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GEOMETRIC FACTORS AFFECTING NOISE SUPPRESSION AND THRUST LOSS OF DIVERGENT-LOBE SUPERSONIC JET NOISE SUPPRESSOR

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16. Abstract

The thrust loss and noise suppression of a divergent-lobe supersonic jet noise suppressor were experimentally determined over a range of nozzle pressure ratios of 1.5 to 4.0. These small-scale cold flow tests were made to determine the effect on thrust and noise of: suppressor length, rearward facing step height, suppressor divergence angle, and ejector shroud length and location. Noise suppression was achieved at nozzle pressure ratios of 2.5 and greater. Maximum lobe jet noise attenuation of 15 dB with thrust loss differences of 1.5 percent compared to the convergent nozzle were obtained at a nozzle pressure ratio of 3.5 with an ejector shroud two nozzle diameters long. Without the ejector the attenuation was 13 dB with thrust loss differences of 11 percent. Short suppressors approximately one primary nozzle throat diameter long performed as well as longer suppressors. Rearward facing step height had a significant effect on noise suppression. Ejector shrouds two nozzle diameters in length are feasible.

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SUMMARY

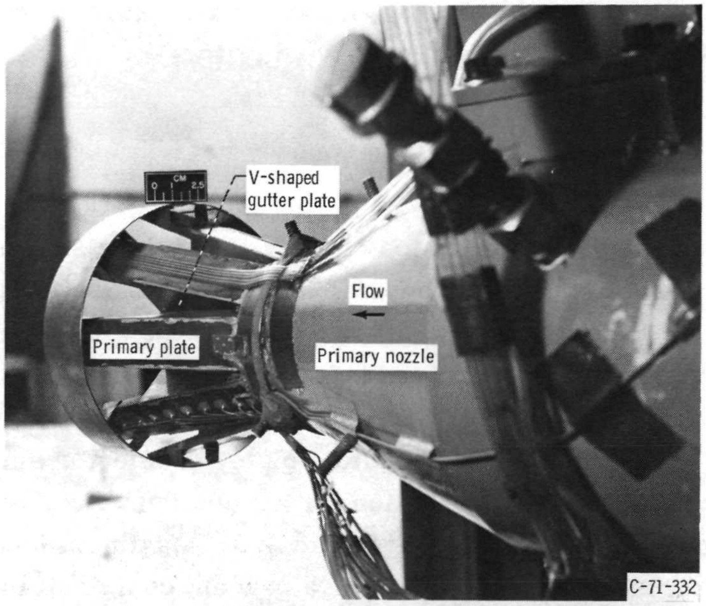
The thrust loss and noise suppression of a divergent-lobe supersonic jet noise suppressor were experimentally determined over a range of nozzle to atmospheric pressure ratios of 1.5 to 4.0. These small-scale (7.62-cm throat diameter) cold-flow tests were made to determine the effect on thrust and noise of such geometric factors as: (1) suppressor length (primary plate length), (2) rearward facing step height, (3) primary plate divergence angle, (4) length of V-shaped gutter plate, (5) ejector shroud length, and (6) ejector axial location. Noise attenuation for all configurations tested was accomplished between nozzle pressure ratios of 2.5 to 4.0. Maximum lobe jet noise attenuations of 15 dB with thrust loss difference of 1.5 percent compared to the convergent nozzle were obtained at a nozzle pressure ratio of 3.5.

These tests show that a suppressor as short as one primary nozzle throat diameter long is feasible; that the rearward facing step height affects, primarily, the suppression and not the thrust; the optimum primary plate divergence angle is 15°; and that the length of the ejector shroud can be as short as two primary nozzle throat diameters.

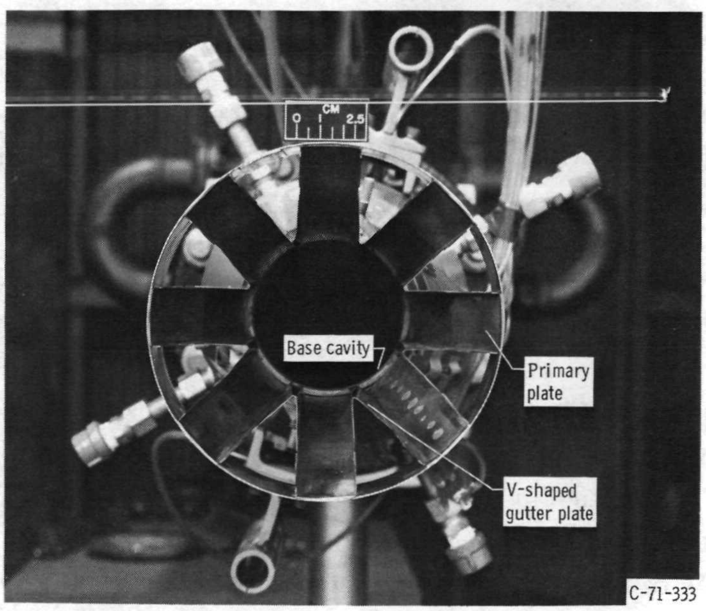
INTRODUCTION

Jet aircraft in the future will be larger and cruise faster than present day aircraft and will necessitate higher thrust engines. Greater thrust can be obtained with larger engines and/or increased jet exit velocity. Jet noise, however, is proportional to the area of the jet and, within the operating range of concern of this report, either the third or eighth power of the jet velocity (refs. 1 and 2). Hence, more jet noise may be generated by the engines of future high-speed jet aircraft. Increasing the size of the jet to produce the desired thrust while minimizing the increase in jet velocity in order to achieve low noise may result in large nacelle drag and weight penalties. The higher jet velocity of a smaller overall diameter engine may be preferable, provided an adequate jet noise suppressor is available for use near airports. In the search for a suitable suppressor nozzle, large numbers of jet noise suppressors have been tested. A summary of several types is given in reference 3.

Reference 4 reported a new device for reducing jet noise. The suppressor nozzle is of the convergent-divergent type shown in figure 1 and uses strong internal shocks to reduce the jet velocity. The initial exploratory work reported in reference 4 considered



(a) Nozzle viewed in direction of jet efflux.



(b) Rear view of nozzle.

Figure 1. - Divergent-lobe nozzle as installed in test facility; configuration 1-V(1.33).

only a 15° divergence angle of the divergent-lobe section, two ejector lengths, two lengths of the V-shaped gutter plates, and a single rearward facing step at the nozzle throat. Because of the potential for noise suppression found in the initial work, additional experimental work was undertaken to determine the effect of further variations of the geometric parameters noted previously (e.g., the effect of shortening the primary plates and the effect of varying the axial position of the ejector) on both the noise suppression and the thrust loss. The experiments were made at the NASA Lewis Research Center using a cold flow air facility.

