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BLOWN FLAP NOISE RESEARCH

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BLOWN FLAP NOISE RESEARCH

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Abstract

Noise data were obtained with models of both internally and externally blown jet-flaps of the type currently being developed for STOL aircraft. The principal tests were conducted with an augmentor-wing model and with an externally-blown double-slotted-flap model. Secondary tests were conducted with a jet flap model. The interaction between the jet and the flap assembly caused both redirection and generation of noise. The data were extrapolated to representative full scale STOL airplane flap systems. It is shown that with a quiet engine the blown flap noise can be the major contribution to the total aircraft noise. Suppression techniques will therefore be required.

I. Introduction

STOL aircraft will operate from airports located within densely populated metropolitan areas. In addition, STOL capability requires a considerable increase in installed engine thrust in order to provide the needed lift augmentation. These two factors combine to provide a potentially serious noise annoyance problem. In view of the growing concern for the quality of our environment it will therefore be necessary to place considerable emphasis on noise reduction efforts during the development of STOL aircraft. A peak perceived noise level of 95 PNdB for a 500 ft flyover is commonly considered as a goal for STOL aircraft.

Among the lift augmentation schemes being considered for STOL aircraft are various types of blown flap devices. The augmentor-wing ejector-flap (fig. 1(a)) and the conventional jet flap (fig. 1(b)) are internally blown. That is, they are blown by air jets from slot nozzles supplied by ducts located within the wing. The externally blown flap (fig. 1(c)) is immersed directly in the engine exhaust. There are two types of noise sources associated with these devices. One source is due to the mixing of the blowing jet with ambient or secondary air. The other source is due to the interaction of the jet with the flap. Further, the flap assembly can redirect the noise from these sources. These additional noise sources must be considered in addition to the usual engine noise sources of interest to CTOL airplanes.

In order to evaluate the importance of this additional noise, blown flap noise research is being conducted at the NASA Lewis Research Center as part of the overall NASA aircraft noise reduction program.(1)

The blown flap noise data obtained to date are summarized in this paper. The principal tests were conducted with a large scale augmentor wing model and with a small scale externally-blown double-slotted-flap model. Secondary tests included the jet flap configuration. The noise data from the principal tests were extrapolated to STOL airplane flap systems representative of planes in the 100,000 lb class and the contribution of the flap noise to the total aircraft noise is assessed.

II. Apparatus and Procedure

A. Model Configuration

Cross sectional views of the blown flap model configurations tested are shown in Fig. 1. The internally blown augmentor-wing flap configuration used (fig. 1(a)) was developed under the joint sponsorship of the Defense Research Board of Canada (with DeHavilland Aircraft of Canada Limited as contractor) and NASA Ames Research Center. Aerodynamic tests leading to this configuration ("Ames Phase-4") are summarized in Refs. 2 and 3.

The augmentor wing noise test facility is shown in Fig. 2. The test model (fig. 2(a)) had a 6 ft span and a 11 ft 4 in. chord length (flaps retracted). Tests were run with extended flaps at a 50° angle (Takeoff) and at a 75° angle (Landing) to the mean chordline. Augmentor nozzle slot heights of 0.575, 0.68, and 0.82 in. were employed. The slot nozzle was attached to a full length plenum inside the wing having an approximately elliptical section with a major axis of 30 in. and a minor axis of 21 in. Pressurized air entered the plenum through a quieting screen from a 20 in. O.D. duct below the wing. The duct was supplied by pressurized and dried air from the laboratory's central propulsion air supply system. The wing was mounted vertically with the mid span section located $10\frac{1}{2}$ ft above grade. The microphone circle was located in this horizontal plane at a 50 ft radius. The augmentor wing test model is shown installed in the noise test facility in Fig. 2(b).

The conventional internally blown jet flap configuration (fig. 1(b)) is one of the older lift augmentation devices being considered. It is basically similar to the augmentor wing without the upper flap (or shroud). The coanda flap however does not have slots. The small scale jet flap model is shown in Fig. 3. The rectangular nozzle had a slot height of 0.575 in. and was 6 in. long. The vertically mounted flap was 33 in. long and had a flap deflection angle of 50°. The removable side plates shown in the photo limited the coanda flow channel to a width of 6 in. A 10 ft radius microphone circle was used. The microphone plane was perpendicular to the flap and passed through the line shown on the model. It was 4 ft above grade.

The externally blown flap configuration (fig. 1(c)) was a small scale model of one of the double-slotted external flow jet flap configurations developed by the NASA Langley Research Center.(4,5) The wing model had a $12\frac{3}{4}$ in. chord length (flaps retracted) and a 24 in. span. The model is shown in Fig. 4. The pod mounted bypass nozzle of configuration 1(c) was approximated by a single 2" convergent nozzle (shown by dashed lines in fig. 1(c)) at the bypass engine secondary nozzle location. The wing and flap were linearly scaled in proportion to the 2 in. nozzle diameter.

Figure 4 shows the flaps at the 30-60° (Landing) position. The flaps were also tested at the 10-20° (Takeoff) position and in the fully retracted (0°) position. The wing was normally mounted in a vertical position. A 10 ft radius microphone circle was used. It was located in a horizontal plane 4 ft above grade and passed through the nozzle centerline. The wing and flap assembly could also be rotated about the nozzle centerline to determine the azimuthal noise distribution.

B. Acoustic Instrumentation

The noise data were measured by 1/2-in. condenser microphones placed in a 360° circle above a hard surface (black top). Usually 24 microphones were employed with the augmentor wing and 14 were employed with the externally blown flap and with the jet flap. The noise data were analyzed by an automated 1/3 octave band spectrum analyzer. The analyzer determined sound pressure level spectra (referenced to 0.0002 microbar) at each microphone position. Three noise samples were taken at each microphone and treated statistically to reject random errors and to obtain either an average or most probable value. The data were then corrected for atmospheric attenuation. From these spectra the overall sound pressure levels and perceived noise levels were calculated at each microphone location.

C. Test Procedure

For each flap angle setting noise measurements were made at a series of nominal pressure ratios. The augmentor wing and jet flap slot nozzles were operated at selected nozzle pressure ratio settings between 1.6 and 2.5.

The externally blown flap was operated at nominal nozzle pressure ratios of 1.1, 1.2, 1.4, 1.7, and 2.2.

The air supply temperature was usually between 40 and 70° F.

III. Results and Discussion

A. Augmentor Wing Noise

The augmentor wing sound power level was found to be proportional to the slot nozzle area and the directivity patterns were similar for the three nozzle slot heights. Therefore only the 0.68 in. slot height data will be summarized in this paper.

The directivity pattern for the augmentor wing slot nozzle was determined by making noise measurements with both flaps removed. The overall sound pressure level (OASPL) at 50 ft as a function of angle is shown in Fig. 5 for three nozzle pressure ratios. The extended lower lip of the nozzle is designed to pre-turn the attached air-jet by 15°. The directivity pattern is thus rotated from that observed with a conventional rectangular nozzle. Inspection of Fig. 5 shows that the pattern is symmetrical about the jet axis for approximately 80° on either side. At greater angles the large wing structure affects the noise pattern due to reflection and shielding. The OASPL was found to increase continuously as the nozzle pressure ratio was increased from 1.6 to 2.5.

The noise directivity pattern for the augmentor wing with both flaps in place (fig. 2(a)) is shown in Fig. 6 for two flap angles. The OASPL as a function of angle at three different nozzle pressure ratios is given for the 50° flap angle (Takeoff) in Fig. 6(a) and for the 75° flap angle (Landing) in 6(b). The most striking characteristics of the two patterns are the highly directional nature of the sound field and the fact that it rotates with flap deflection. Figure 6(a) shows that the directivity pattern has been rotated an additional 35° (compared to the nozzle alone) and has been distorted in shape due to the presence of the flaps. The two downstream lobes are located at approximately 45° to each side to the augmentor flap exhaust. There is an additional lobe located above the wing in the forward direction (at about 240° on the polar plot). This lobe is caused by noise radiating out the augmentor ejector inlet on top of the wing. The 75° directivity pattern (fig. 6(b)) is generally similar to the 50° data but has been rotated an additional 25° to conform to the new exhaust direction. Further, there is an increase in the peak sound level below the wing at this flap position compared to the 50° data. Comparison of the total power levels showed that this increase is caused primarily by redirection of sound (into the jet exhaust lobes) rather than by additional noise generation.

Whereas the nozzle-only noise level was found to increase continuously with pressure ratio the noise level with the augmentor flaps attached tended to peak before the maximum test pressure ratio of 2.5 was reached. This effect is shown in Fig. 7 where the peak value of OASPL (from the max lobe below the wing) is shown as a function of augmentor nozzle jet velocity for the nozzle only and the two flap angle positions. The nozzle-only peak OASPL is proportional to the eighth power of the jet velocity until the nozzle exhaust velocity becomes supersonic. For pressure ratios above 1.9 the unsteady shock structure causes additional high frequency broad band shock noise which results in a steeper slope of the OASPL as a function of velocity curve. The 50° flap curve is parallel to the nozzle-only data (and about 1 dB less) up to about 1150 ft/sec (PR 2.2). At this pressure ratio (under the static condition of this test) the augmentor ejector is beginning to draw in considerably more secondary air so that the relative velocity between it and the nozzle exhaust jet is beginning to decrease. The curve reaches a maximum value at a pressure ratio of 2.3. This effect is not too surprising because the augmentor ejector was initially designed for operation at a pressure ratio in the vicinity of 2.4. The 75° flap angle curve is parallel to and about 3.5 dB above the 50° data up to a pressure ratio of 1.9. At supersonic pressure ratios there is again evidence of increased noise caused by shock noise. The 75° curve reaches a peak OASPL value at a pressure ratio of about 2.4.

