure level referenced to 2×10^{-5} N/m^2, dB
T	jet thrust, N
δ_f	geometric departure angle between flap upper surface at trailing edge and airfoil chordline, deg

Subscripts:

C	scrubbing and wake noise
N	nozzle

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TABLE I. - NOZZLE ACOUSTIC DATA

Nozzle	Nominal jet velocity, m/sec	Normalized $OASPL_N^*$, dB	
		80° from inlet	100° from inlet
Circular	180	83.7	85.1
	225	90.0	92.1
	280	98.0	99.6
5:1 Slot	180	85	86.5
	225	93.2	95
	280	100.5	102.2
10:1 Slot	180	84.9	86
	225	91.6	93.1
	280	98.8	100

*Normalized to 20.4 cm^2 area.

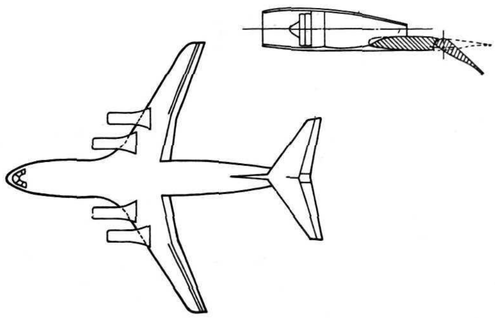

Figure 1. - Engine-over-the-wing concept.

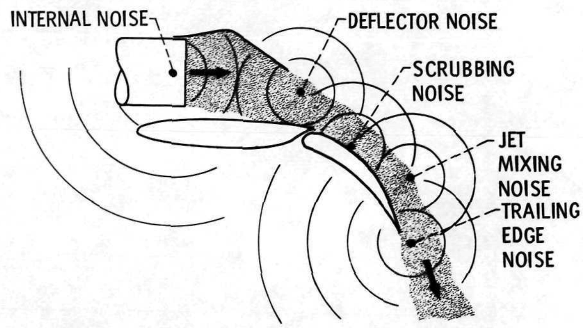

Figure 2. - Noise sources for engine-over-the-wing configurations.

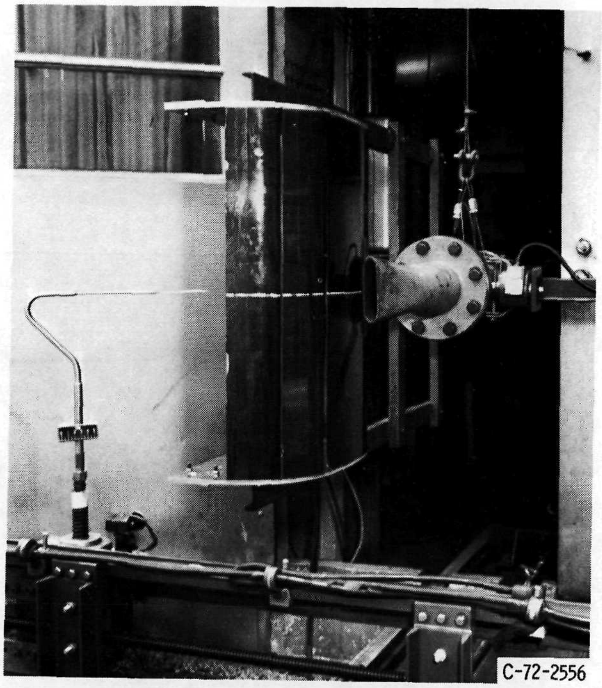

Figure 3. - Engine-over-the-wing model in lift-thrust rig.