The primary convergent nozzle used in these experiments had a nozzle throat diameter of 7.62 centimeters. The air temperature was approximately 280 K, and the nozzle pressure ratio was varied from 1.5 to 4.0. Thrust and noise measurements were made for systematic changes in suppressor nozzle geometry.

Thrust loss is presented using the theoretical thrust of a convergent nozzle as the reference nozzle. The jet noise attenuation is presented as the difference of the maximum lobe sound pressure level of the plain convergent nozzle and the sound pressure level (SPL) of the suppressor nozzle.

Suppressor Description and Operation

A detailed description of the divergent-lobe nozzle is given in reference 4. A brief summary of the description and operation of the suppressor is given here to aid the reader in understanding the aerodynamics of the divergent-lobe suppressor nozzle.

The suppressor uses the pumping action of the jet leaving a convergent (primary) nozzle on a base cavity to create a low pressure region in a diverging multilobe passage downstream of the primary nozzle exit (figs. 1 and 2). The base cavity pressure is much lower than ambient pressure. The low pressure causes the flow to overexpand and fill the divergent-lobe section of the nozzle. The overexpansion results in a higher supersonic Mach number than would have resulted from a free expansion of the air from the convergent nozzle to ambient pressure. In any supersonic flow the higher the Mach number of the flow the stronger the shock is and this results in a lower Mach number downstream of the shock. When the flow enters the divergent-lobe section of the nozzle and experiences the overexpansion to the base cavity static pressure, the Mach number is increased far above the Mach number obtainable in a free expansion from the plain convergent nozzle. A strong system of shocks exist in the divergent-lobe section of the nozzle due to the impingement of the supersonic flow on the nozzle wall and the necessary adjustment of the jet static pressure to ambient pressure. This shock system results in a more rapid decrease in the jet Mach number and hence velocity then exists for the flow from a plain convergent nozzle operating at an identical nozzle pressure ratio

P_N/p_o. The resulting lower jet velocity yields less noise than the plain convergent nozzle due to the noise dependence on the third or eighth power of the jet velocity.

An additional noise benefit results from the splitting of the flow between the lobes in the divergent section of the nozzle: the several smaller jets create a flow pattern similar to the multitube jet noise suppressors in current use.

APPARATUS

Nozzle Configurations

Figure 2 is a drawing of the basic nozzle with the nomenclature used for the nozzle parts. Table I lists the configurations and their dimensions. The configuration coding

TABLE I. - CONFIGURATION PERTINENT DIMENSIONS

[7.62-cm throat; convergent primary nozzle.]

Configuration number/designation	Primary plate angle, θ, deg	Primary plate length, L_p, cm	V-shaped gutter plate length, L_V, cm	Ejector shroud length, L_e, cm	Step height, h, cm
1-V(0.50)	15	13.49	3.81	None	0.318
1-V(0.75)			5.72	None	
1-V(0.75)-E(4)			5.72	30.48	
1-V(1.00)			7.62	None	
1-V(1.00)-E(4)			7.62	30.48	
1-V(1.17)			8.89	None	
1-V(1.17)-E(4)			8.89	30.48	
[a]1-V(1.33)			10.16	None	
[a]1-V(1.33)-E(4)			10.16	30.48	
[a]2-V(0.75)		10.59	5.72	None	
[a]2-V(0.75)-E(2)				15.24	
2-V(0.75)-E(3)				22.86	
2-V(0.75)-E(4)				30.48	
2-V(0.75)-0		11.67		None	.000
2-V(0.75)-E(2)-0		11.67		15.24	.000
3-V(0.75)		6.83		None	.318
3-V(0.75)-E(2)		6.83		15.24	
4-V(0.55)	20	10.21	4.22	None	
4-V(0.55)-E(2)	20	10.21	4.22	15.24	
5-V(1.14)	10	20.11	8.69	None	
5-V(1.14)-E(3)	10	20.11	8.69	22.86	
5-V(1.14)-E(4)	10	20.11	8.69	30.48	
6-V(0.75)	15	6.83	5.72	None	
6-V(0.75)-E(2)	15	6.83	5.72	15.24	

[a]Configurations reported on in ref. 4.