A typical 1/3 octave spectrum measured at 50 ft in the maximum lobe below the wing (95° on the polar plot of fig. 6) is shown (circular symbols) in Fig. 8. The flaps were at 50° and the nozzle was operating at a pressure ratio of 2.0 (jet velocity of 1070 ft/sec). The noise is broadband and typical of jet noise spectra. The peak frequency in Fig. 8 occurs a little above 3000 Hz. This center frequency is predictable from the

Strouhal relation if one uses the 0.68 in. slot height for the reference length, a Strouhal number of 0.18, and the nozzle jet velocity. At higher pressure ratios (2.2 to 2.5) an additional hump shows in the spectra at frequencies between 6000 and 12,000 Hz. This is caused by broadband shock noise.

The augmentor flaps were normally run with hard inside surfaces. In order to study ways of reducing the flap noise some runs were made with acoustically treated inside surfaces consisting of perforated sheet bonded to honeycomb backing as shown in Fig. 9. The effect of the lining on the spectra (square symbols) is also shown in Fig. 8. A maximum reduction of about 8 dB was measured at a frequency of 5000 Hz. Figure 8 indicates that while the noise can be attenuated the lining used should have been tuned to a lower resonant frequency in order to maximize the reduction in perceived noise level. Further, it would be desirable to develop a lining with a broader bandwidth.

Although the augmentor wing spectra were generally free of spikes, discrete screech tones were heard at some test conditions (particularly at the 75° flap setting). A narrow band spectrum (10 Hz bandwidth) at the 120° mike (max lobe) for a pressure ratio 2.4, 75° flap run is shown in Fig. 10. A very intense screech tone (25 dB above the broadband level) is present at 3325 Hz accompanied by a strong harmonic at 6650 Hz. This tone has the very narrow spectral characteristic of a tuned feedback oscillation and may be an edge tone caused by attachment and reattachment of the jet exhaust sheet to the lower lip of the augmentor nozzle (or possibly to the lower coanda flap).

The perceived noise level (PNL) was calculated from the spectral data. The directivity pattern at 500 ft radius for the two flap angle settings is shown in Fig. 11. The results for the 50° flap at three pressure ratios are shown in Fig. 11(a) and the 75° flap results in 11(b). The figure shows that a noise problem exists for the augmentor wing. At the 50° flap angle (fig. 11(a)) the noise level for this 6 ft-span wing section is greater than 95 PNdB at 500 ft for nearly all angles below the wing at nozzle pressure ratios of 2.0 and above. Further, the directivity pattern intensifies the noise problem since the maximum lobe has been rotated to a position directly below the wing for level flight. At 75° (fig. 11(b)) the directivity pattern is somewhat more favorable in that the maximum does not occur directly below the wing. However in general the noise level is higher at each pressure ratio so that the perceived noise level directly below the wing is comparable to the 50° case. The effect of screech (should it occur) is shown in the pressure ratio 2.4 results of Fig. 11(b). The solid symbols give the PNL with screech tones present and the open symbols show the same data with the screech tones subtracted out of the spectrum. The presence of screech increased the PNL at the lobes by about 5 PNdB. Thus, screech must be avoided. Fortunately nozzle screech usually can be eliminated by rather minor geometry changes and therefore may not be a major problem.

B. Jet Flap Noise

The noise directivity pattern for the small scale internally blown jet flap model (fig. 3) is shown in Fig. 12. The overall sound pressure level at a radius of 10 ft is given as a function of angle for slot nozzle pressure ratios of 1.8, 2.1, and 2.4. The most notable feature of the directivity pattern is the redirection of noise upward and rearward (0°) in comparison to the augmentor wing (fig. 5). The jet flap directivity pattern of Fig. 12 is very similar to the earlier data of Maglieri and Hubbard(6) if one extrapolates their results to the same jet turning angle and ratio of flap length to nozzle height (57).

For comparison purposes the pressure ratio 1.8 and 2.4 jet flap data of Fig. 12 were scaled up to the six foot span size of the augmentor wing model. The slot heights were nearly the same so no frequency shift was applied. The sound pressure level at each frequency was assumed to be proportional to nozzle area when scaling. The resultant perceived noise level at 500 ft and for a 50° jet turning angle is shown by solid symbols in Fig. 13. As mentioned in the Apparatus and Procedure section the augmentor wing with the upper flap removed approximates the jet flap except for the presence of slots in the coanda flap. Noise tests were therefore also conducted with the augmentor wing lower flap only. The flap was set at a 50° angle. The results at pressure ratios of 1.8 and 2.4 are shown as open symbols in Fig. 13. The directivity patterns for the lower flap are very similar in shape to those for the jet flap (solid symbols). However the jet flap is quieter at virtually all angles. That is, not only is the jet flap quieter below the wing (as one might expect due to the absence of slots) it is also quieter above the wing. At a pressure ratio of 2.4 a small amount of additional noise (2 or 3 dB) does appear to "leak" through the augmentor wing lower flap slots making the total noise 5 to 6 dB higher directly below the wing. The main effect of removing the slots however appears to be a general reduction in the overall noise level.

Comparison of Fig. 13 with Fig. 11(a) shows that the jet flap is considerably quieter below the wing than the augmentor wing with both flaps. For example, at a pressure ratio of 2.4 the jet flap has a peak PNL value below the wing of 95.5 PNdB compared to about 105 PNdB for the augmentor wing.

C. Externally Blown Flap Noise

The sound directivity pattern at a 10 ft radius for the externally blown flap model (fig.4) is shown in Fig. 14 for an exhaust nozzle pressure ratio of 1.7 (925 ft/sec). The OASPL as a function of angle (θ) in the plane perpendicular to the wing ($\varphi = 0^\circ$) is given for flap deflections of 30°-60°, 10°-20°, and 0° (fully retracted). The sound field is less directional than measured for the augmentor wing. However, the striking feature of the data of Fig. 14 is the large increase in OASPL below the wing as the flaps are lowered. At 90° there is a 11 dB increase in noise as the flaps are lowered from the fully retracted (0°) cruise condition to the landing configuration (30°-60°). These results are generally similar to those obtained with a small scale double slotted flap assembly blown with a six inch diameter fan.(1)

The effect of velocity on the overall sound pressure level is shown in Fig. 15. The OASPL at

10 ft radius for the 30°-60° flap setting is plotted as a function of angle (θ) for nozzle pressure ratios of 1.1, 1.2, 1.4, 1.7, and 2.2. The data of Fig. 15 show that the shape of the directivity pattern is similar over a wide range of nozzle pressure ratios. Further, there is a strong increase in OASPL as the nozzle pressure ratio (and therefore the impingement velocity) increases.

This effect can also be seen in Fig. 16 where the nominal total sound power level (PWL') is shown as a function of nozzle exhaust velocity for the four test configurations. The PWL is "nominal" (except for the nozzle) because it is based on data measured in the plane through the jet axis perpendicular to the wing and does not take into account the spherical asymmetry of the sound field. The nominal PWL is useful because it shows the trends with velocity seen in the OASPL data of Fig. 15 in a simplified form suitable for configuration comparisons. The nominal PWL increases with the 6th power of the velocity for the three flap positions in contrast to the nozzle which follows the well established 8th power law at subsonic pressure ratios. Further, as the flap deflection angle increases the flap interaction noise becomes so much louder than the nozzle jet noise that it completely dominates the sound field. Note also that when the engine nozzle is in its installed position below and just ahead of the wing (0° curve), considerably more noise is produced than for the nozzle alone. This is apparently caused by some scrubbing by the expanding jet.

The basic mechanism of flap interaction noise is not clearly understood at this time. The fact that the PWL has a 6th power dependence on the blowing velocity suggests a dipole type noise source. Dipole noise sources are associated with fluctuating forces at solid boundaries. Thus one suspects that much of the interaction noise is generated by scrubbing of the flap surface by the impinging jet. In order to determine the importance of the two wing slots additional tests were run with the flaps replaced by a 1/4 in. thick aluminum plate rolled to conform to the lower boundary of the wing with 30°-60° flaps. The directivity pattern for the slot-less metal wing-flap combination with a jet exhaust velocity of 925 ft/sec is compared with the double-slotted externally blown flap in Fig. 17. The two polar plots are generally similar in shape with the slot-less metal wing being 3 to 5 dB quieter at nearly all angles both above and below the wing. This result is very similar to that found for the effect of slots on the jet flap noise (fig. 13). The nominal sound power level for the slot-less metal wing was also found to vary with the 6th power of the blowing velocity and was about 3 to 4 dB quieter at each nozzle pressure ratio.