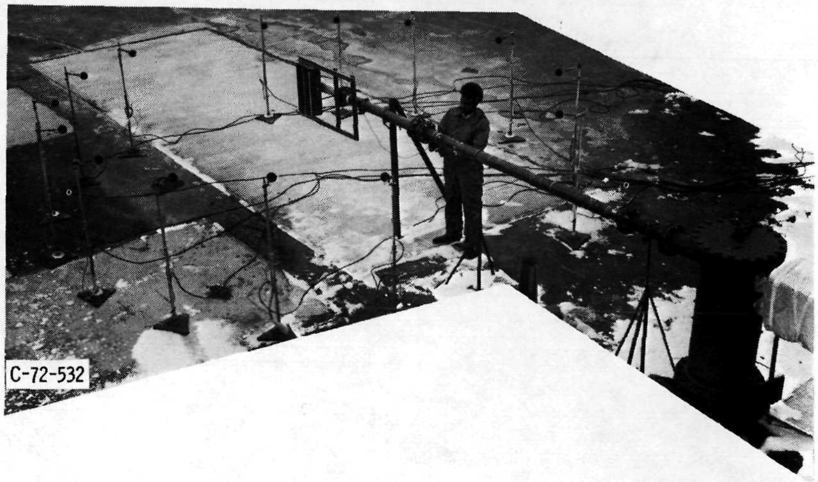

Figure 4. - Acoustic test stand used for noise tests with engine-over-the-wing model.

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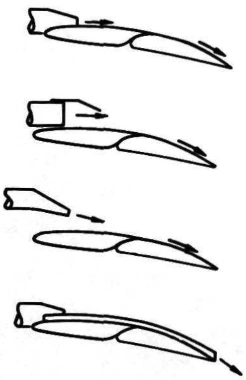

Figure 5. - Engine-over-the-wing configurations with various flow attachment devices.

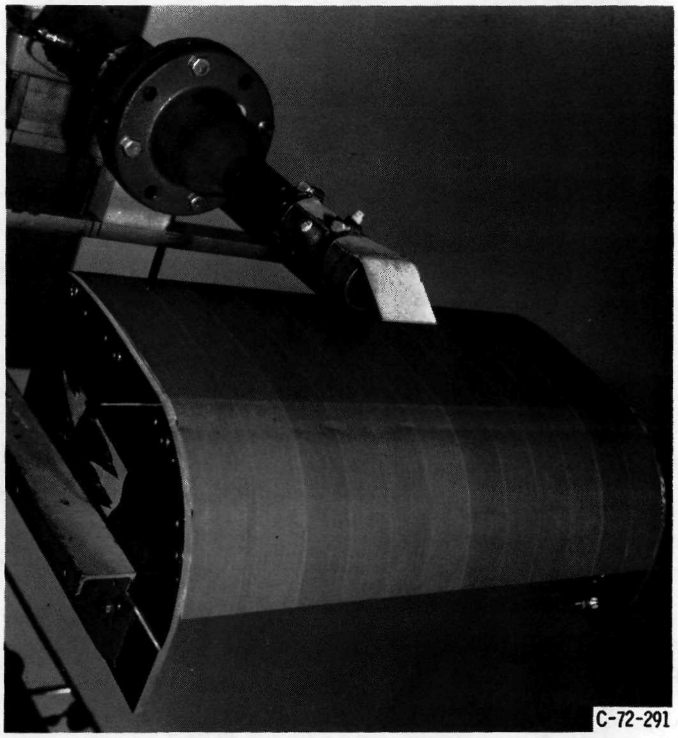

Figure 6. - Typical test configuration of the engine-over-the-wing model with the flaps in approach position.

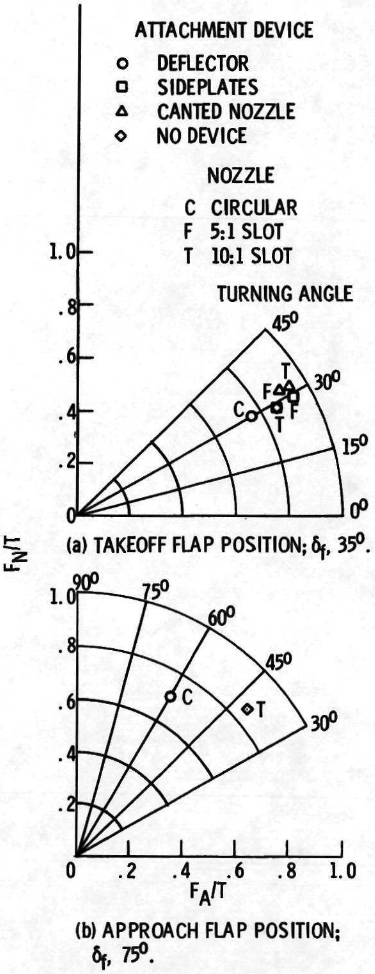

Figure 7. - Summary of flow turning angle and turning efficiency for various nozzles and flow attachment devices. Static conditions.