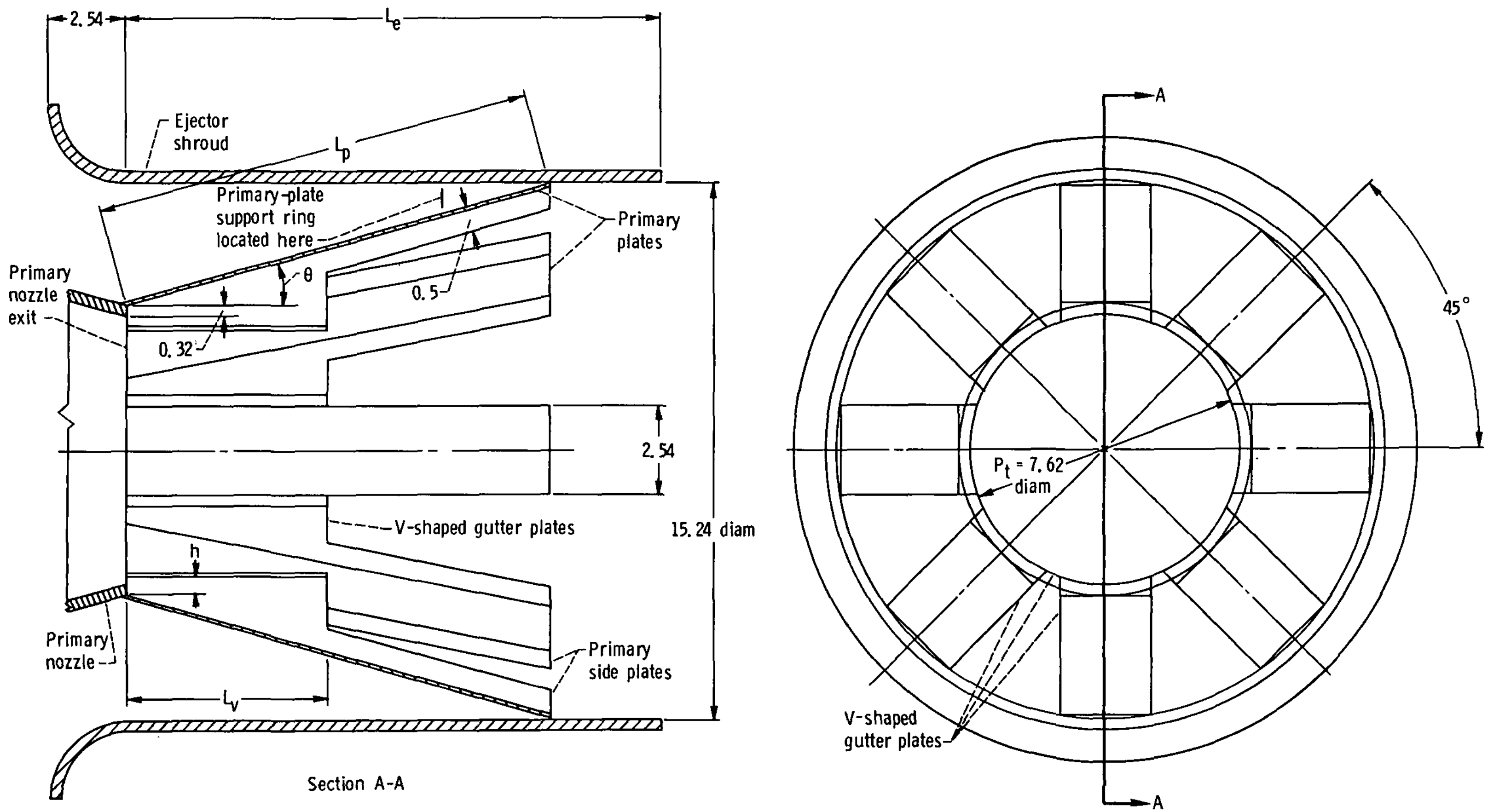


Figure 2. - Divergent-lobe suppressor nozzle. (All dimensions in cm unless indicated otherwise.)

used in reference 4 has been used in this report for continuity reasons. A brief explanation follows here:

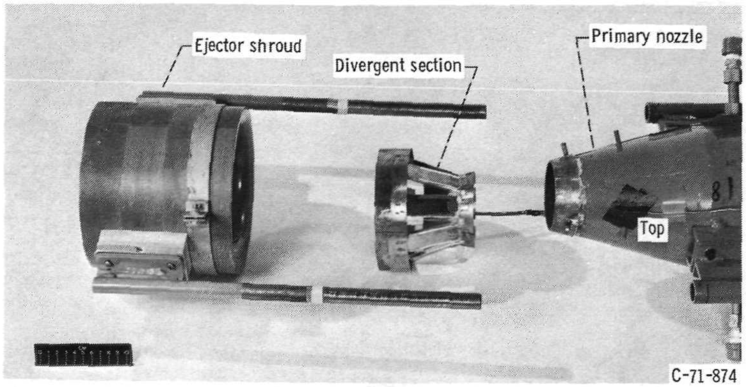
$$\text{Configuration number} - \mathrm{V}\left(\begin{matrix}\text{Length of V-shaped gutter} \\ \text{plate in primary nozzle} \\ \text{throat diameters,} \\ L_V/D_t\end{matrix}\right) - \mathrm{E}\left(\begin{matrix}\text{Length of ejector in} \\ \text{primary nozzle} \\ \text{throat diameters,} \\ L_e/D_t\end{matrix}\right) - 0$$

The configuration number refers to the primary plate angle and length (columns 2 and 3). The V used in the code refers to the V-shaped gutter plates (column 4); the E refers to the ejector (column 5); the 0 denotes a zero step height at the throat (column 6). In all other configurations the step height was constant at $h/D_t = 0.042$. The configuration number is sometimes used alone when the lengths of the V-shaped gutter plates or ejectors are not necessary. Data for configuration numbers 1-V(1.33), 1-V(1.33)-E(4), 2-V(0.75), and 2-V(0.75-E(2) have been reported in reference 4 and are used in this report for comparison purposes. The ejector inside diameter was two primary nozzle diameters. The ejector inlet was positioned as shown in figure 2 with the cylindrical section beginning in the plane of the primary nozzle exit except for the ejector position tests.

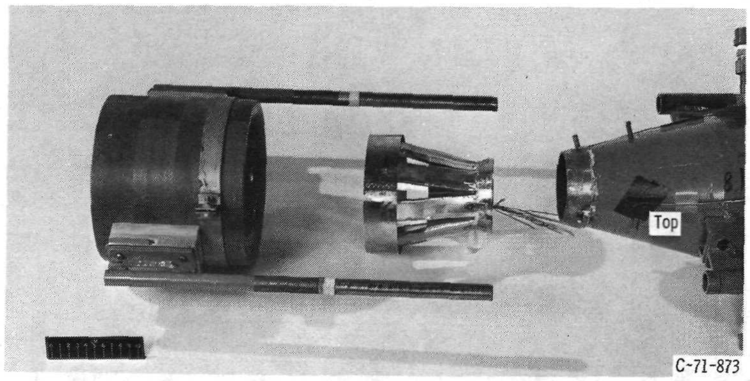
Configurations 1 to 3 have a primary plate divergence angle θ of 15°. Configurations 4 and 5 have primary plate angles of 20° and 10°, respectively. Photographs of configurations with the three plate angles are shown in figure 3. The exploded views show the three basic parts of the divergent-lobe suppressor nozzle. They are the primary nozzle (convergent), the divergent-lobe section, and the ejector shroud. The lengths of the V-shaped gutter plates for these three configurations were selected so that the ratio of the flow area at the end of the V-shaped gutter plates to the primary nozzle throat area equaled 1.85.

Configuration 2 was used to vary the height of the rearward facing step and ejector length. Configuration 3 was the same as configuration 2, but with the primary plates cut off just downstream of the V-shaped gutter plates.

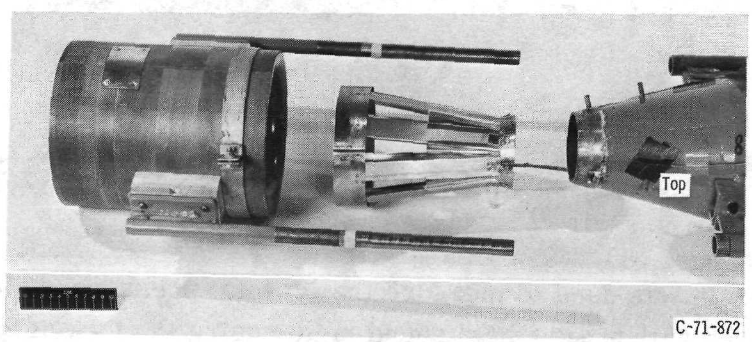
Configuration 2-V(0.75)-0 had slightly longer primary plates than the other configurations labeled as 2, due to the smaller step height requiring the added length for the primary plates to reach the inside wall of the ejector. Configuration 6-V(0.75) was a modification of configuration 3-V(0.75). Figure 1 shows configuration 1 which had a band around the end of the primary plates for structural reasons. A similar band was also used on configuration 3. For configuration 6 this band was removed and replaced with a 1.59-millimeter-diameter wire soldered directly to the back of the primary plates. This small wire allowed an essentially unobstructed flow path during the ejector axial position optimization tests with the short primary plates of configuration 3.