Typical 1/3-octave sound pressure level spectra measured at 10 ft with the $\theta = 100^\circ$ microphone for the four externally blown flap test configurations are given in Fig. 18. The nozzle pressure ratio was 1.7 (925 ft/sec) for all cases. The spectra are broadband and they are generally similar in shape but differ in level. The strong increase in sound pressure level as the flaps are deflected is again readily apparent.

As mentioned previously the sound field is asymmetrical. In order to evaluate sideline noise (in comparison to flyover noise below the wing) the model (fig. 4) was rotated (about the jet axis) from its normal position (φ=0) to several azimuthal angular positions and noise measurements were made with the same circle of microphones. The effect on the OASPL at the $\theta = 100^\circ$ microphone as the azimuthal angle, φ, was varied is shown in Fig. 19. The noise was found to decrease nearly linearly with azimuthal angle indicating that the flap system is quieter when viewed directly from the side. This amounts to a reduction of 12 dB for the 30°-60° flap. It should be pointed out that this is the maximum reduction that was observed as the effect is smaller at other microphone locations.

D. Comparison of Model Results

The magnitude of the overall sound pressure levels measured with the three blown flap models generally followed similar trends with parameter changes. That is, the sound levels generally increased with increase in nozzle size, nozzle pressure ratio, and flap deflection (or jet turning angle). At a given set of test parameters, however, the relative magnitudes differed considerably for the three systems as can be seen from the data of Fig. 20. In Fig. 20 the peak OASPL measured at 10 ft below the wing model is given for the three flap types. The data are normalized to the same nozzle area (3.45 in.^{2}) and the jet turning angle is approximately 50° in all cases. It can be seen that the externally blown flap model is 15 to 18 dB louder than the jet flap model. The augmentor wing model is about midway in between in loudness.

These differences between the measured noise levels for the three flap systems are very striking. However, the differences will be much smaller in practice than might at first appear from Fig. 20 for several reasons. First, the internally blown systems must operate at considerably higher nozzle pressure ratios (because of wing duct-size problems) than the externally blown flap systems. Further, the use of slot nozzles in the internally blown flap systems results in higher frequency noise than is obtained with the externally blown flap system. This increases the perceived noise level for the internally blown systems.

Second, although from purely a noise standpoint the internally blown jet flap appears to have a definite advantage over the internally blown augmentor wing flap, this must be balanced against a loss in both lift and thrust augmentation when a shroud (upper flap) is not employed. The increased nozzle pressure ratio required to compensate for these losses would raise the noise level. This along with the fact that conventional acoustic lining treatment can't be employed with the jet flap tends to cancel much if not all of its noise advantage.

It should be pointed out that the jet flap has a very simple mechanical system compared to the augmentor wing. This makes it attractive if it can be shown to have no jet attachment problems. However, the jet flap noise data will not be extrapolated to a full scale airplane in the next section because the authors did not have a basis for making comparisons with the augmentor wing at equal lift and thrust.

IV. Extrapolation to Full Scale Flap Systems

Blown flap noise estimates were made for two hypothetical 4-engine 100,000 lb gross weight STOL aircraft. The blown flap system on one aircraft was assumed to be an augmentor wing having a wing thrust of 38,000 lb. The other aircraft was assumed to have an externally blown flap system with a total engine thrust of 60,000 lb. The maximum perceived noise level at 500 ft below the aircraft during flyover was calculated for each flap system by extrapolation of the small scale data in the following manner. First, all model nozzle and flap dimensions were linearly scaled up to conform to the new nozzle area required at each pressure ratio in order to obtain the specified thrust level. For the augmentor wing slot nozzle a constant augmentor length of 60 ft was also assumed. The noise data at each nozzle pressure ratio (or more accurately nozzle exhaust velocity) were then extrapolated by assuming that the measured 1/3-octave spectra could be scaled by using the Strouhal reciprocal relationship between frequency and nozzle diameter (or slot height) and that the magnitude of the SPL at each frequency is proportional to nozzle area. The PNL was then calculated from the resultant 1/3-octave spectra in the usual manner. The augmentor wing PNL values were adjusted for relative velocity effects due to forward motion. No adjustment for forward velocity was included in the externally blown flap calculations because the scrubbing action is probably not affected by forward velocity.

Noise estimates for the augmentor-wing-airplane flap system at 50° deflection (Takeoff) are given in Fig. 21. The perceived noise level at 500 ft is given as a function of the wing slot-nozzle pressure ratio for constant wing thrust (38,000 lb_f). At each pressure ratio the upper curve gives the peak PNL for a 500 ft flyover at 80 knotts airspeed and the corresponding 500-ft-sideline peak PNL is given in the lower curve. The sideline noise levels are about 5 PNdB less than the flyover values because the sound field is less intense when viewed from the side (similar to effect shown in fig. 19) and also because after lift-off the acoustic path distance is greater than 500 ft. A peak perceived noise level of 95 PNdB at 500 ft is commonly considered as a goal for STOL aircraft. Both curves of Fig. 21 are well above this level. At a pressure ration of 2.0, for example, the peak PNL is 111 PNdB for flyover and 106 PNdB at sideline.

The augmentor wing peak noise estimates of Fig. 21 were based on the 50° flap angle data. It was assumed that the takeoff condition would be the worst case because the engines are operated at full thrust compared to about 60 percent thrust on landing. If the throttle settings for landing should approach those used on takeoff then the landing condition (75° flap angle) may be the maximum noise case particularly if steep approach angles are employed.

The noise estimates for the externally blown flap system are shown in Fig. 22 for a 500-ft flyover. The peak perceived noise level for flap angles of 10-20° and 30-60° is shown as a function of nozzle exhaust velocity for constant engine thrust (60,000 lb_f). Approximate engine fan pressure ratios (assuming the fan to core exhaust velocity ratio is near unity) are also given for reference. The peak 500 ft sideline PNL values would be about 5 PNdB lower than the flyover values shown as was the case for the augmentor wing (fig. 21). The noise estimates show that the externally blown flap noise is below the 95 PNdB goal only at very low jet exhaust velocities (450 ft/sec or less). At an exhaust velocity of 690 ft/sec (pressure ratio of 1.3) which roughly corresponds to a fan jet engine with a by-pass ratio of about 10 the 500 ft flyover flap noise is estimated to be 107 PNdB at the 10-20° takeoff flap setting. At 500 ft sideline the peak noise would be about 102 PNdB. As in the case for the augmentor wing the PNL is higher at larger flap deflections (111 PNdB for the 30-60° flap at a velocity of 690 ft/sec). If again it is assumed that the engines will be operated at about 60 percent thrust on landing then the landing noise with the 30-60° flap deflection would actually be a little less than the takeoff condition. Use of a larger fraction of the power on landing could make the landing case the critical one especially in view of the fact that the airport approach angle will probably be smaller than the climb out angle and thus the aircraft will be nearer to ground observers for a greater length of time.

V. Conclusions

The full scale (100,000 lb STOL aircraft) blown flap noise estimates based on the experimental data summarized in this paper indicate that both the augmentor wing and externally blown flap systems will present serious noise problems. That is, if one assumes that the inlet and exhaust noise of the four engines can be suppressed to levels below the 95 PNdB goal it will still be necessary to find some means of suppressing the blown flap noise. The only exception appears to be for fan pressure ratios of the order of 1.1 or lower (i.e., prop-fans, and shrouded propellers) where the externally flown flap noise estimates fell below the 95 PNdB goal. However, high speed cruise considerations appear to make these very low pressure ratio propulsion systems less attractive than a fan-jet.

The augmentor-wing flaps are particularly amenable to noise suppression techniques because the blowing jet passes through a channel. About 5 PNdB can probably be removed by employing acoustic linings on the inner surfaces. Additional noise will have to be removed by a combination of nozzle noise suppression techniques similar to those used on engine exhaust nozzles and by flap (and ejector) geometry modifications.

The externally blown flap does not appear to be amenable to conventional acoustic lining treatment. The most obvious means of suppressing the flap-interaction noise appears to be the use of some type of engine exhaust mixing nozzle which would mix ambient air with both the fan and core exhaust streams in order to lower the jet impingement velocity at the flaps. For a fan jet engine with a fan pressure ratio of 1.3 roughly a 50 percent reduction in exhaust velocity is required at the flaps in order to reduce the flap noise below the 95 PNdB level. This amount of velocity reduction appears to be technically feasible without excessive thrust loss.

An important area of uncertainty in the evaluation of the potential of both the augmentor wing and the externally blown flap systems is the effect of forward velocity on blown flap noise. Test data are needed to resolve this point.

In summary it has been shown that for both augmentor-wing and externally-blown flap STOL aircraft equipped with quiet engines the blown flap noise can be the major contribution to the total aircraft noise at all except the very lowest blowing velocities. Noise suppression techniques must therefore be developed for both systems in order to make the aircraft acceptable.