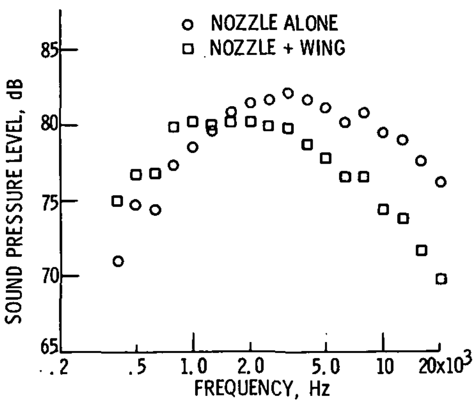

Figure 8. - Shielding effect of wing on jet noise. Unattached flow; circular nozzle; takeoff flap position; jet velocity, 225 m/sec; angular position, 100° from inlet.

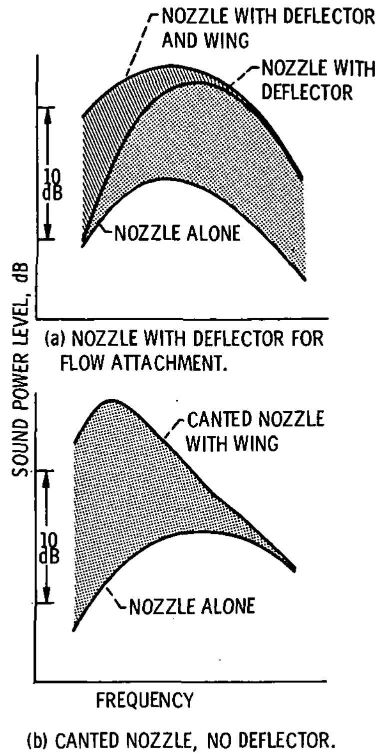

Figure 9. - Comparison of noise generation for typical engine-over-the-wing concepts.

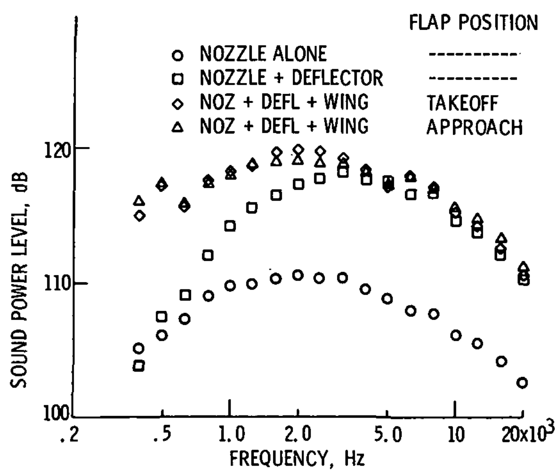

Figure 10. - Sound pressure levels for circular nozzle configurations. Jet velocity, 225 m/sec.

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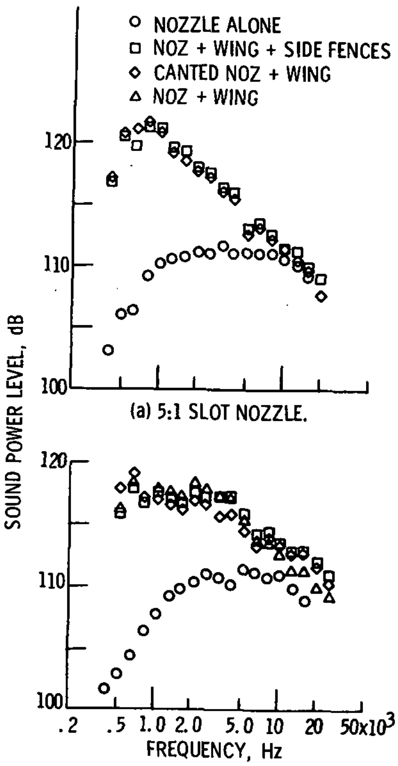


(b) 10:1 SLOT NOZZLE.