(a) Primary plate angle θ = 20°.



(b) Primary plate angle θ = 15°.



(c) Primary plate angle θ = 10°.

Figure 3. - Exploded view photographs showing three basic parts of divergent-lobe suppressor nozzle and the configurations used to study effect of primary plate angle.

Facility Description and Instrumentation

The facility used for this work is described in detail in reference 4. A brief description is given here. Figure 4 is a facility piping schematic. The flow rate is measured using an orifice plate and controlled by a valve in the supply line. Flexible joints between the supply line and pipe which terminates in the test nozzle give the pipe freedom to move in the axial direction. The axial motion is restrained by a load cell that measures the thrust of the jet in the axial direction. A nozzle total pressure probe just

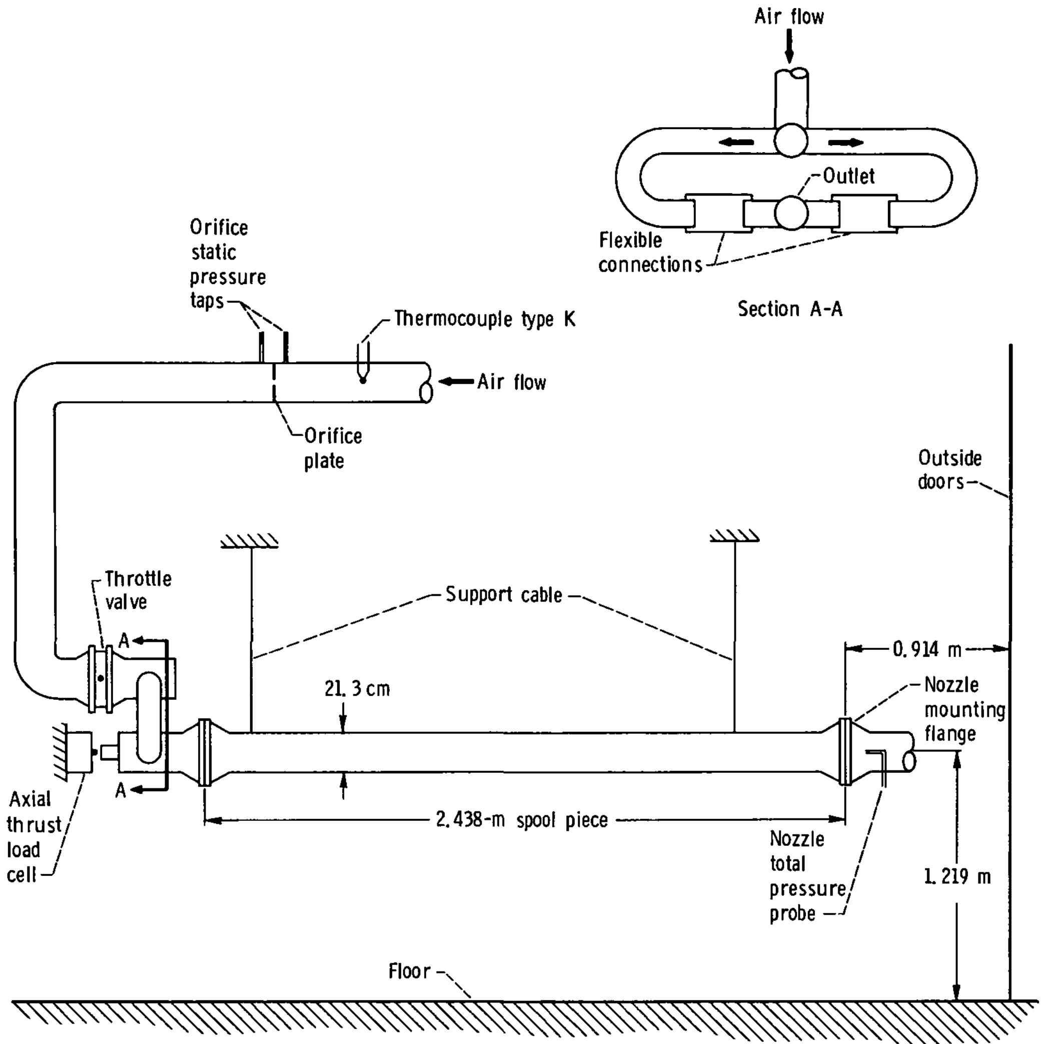


Figure 4. - Air flow and thrust measuring system.

upstream of the nozzle was used to measure the jet total pressure. The sound pressure levels were measured with a hand-held sound meter using the C-weighted compensating filter network. The sound readings were taken around a circle having a radius of 6 meters and a center located at the throat of the convergent section of the nozzle. Details of the sound field are given in reference 4.

Test Procedure and Data Reduction

The total pressure at the nozzle inlet was adjusted using the throttle valve to give ratios of jet total to atmospheric pressure of 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0. At each of these pressure ratios the thrust and sound readings were recorded. The total temperature of the air ranged from 280 to 285 K.

The ideal conical nozzle net thrust was calculated as given in reference 4 and was used for comparison purposes in determining the thrust loss which is defined as the difference between the conical convergent nozzle ideal net thrust $F_{n,th}$ and the measured net thrust $F_{n,exp}$ divided by the ideal conical net thrust $F_{n,th}$, converted to a percentage. The sound readings were taken at 15°, 30°, 45°, and 60° locations measured from the downstream jet axis centerline. Details are given in reference 4.

The attenuation of a particular configuration was defined as the difference between the maximum C-weighted sound pressure level (SPL) of the plain convergent nozzle (primary nozzle) and the maximum C-weighted SPL of the convergent nozzle plus the divergent-lobe suppressor. Hence, the plain convergent nozzle was used as the reference. The maximum C-weighted SPL angular location was between 30° to 45° measured from the downstream jet axis.

RESULTS AND DISCUSSION

In the following sections the thrust loss and noise attenuation are plotted as a function of nozzle pressure ratio P_N/p_o. These plots give the basic data for each of the test configurations. Cross plots of these data showing the effect of primary plate divergence angle, length of V-shaped gutter plate, and ejector shroud length are also included. The effect of primary plate length and rearward facing step height are shown by comparison of the basic data plots.

In general the basic data show that noise attenuation exists when the nozzle pressure ratio P_N/p_o is 2.5 or greater. This is a direct result of the attachment of the flow from the primary nozzle to the primary plates at a pressure ratio of 2.5. As should be expected, pressure ratios greater than or equal to 2.5 result in noise attenuation, and ratios less than 2.5 resulted in little attenuation or even more noise being generated than the plain convergent nozzle. Hence the emphasis in the following discussion will be placed on the data for nozzle pressure ratios equal to or greater than 2.5 where the flow is attached to the divergent-lobe section of the nozzle. The thrust loss curve as a function of nozzle pressure ratio for the plain convergent nozzle is shown in figure 5(a). The thrust loss on the order of 2 to 3 percent is about what could be expected with a plain convergent nozzle.