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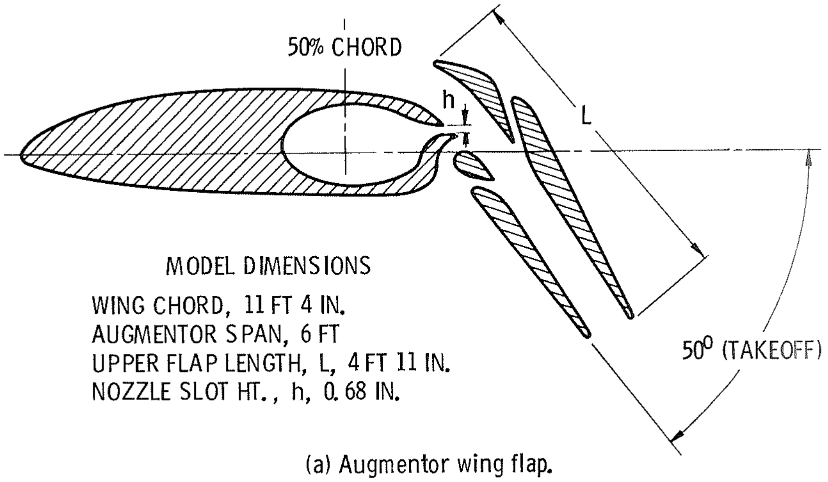
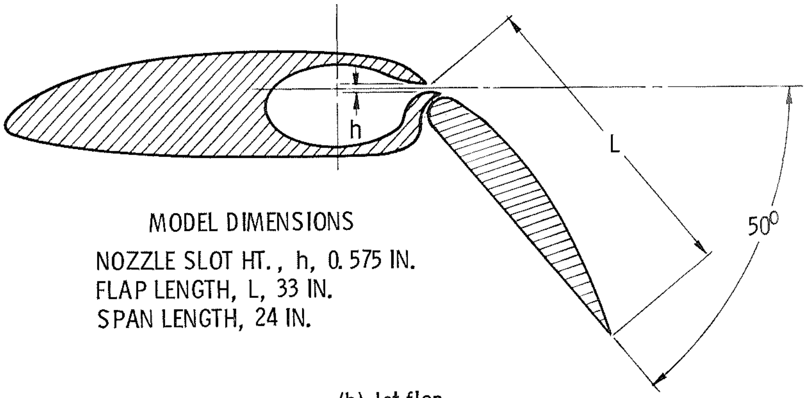


MODEL DIMENSIONS

WING CHORD, 11 FT 4 IN.
AUGMENTOR SPAN, 6 FT
UPPER FLAP LENGTH, L, 4 FT 11 IN.
NOZZLE SLOT HT., h, 0.68 IN.

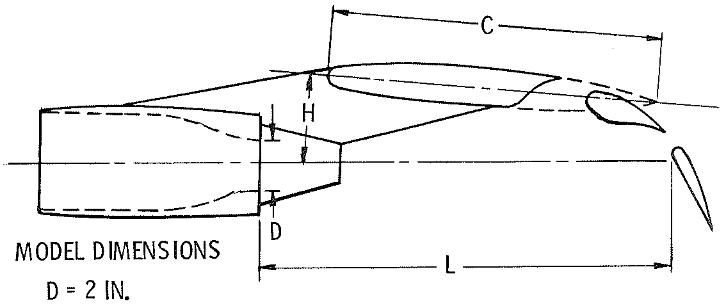
(a) Augmentor wing flap.



MODEL DIMENSIONS

NOZZLE SLOT HT., h, 0.575 IN.
FLAP LENGTH, L, 33 IN.
SPAN LENGTH, 24 IN.

(b) Jet flap.



MODEL DIMENSIONS

D = 2 IN.
C = 12.75 IN.
$H = 3\frac{1}{16}$ IN.
L = 14.5 IN.
SPAN = 24 IN.

(c) Externally blown flap.

Figure 1. - Blown flap noise test configurations.

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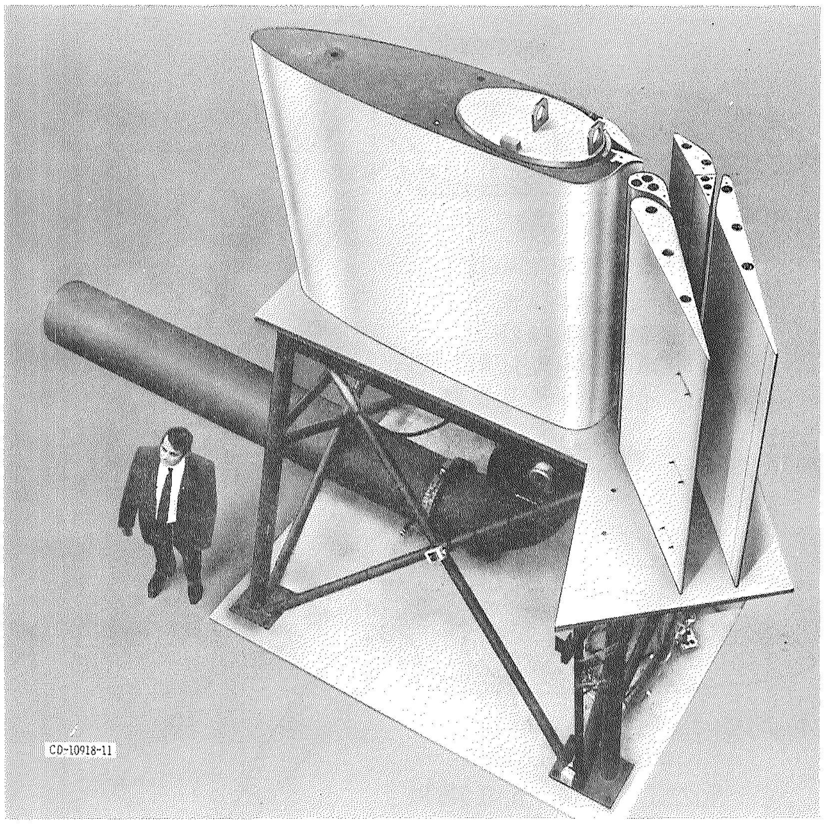
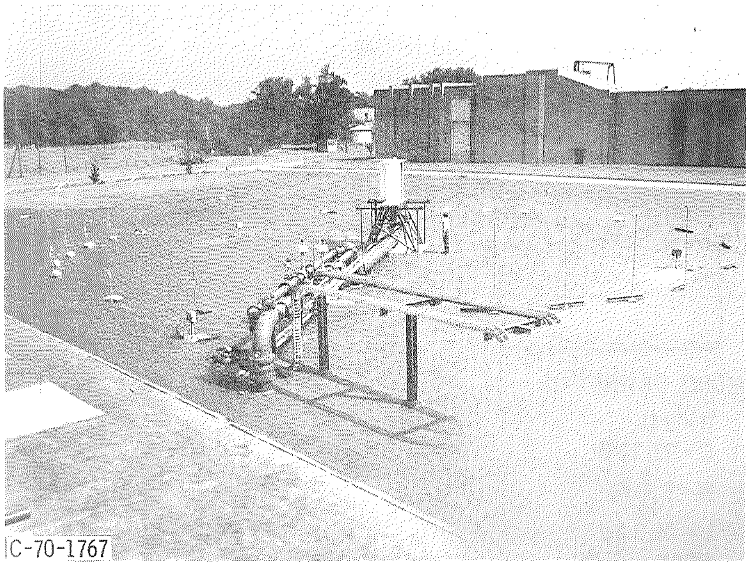


(a) Augmentor wing test model.



(b) Model installed in test facility.

Figure 2. - Augmentor wing noise test.

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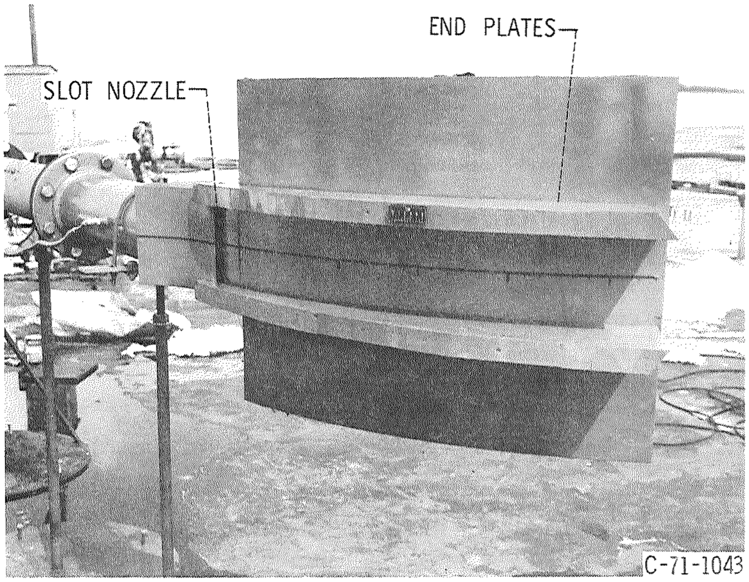


Figure 3. - Small scale jet flap model.