Figure 11. - Sound power level spectra for slot nozzle configurations. Takeoff flap position; jet velocity, 225 m/sec.

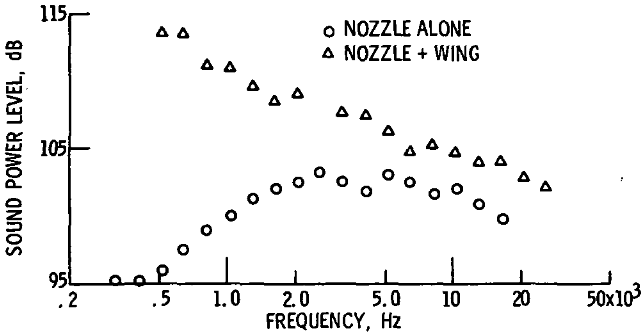
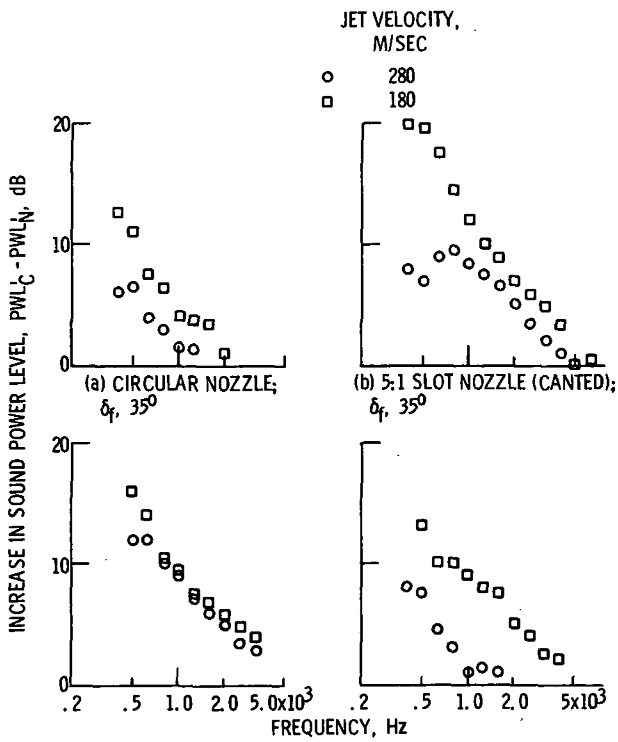


Figure 12. - Sound power level spectra for 10:1 slot nozzle. Approach flap position; jet velocity, 180 m/sec.



(c) 10:1 SLOT NOZZLE (CANTED); δ_f, 35^0.

(d) CIRCULAR NOZZLE; δ_f, 75^0.

Figure 13. - Effect of jet velocity on the increase in sound power level caused by presence of wing.

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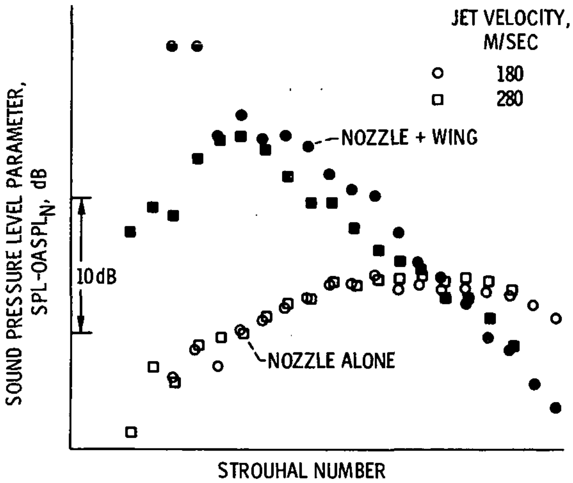

Figure 14. - Typical effect of jet velocity on variation of sound pressure level parameter with Strouhal number. 5:1 canted slot nozzle. Takeoff flap position.