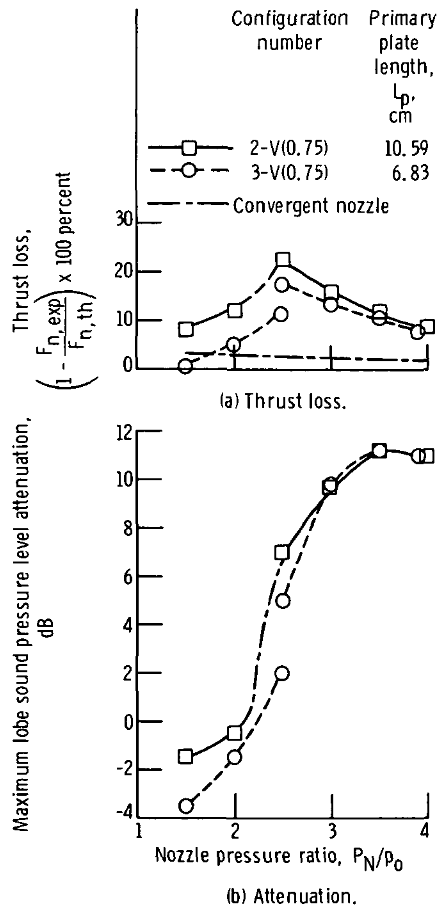


Figure 5. - Effect of primary plate length on thrust loss and noise attenuation as a function of nozzle pressure ratio.

Short Primary Plates

The divergent-lobe suppressor nozzle reported in reference 4 (configurations 1 and 2, table I), used primary plates that extended nearly one throat diameter past the end of the V-shaped gutter plates. This shielded the primary flow and delayed the velocity decrease due to mixing. In a real nozzle with the primary flow operating at elevated temperature levels, the temperature of the primary plates must be considered. In order to minimize the heat transfer problem and promote the velocity decay of the primary plate flow, the primary plates of configuration 2-V(0.75) were cut off just downstream of the V-shaped gutter plates. This modification is designated configuration 3.

Figure 5 compares the thrust loss and attenuation of the short primary plates of configuration 3 to the longer plates used for configuration 2-V(0.75). Configuration

2-V(0.75) was considered to be the best configuration reported in reference 4. Inspection of figure 5 shows that the thrust loss (fig. 5(a)), is lower for the shortened primary plates (configuration 3) than it is for the longer plates (configuration 2). The attenuation (fig. 5(b)) of configuration 2 and 3 is the same above a pressure ratio of 3.0. Near a pressure ratio of 2.5 where the flow is close to detaching from the primary plates, the attenuation drops about 2 dB for the shortened primary plates. Because of the lower thrust loss and the negligible effect on attenuation that shortening the primary plates had, it appears that configuration 3 is better. Configuration 3 has less material and less material surface exposed to the hot gases. These are important factors in the design of a suppressor.

The thrust loss and the noise attenuation are plotted as a function of pressure ratio in figure 6 for configuration 3 with and without a two diameter D_t long ejector. The ejector did not significantly affect the thrust loss or the attenuation above nozzle pressure ratios of 2.5.

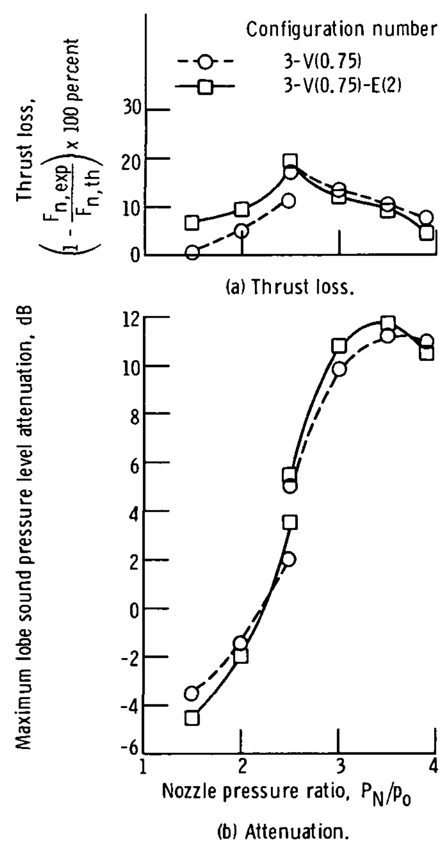


Figure 6. - Thrust loss and noise attenuation as a function of nozzle pressure ratio for short primary plate configuration with and without ejector.

Rearward Facing Step Height

The role of the rearward facing step in the aerodynamics of the divergent-lobe suppressor nozzle is to create a base area for the flow to expand into. Due to the shear of the flow over the base cavity, the pressure in the base cavity is reduced far below atmospheric pressure. This causes the flow to overexpand. In turn then, when the supersonic flow impinges on the primary plates, a strong oblique shock positions itself at the impingement point. The strength of the shock depends on the Mach number of the expanded flow and the angle that the flow must turn through to flow along the primary plate. It is reasonable to expect that the height of the step should control to some extent the shock strength and hence the downstream Mach number, which should, in turn, affect the noise level.

To determine the effect of step height on the attenuation and thrust loss, the basic design of configuration 2-V(0.75) was used to construct a divergent-lobe suppressor with a zero step height. The construction using flat primary plates allowed the centerline of the plates to intersect the convergent nozzle lip, thus giving a zero step height at this point. Since the primary plates were flat, a slight step remained at the corners of the V-shaped gutter plates and the primary plate. This was not considered significant for the information required.

The thrust loss and attenuation for the zero step height configuration 2-V(0.75)-0 and the 0.32-centimeter step height configuration 2-V(0.75) are shown in figure 7 as a function of nozzle pressure ratio. The thrust loss, figure 7(a), is not affected by the step height in the pressure ratio range at and above 2.5. Below this value where the flow detaches from the primary plates having a step, the no step configuration allows the flow to remain attached and hence the thrust loss remains higher due to the low plate static pressure. The attenuation, figure 7(b), is about 2.0 dB greater for the configuration having the 0.32-centimeter step height. This holds over the attached flow pressure ratio range from 2.5 to 4.0. Therefore, it is concluded that, over the pressure ratio range where the flow is attached to the primary plates, the rearward facing step is a desirable feature of the divergent-lobe suppressor nozzle.