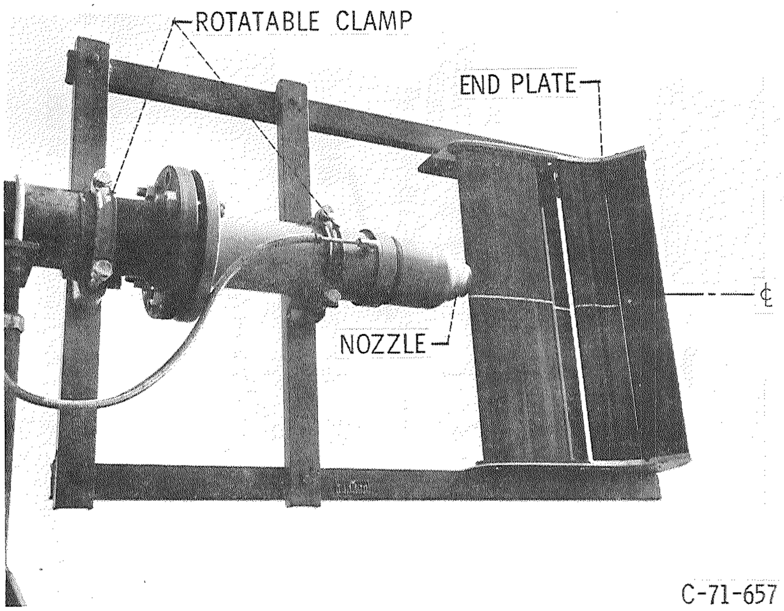


Figure 4. - Externally blown flap model. Flaps in 30-60° position.

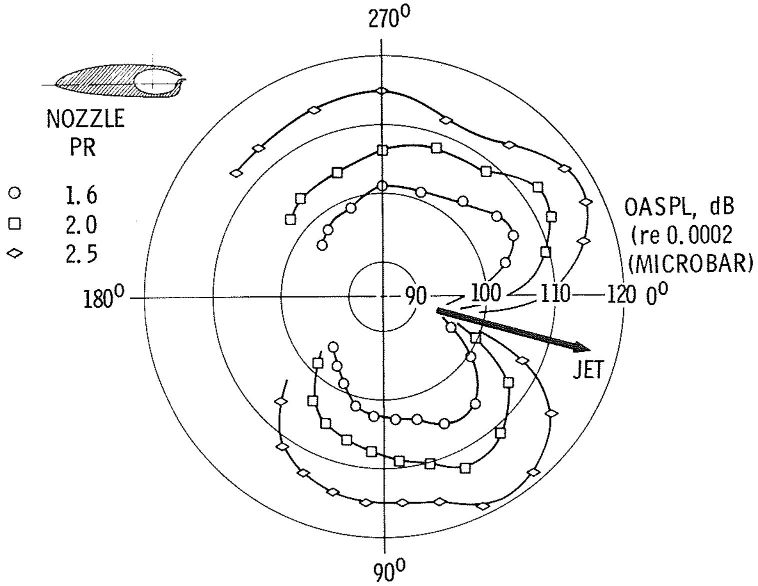
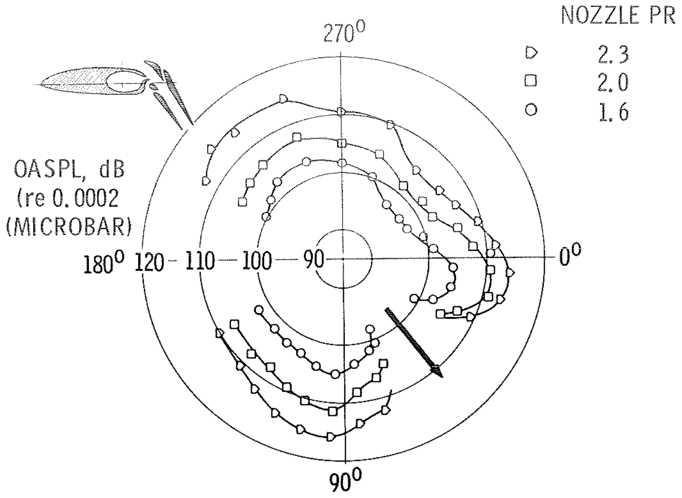
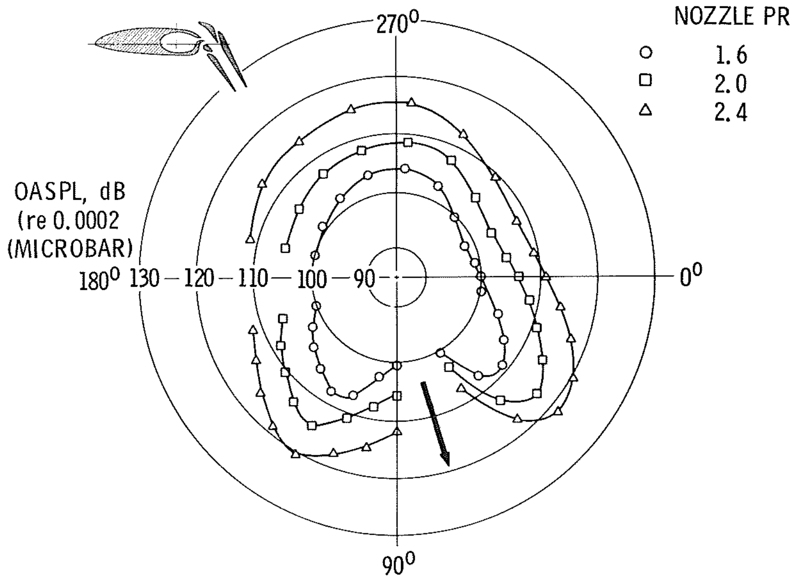


Figure 5. - Directional pattern for augmenter wing slot-nozzle noise (flaps removed). Slot height, 0.68 in.; microphone radius, 50 feet.



(A) FLAP ANGLE, 50° (TAKEOFF).



(B) FLAP ANGLE, 75° (LANDING).

Figure 6. - Directional pattern for augmentor-wing blown flap noise. Microphone radius, 50 feet.

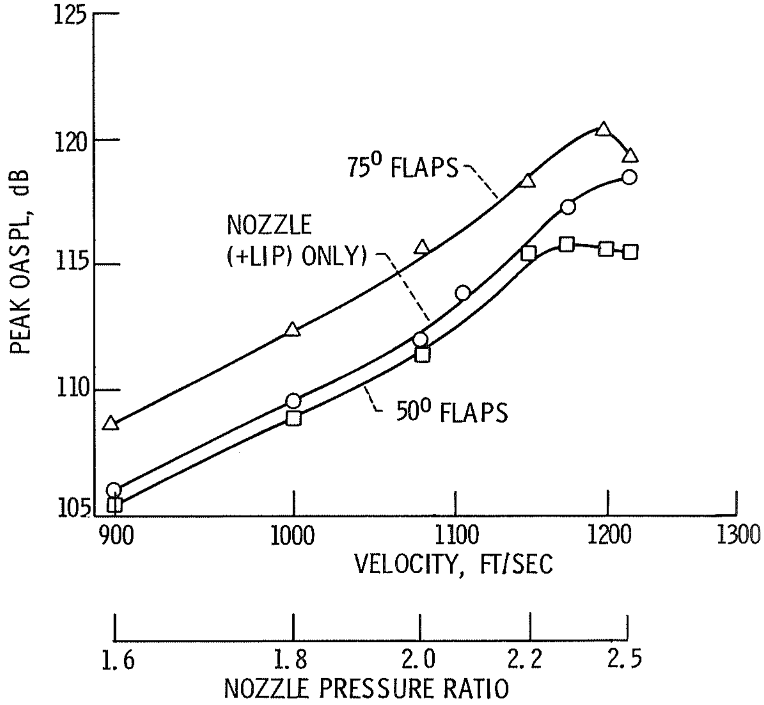


Figure 7. - Peak overall sound pressure level at 50 feet as a function of slot-nozzle exhaust velocity for three augmentor wing configurations.

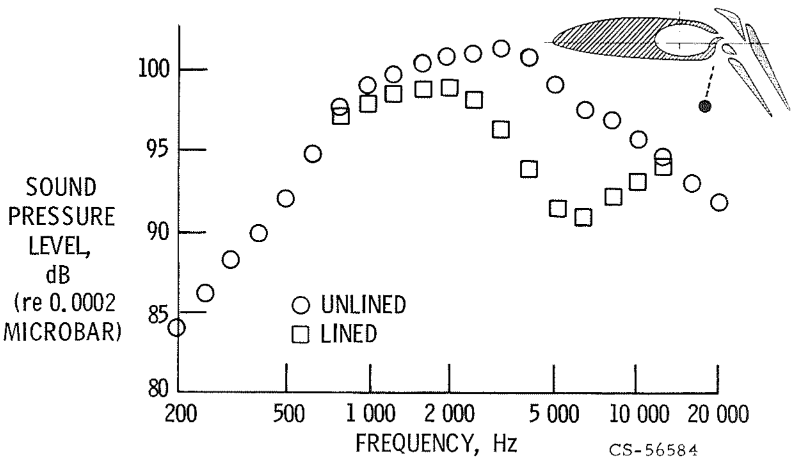


Figure 8. - Typical augmentor wing 1/3-octave spectrum at 50 feet. Mike angle, 95°; nozzle pressure ratio, 2.0; flap angle, 50°; nozzle slot height, 0.68 inch. Flap channel unlined and with acoustic lining.