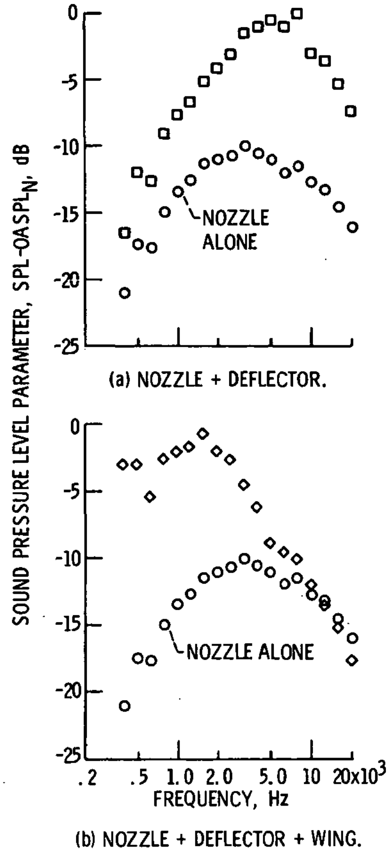

Figure 15. - Sound pressure level spectra obtained with circular nozzle configurations. Takeoff flap position; angular flap position, 100^0 from inlet; jet velocity, 225 m/sec.

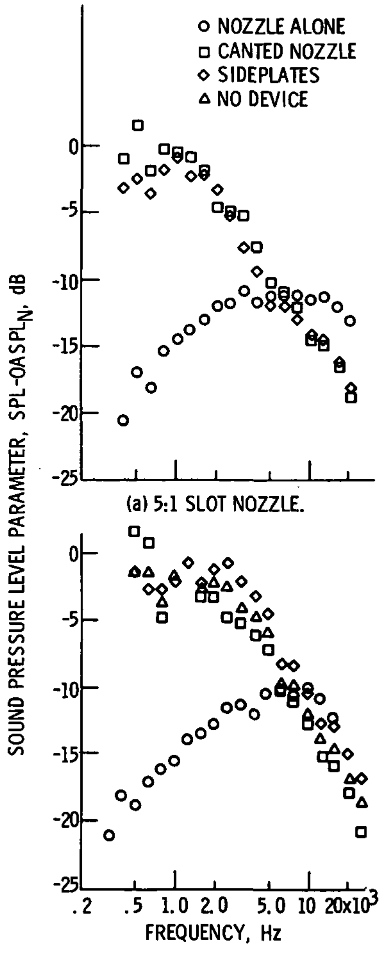

Figure 16. - Sound pressure level spectra obtained with slot nozzle configurations. Takeoff flap posiition; angular position, 100° from inlet; jet velocity, 225 m/sec.

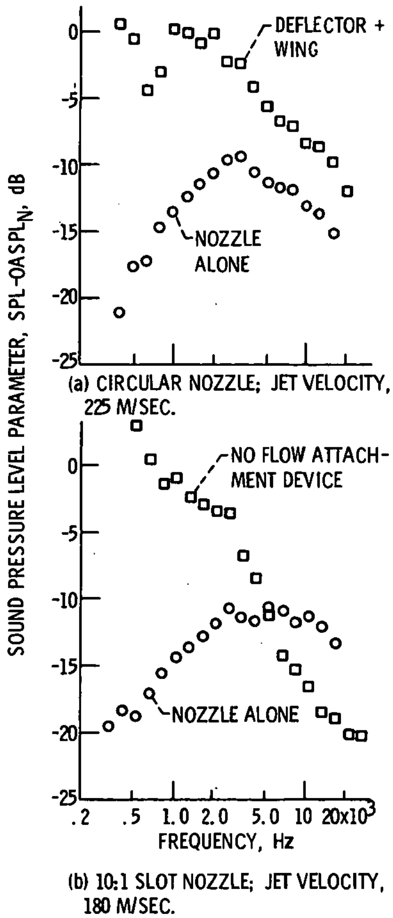

Figure 17. - Sound pressure level spectra for configurations at approach flap position. Angular position, 80° from inlet.