Primary Plate Angle

In the discussion concerning step height, the turning angle of the flow at the point of impingement on the primary plates was mentioned as a factor in the strength of the oblique shock, the downstream velocity and hence the noise. To determine the effect of the primary plate angle on the thrust loss and attenuation, configurations having primary plate angles of 10°, 15°, and 20° were constructed; these were called configurations

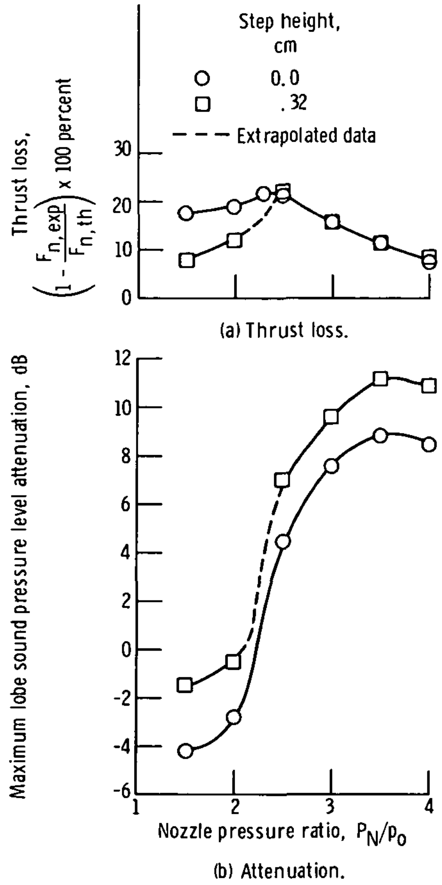


Figure 7. - Effect of step height on thrust loss and attenuation as a function of nozzle pressure ratio. V-shaped gutter plate length, 5.72 centimeters; primary plate angle, 15°; configuration 2-V(0.75).

5-V(1.14), 2-V(0.75), and 4-V(0.55), respectively.

Figure 8 is a plot of the thrust loss and the attenuation as a function of the nozzle pressure ratio for the three primary plate angle configurations tested. The thrust loss (fig. 8(a)) of the 10° and 15° configurations is the same at and above a pressure ratio of 2.5. The thrust loss of the 20° configuration is significantly (5 to 8 percent) higher than the 10° and 15° models over the same pressure ratio range. The thrust loss of the 20° configuration seems to be decreasing with pressure ratio at a higher rate than that of the 10° and 15° models.

The attenuation is shown in figure 8(b) for the three plate angle configurations tested. The greatest attenuation was achieved with the 15° primary plate angle. This reached its peak attenuation at a pressure ratio of 3.5. A pressure ratio of 3.5 also yields the peak attenuation for the 10° configuration. The 20° configuration has not quite reached its peak at a pressure ratio of 4.0.

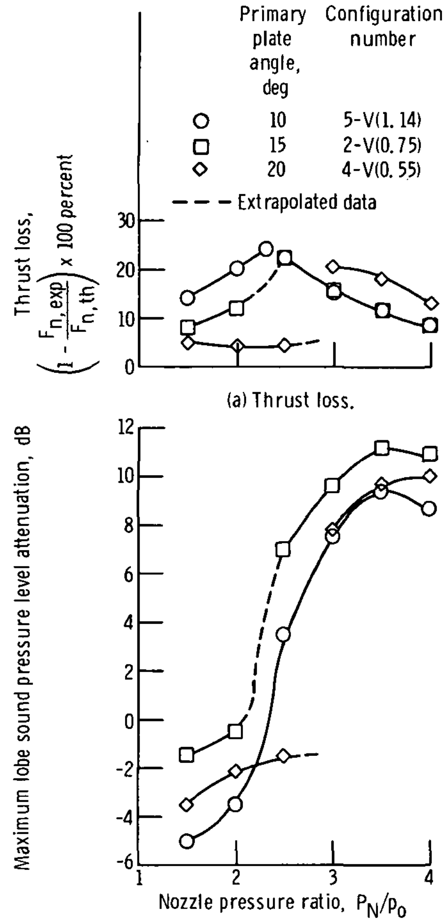


Figure 8. - Effect of primary plate angle on thrust loss and attenuation as a function of nozzle pressure ratio.

Figure 9 is a cross plot of the data shown in figure 8. Here the thrust loss and attenuation are plotted as a function of the primary plate angle for each pressure ratio between 2.5 and 4.0. Figure 9(a) shows that the thrust loss is constant between 10° and 15° and then increased with primary plate angle except when the flow detached from the primary plates as it did in the case of the 20° plate at a pressure ratio of 2.5. The attenuation (fig. 9(b)), as was pointed out in the discussion of figure 8(b), maximizes at the 15° primary plate angle and a nozzle pressure ratio of 3.5.

The near maximum attenuation is obtained with a primary angle of 15°. The nozzle pressure ratio giving the lowest thrust loss for a 15° primary plate angle is, from figure 9(a), 4.0. However, if more thrust loss is tolerable, lower pressure ratios could be used.

It is concluded from the previous discussion that the 15° primary plate represents

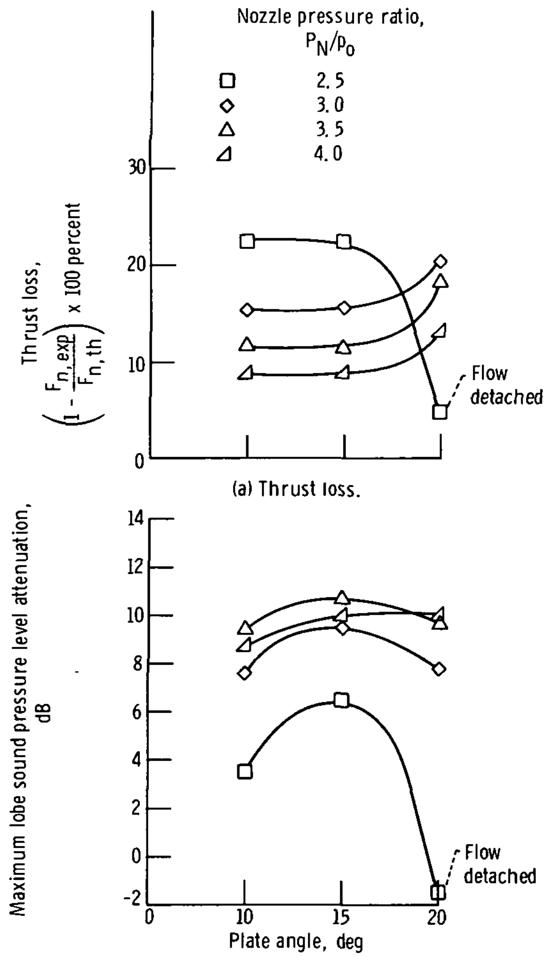
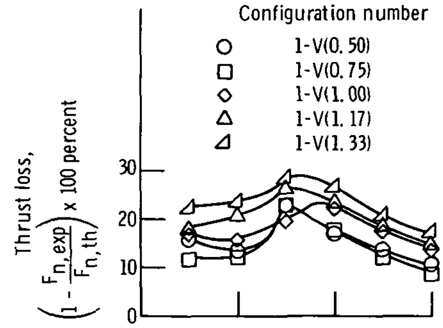


Figure 9. - Variation of thrust loss and attenuation with primary plate angle average of nozzle pressure ratios.