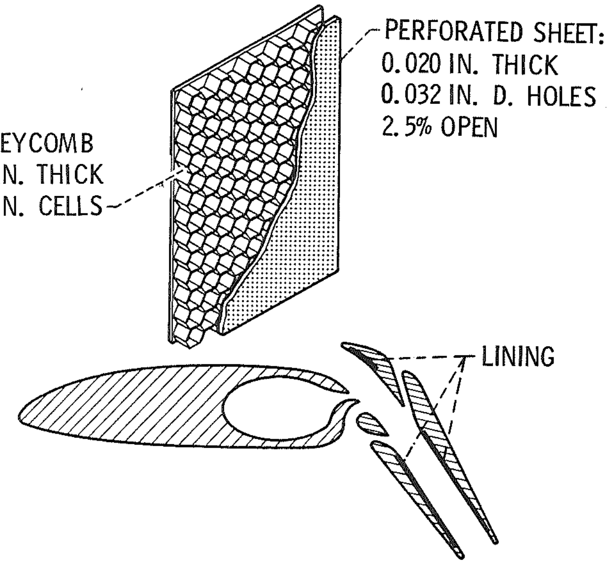


Figure 9. - Flap acoustic liner.

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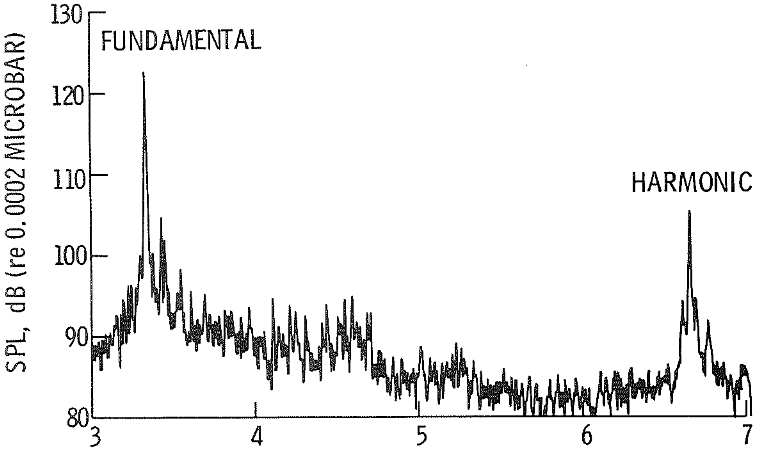
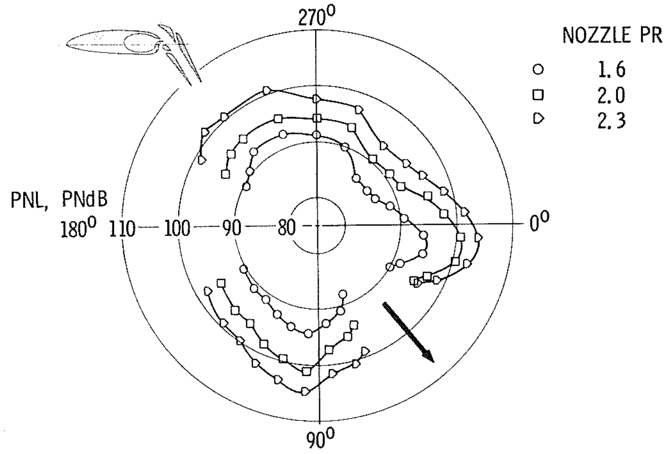
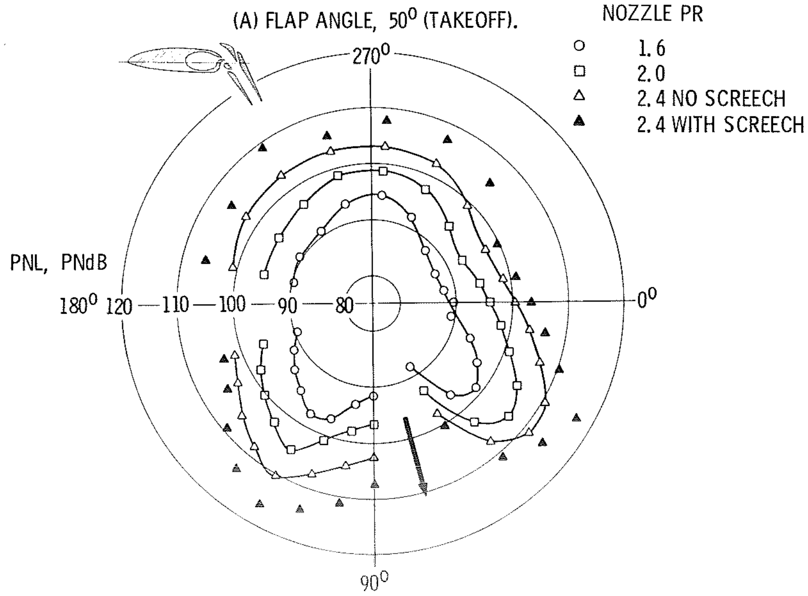


Figure 10. - Augmentor wing narrow band (10 Hz) spectrum showing presence of screech tones. Microphone angle, 120°; distance, 50 feet; nozzle pressure ratio, 2.4; flap angle, 75°.



(A) FLAP ANGLE, 50° (TAKEOFF).



(B) FLAP ANGLE, 75° (LANDING).

Figure 11. - Perceived noise level directivity pattern for augmentor wing at 500 feet.

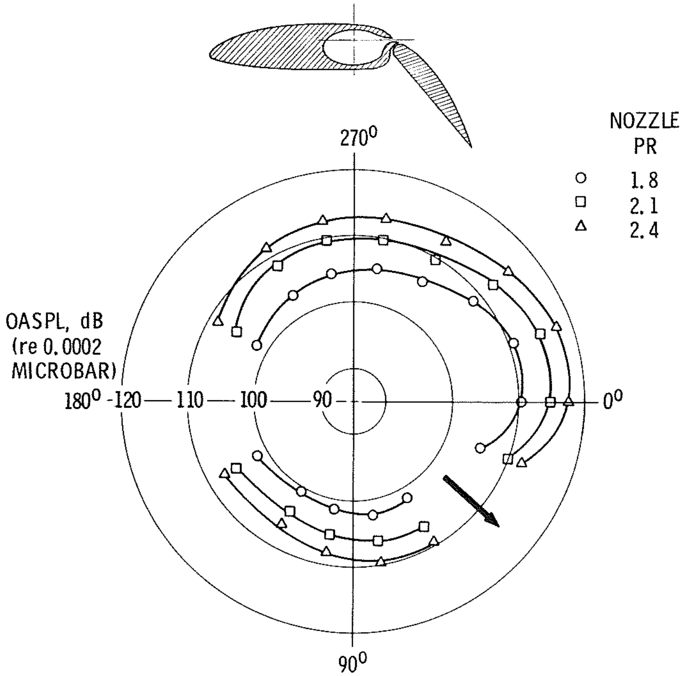


Figure 12. - Overall sound pressure level directional pattern for jet flap at 10 feet.

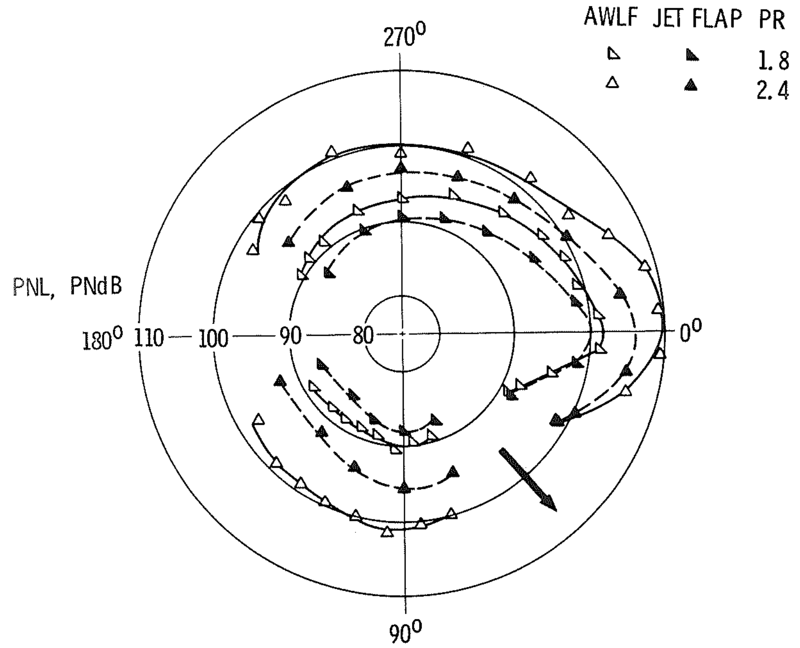


Figure 13. - Comparison of jet flap and augmentor wing lower flap perceived noise level directional patterns at 500 feet. Jet flap data scaled up to augmentor wing size. Flap angle, 50°.