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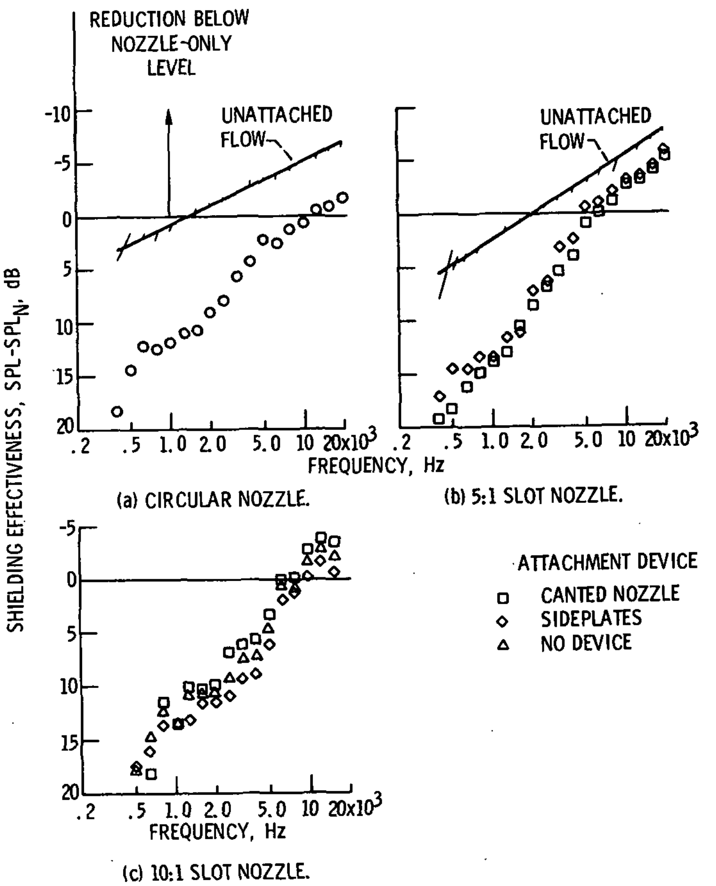

Figure 18. - Shielding effectiveness with engine-over-the-wing configurations for takeoff flap position. Angular position, 100° from inlet; jet velocity, 225 m/sec.

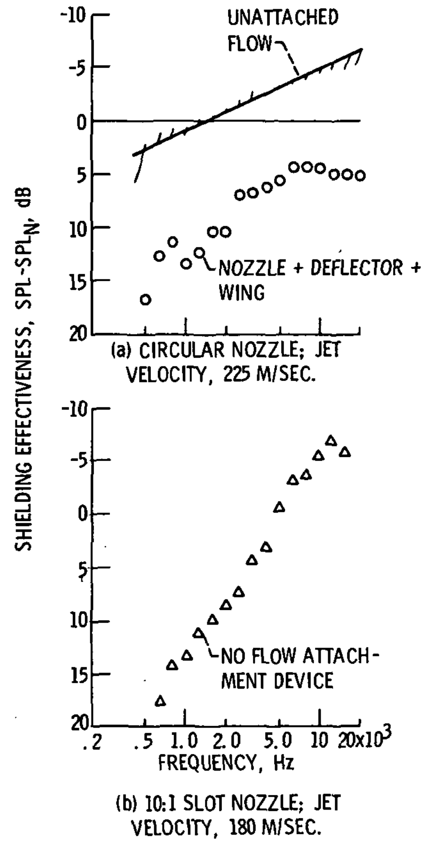

Figure 19. - Shielding effectiveness with engine-over-the-wing configurations for approach flap position. Angular position, 80° from inlet.