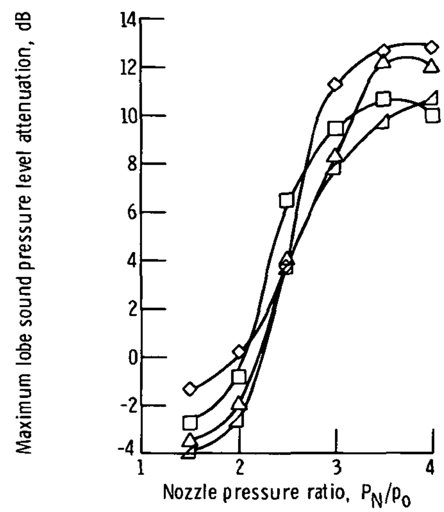
the best choice. The 10° configuration gives lower attenuation for approximately the same thrust loss, while the 20° configuration has a larger thrust loss and little or no added suppression.

V-Shaped Gutter Plate Length

To determine the effect of the length of the V-shaped gutter plate on thrust loss and attenuation, several models were constructed using as their basic geometry that of configuration 1, but having different length gutter plates. Figure 10 is a plot of the thrust loss and attenuation as a function of nozzle pressure ratio for configuration 1 with varying lengths of the V-shaped gutter plates.



(a) Thrust loss.



(b) Attenuation.

Figure 10. - Effect of V-shaped gutter plate length on thrust loss and attenuation as a function of nozzle pressure. Primary plate angle, 15°.

Configurations 1-V(0.75) and 1-V(0.50) (in the region where the flow is attached to the primary plates) have the lowest thrust loss. Attenuation data for configuration 1-V(0.50) were not taken. The attenuation data for configuration 1-V(0.75), however, indicated that the shorter gutter plates, while having less thrust loss, provide a smaller attenuation than the longer gutter plate configurations.

Peak attenuations as a function of pressure ratio occur for configurations 1-V(1.00) and 1-V(1.17) at pressure ratios less than 4.0. Configuration 1-V(1.33) had the largest thrust loss. The attenuation of this configuration had not yet reached a peak at a nozzle pressure ratio of 4.0; however, its attenuation was approximately equal to that of configuration 1-V(0.75) at this pressure ratio.

The thrust loss and attenuation of figure 10 are plotted as a function of V-shaped gutter plate length in figure 11 for each nozzle pressure ratio above that which produced flow attachment to the primary plates. From figure 11(a) it is apparent that from the

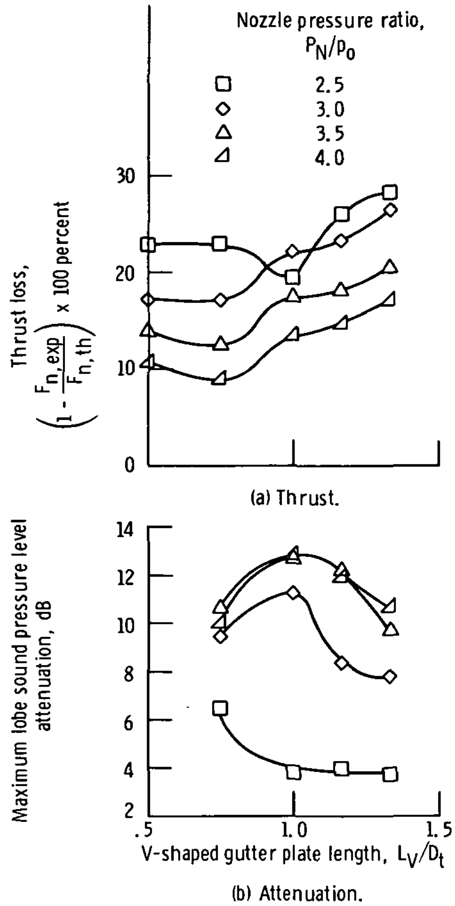


Figure 11. - Variation of thrust loss and attenuation with V-shaped gutter plate length over range of nozzle pressure ratios.

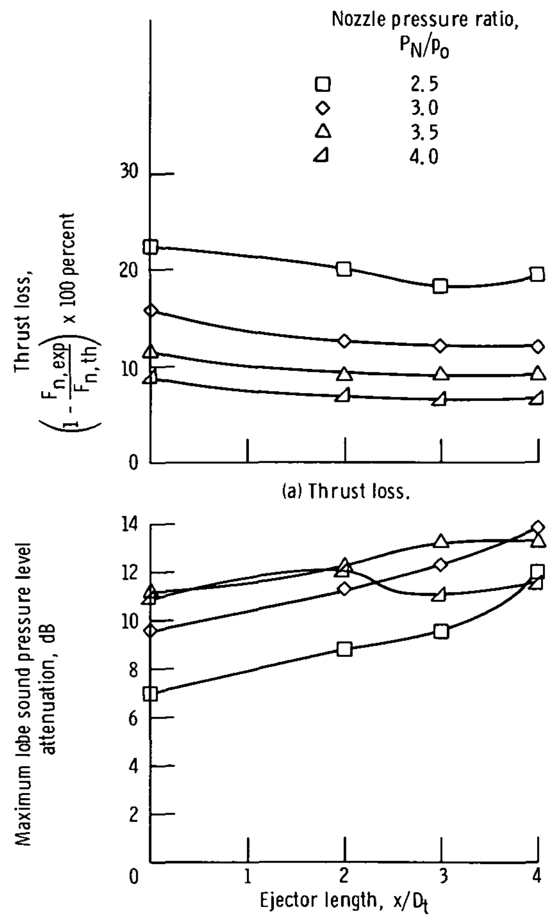
minimum thrust loss point of view, the length of the V-shaped gutter plates should be approximately 0.75 nozzle throat diameters. However, from the maximum attenuation point of view, figure 11(b), the V-shaped gutter plates should be about 1.0 nozzle throat diameters. Near the primary-plate flow-detachment nozzle pressure ratio of 2.5, these generalized conclusions do not hold true so that care must be exercised in selecting the gutter plate length at the lower nozzle pressure ratios. A compromise must be made between thrust loss and attenuation when selecting the length of the V-shaped gutter plates.