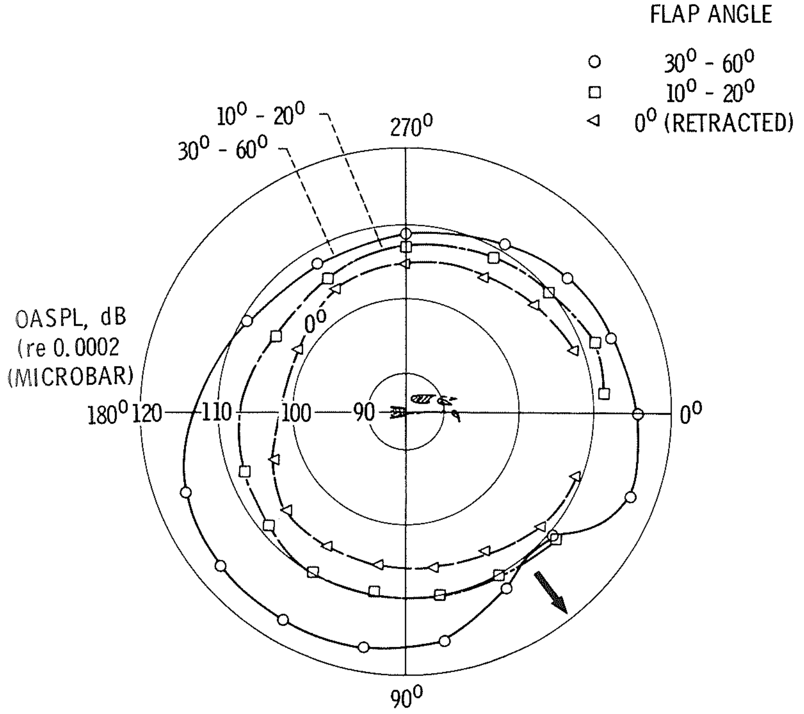


Figure 14. - Directional patterns for externally blown flap noise. Flap angles, 30° - 60°, 10° - 20°, and 0°. Nozzle pressure ratio, 1.7. Exhaust velocity 925 ft/sec. Microphone radius, 10 feet.

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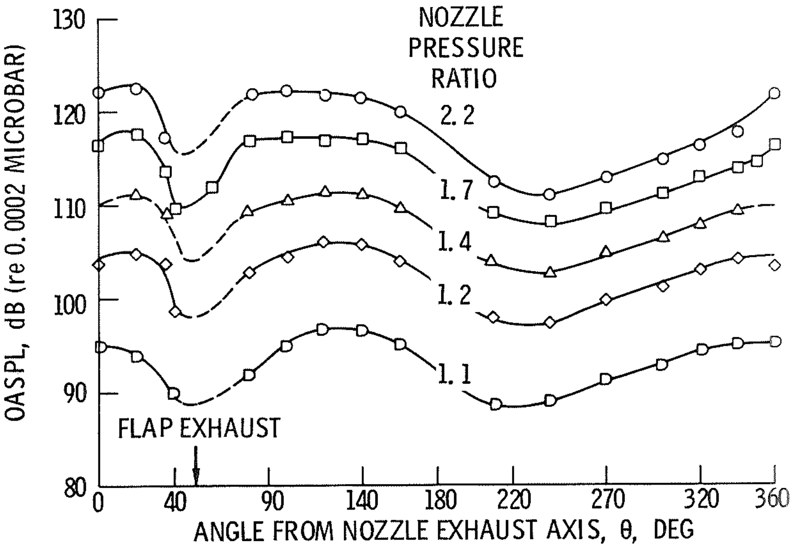

Figure 15. - Effect of exhaust nozzle pressure ratio on overall sound pressure level. Flap angle, 30°-60°; microphone distance, 10 feet.

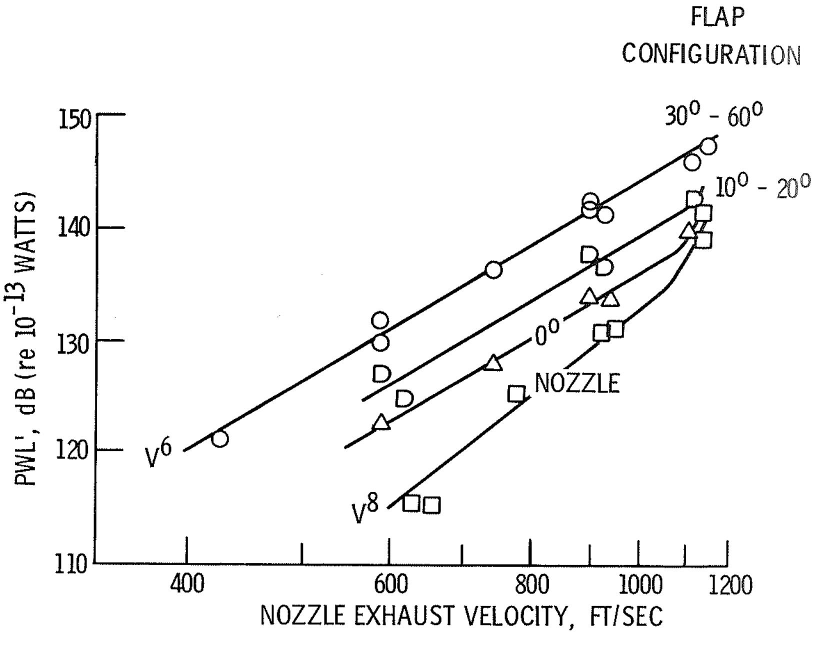

Figure 16. - Nominal total sound power level, PWL', as a function of nozzle exhaust velocity.

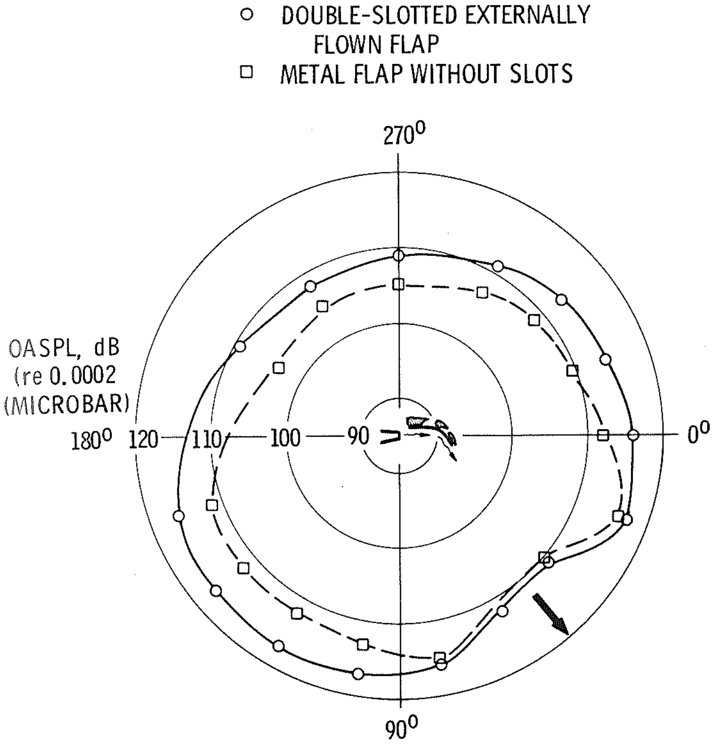

Figure 17. - Comparison of double-slotted externally blown flap with metal flap without slots. Microphone radius, 10 feet.

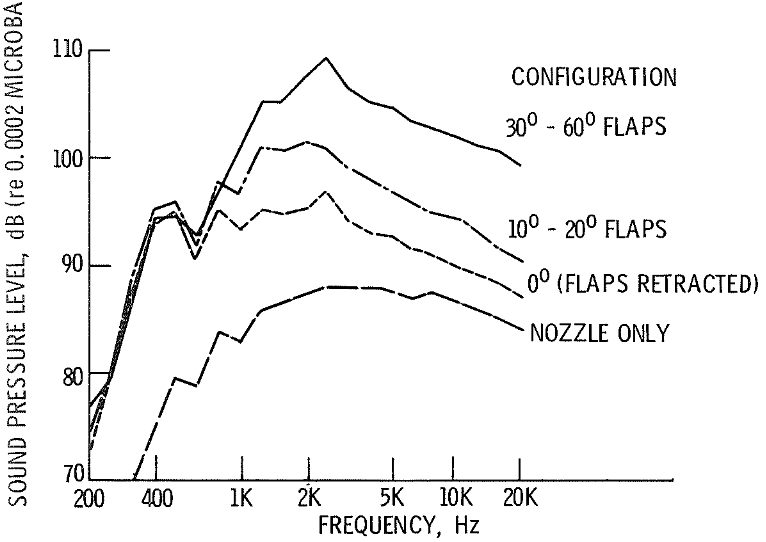

Figure 18. - Typical externally blown flap 1/3-octave spectra for for the four configurations tested. Microphone angle, 100°; nozzle pressure ratio, 1.7; jet velocity 925 ft/sec; distance 10 feet.