Ejector Shroud Length

The length of the ejector shroud may be critical in an actual airplane installation. To determine the effect of ejector shroud length on the thrust loss and attenuation, ejector shroud lengths of 2, 3, and 4 nozzle throat diameters were installed on configuration 2. During the initial phase of testing, no attempt was made to optimize the thrust by varying the position of the ejector inlet. The bellmouth portion of the ejector was fixed at the primary nozzle throat station. The thrust loss and attenuation as a function of ejector length are shown in figure 12 for the nozzle pressure ratios for which the flow was attached to the primary plates.

The thrust loss, figure 12(a), was constant within 2 percent over the ejector length variations from 2 to 4 nozzle throat diameters. Near the primary plate flow detachment pressure ratio of 2.5, the thrust loss tends to increase with ejector lengths greater than 3 diameters.

For nozzle pressure ratios of 2.5 to 3.5 the attenuation tends to increase with increasing ejector shroud length as shown in figure 12(b). This was not true for the pressure ratio 4.0 data. In an aircraft installation the shorter ejector is preferred.



(a) Thrust loss.

(b) Attenuation.

Figure 12. - Variation of thrust loss and attenuation with ejector length for nozzle pressure ratios from 2.5 to 4.0. Primary plate angle, 15°; configuration 2.

Ejector Axial Position

Configuration 6 was used in ejector positioning tests. The axial position of the ejector inlet was varied from 0.33 D_t upstream of the primary nozzle throat to 1.67 D_t downstream. An optimum position with regard to thrust loss was found at 1 D_t downstream from the primary nozzle throat. The results of the thrust loss and attenuation tests with the ejector at its optimum axial position, $x/D_t = 1$, are shown in figure 13. With the ejector installed in the optimum position, the thrust loss has been drastically reduced in the range of pressure ratios where the maximum attenuation exists ($P_N/p_o \sim 3.0$). The thrust loss for the plain convergent nozzle is also shown in figure 13(a). This curve differs from the curve shown in figure 5(a) for the plain convergent nozzle. The difference is believed to be due to a deterioration of the flexible joints (O-rings) used to isolate the nozzle from the air supply lines. The ejector axial position

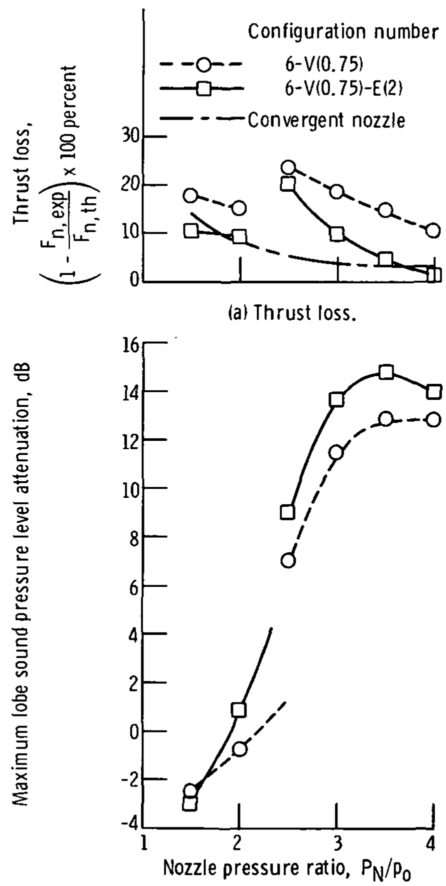


Figure 13. - Thrust loss and noise attenuation of divergent-lobe suppressor nozzle with ejector at optimum axial position $x/D_t = 1$. Configuration 6-V(0.75)-E(2).

tests were made at a considerably later date than the other tests, hence the seemingly drastic change in thrust loss for the convergent nozzle. The accuracy of the absolute value of the thrust loss referenced to the theoretical thrust of a convergent nozzle as plotted in figure 13(a) is therefore questionable. However, since the data for the plain convergent nozzle and the suppressor nozzle, configuration 6, were taken during the same day it can be assumed that thrust difference between the convergent and suppressor nozzles represent the true values of thrust loss. If the difference between the measured thrust of the plain convergent nozzle and the nozzle with the divergent-lobe suppressor is considered then; the thrust difference is near zero at nozzle pressure ratios above 3.5. Some thrust augmentation is apparent at pressure ratios of 4.0.

At a nozzle pressure ratio of 3.5 the peak lobe noise attenuation has reached nearly 15 dB (fig. 13(b)) with a thrust loss difference compared to the primary convergent nozzle, of only 1.5 percent.

CONCLUDING REMARKS

Unpublished NASA spectral data taken for configuration 3 of this report show that the lower frequencies are attenuated leaving the higher frequencies. Higher frequency noise may be treated by lining an ejector with suitable sound absorbing material (ref. 5). A reasonable estimate of the additional maximum lobe attenuation possible using a soft wall ejector, from reference 5, is 11 dB at 1600 hertz. An overall SPL attenuation of 6 dB might be expected in the high frequency range. This indicates a maximum lobe noise attenuation of 21 dB with a thrust loss difference of 1.5 percent is possible with the divergent-lobe suppressor nozzle compared to a convergent nozzle at a nozzle pressure ratio of 3.5.

CONCLUSIONS

Thrust loss and noise attenuation data were taken for a divergent-lobe suppressor nozzle which suppressed jet noise. The cold flow tests covered a range of nozzle pressure ratio from 1.5 to 4.0. The data showed that significant noise attenuation was achieved over the flow attachment pressure ratio range from 2.5 to 4.0.

The following specific conclusions apply in this range of pressure ratios:

1. A shortened version of the suppressor nozzle reported in TN D-6667 can be used with some (1 to 4 percent) decrease in thrust loss and no change in the noise attenuation.

2. The height of the rearward facing step located at the convergent nozzle throat did not affect the thrust loss, but increasing the step height increased the attenuation.

3. The primary plate divergence angle is approximately 15° for low thrust loss and high attenuation.

4. The V-shaped gutter plate for minimum thrust loss is 0.75 primary nozzle throat diameter.

5. The V-shaped gutter plate for maximum noise attenuation is one primary nozzle throat diameter.

6. A maximum lobe sound pressure level attenuation of 15 dB and a thrust loss difference of 1.5 percent compared to a convergent nozzle was achieved at a pressure ratio of 3.5 with a 2-diameter-long ejector.

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501-24.

APPENDIX - SYMBOLS

D_t	primary nozzle throat diameter, cm
F	thrust, N
h	rearward facing step height, cm
L	length, cm
P	total pressure, N/m^2
p	static pressure, N/m^2
T	total temperature, K
x	axial distance measured from the primary nozzle exit or throat station, cm
θ	primary plate divergence angle, deg

Subscripts:

e	ejector
exp	experiment
N	nozzle inlet
n	net
o	atmosphere
p	primary
t	throat
th	theoretical
V	V-shaped gutter plate

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