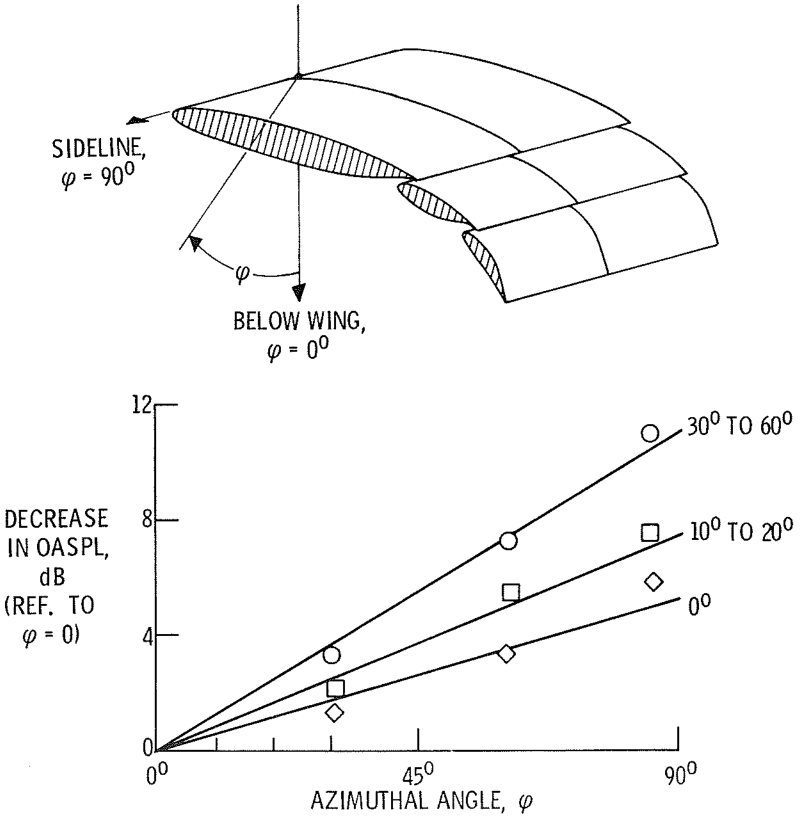

Figure 19. - Decrease in externally blown flap noise with azimuthal angle, φ. Microphone angle, θ, 100^0; jet exhaust velocity 925 ft/sec (PR 1.7).

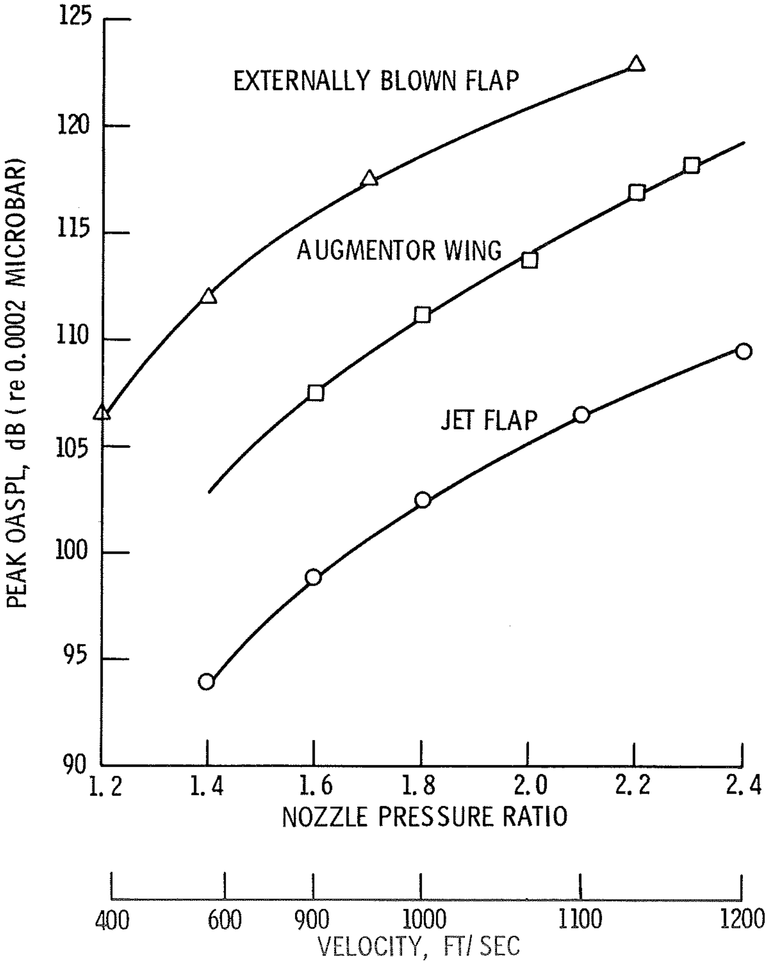

Figure 20. - Variation of peak overall sound pressure level below blown flap wing models with nozzle pressure ratio. Flap exhaust turning angle, 50^0; distance, 10 feet; nozzle area (normalized), 3.45 in.^{2}; nominal total temperature, 50^0 F.

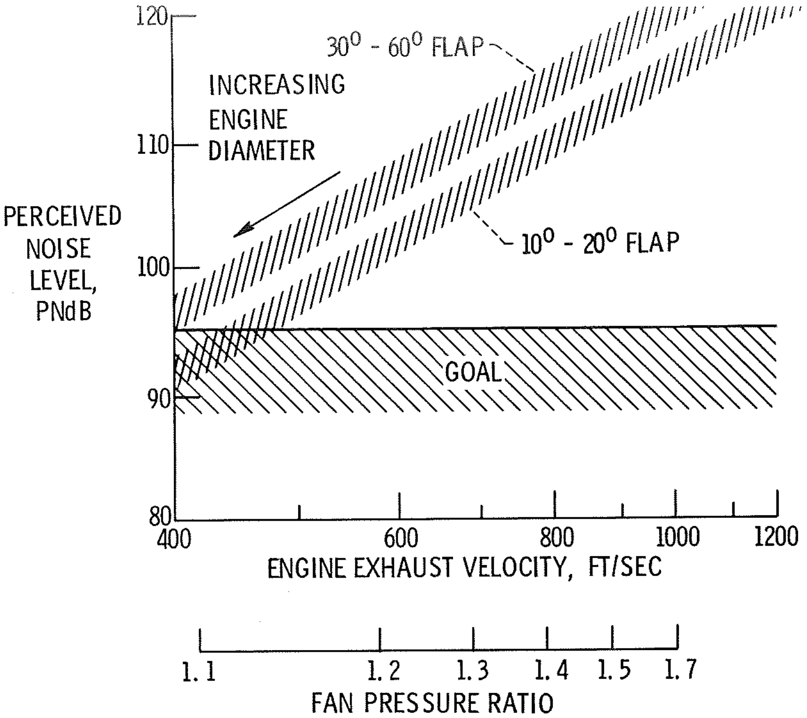

Figure 22. - Peak noise estimates for externally blown flap for 500 foot flyover as a function of engine exhaust velocity. Aircraft gross weight, 100 000 lbs; total thrust (4 engines), 60 000 lb_f.

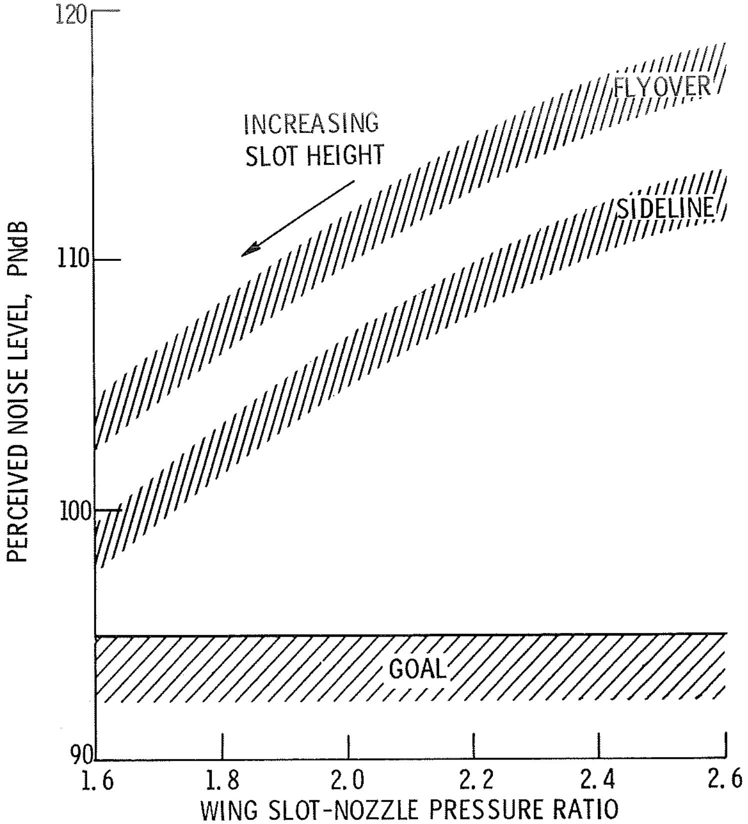

Figure 21. - Peak perceived noise level estimates for augmentor wing flap at 500 feet as a function of wing slot pressure ratio. Aircraft gross weight, 100 000 pounds; wing thrust 38 000 lb_f; airspeed, 80 knots.