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NOISE EVALUATION OF FOUR EXHAUST NOZZLES FOR AFTERBURNING TURBOJET ENGINE

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SUMMARY

Sea level static tests were made of the jet noise characteristics of three different nozzle designs suitable for a supersonic cruise aircraft. A GE J85-13 afterburning turbojet engine was used as the gas generator. At military power, results obtained with a plug nozzle, a variable flap ejector, and an auxiliary inlet ejector were compared with that of a convergent primary nozzle. At full afterburning only the primary and two ejector nozzles were tested. The plug nozzle could not be tested when the engine was operating in the afterburning mode.

At military power the overall sound power level was lowest with the plug nozzle; it increased as the configuration was successively changed to the variable flap ejector, the primary nozzle, and the auxiliary inlet ejector. The sound power level for the auxiliary inlet ejector was 4 decibels higher than that of the plug nozzle. At maximum afterburning, the overall sound power level increased 5 to 6 decibels above that obtained at military power for each nozzle type. At maximum afterburning, the auxiliary inlet ejector and the primary nozzle sound power level were about 3 decibels higher than that for the variable flap ejector.

Based on the noise measurements made, for a flyover at 1000 feet (304.8 m) altitude, the maximum perceived noise level on the ground would be 6 decibels less with the plug nozzle than with the auxiliary inlet ejector.

INTRODUCTION

Engine exhaust noise during takeoff and climbout will be a problem for supersonic cruise aircraft if high thrust augmentation is used. Thrust augmentation will result in much higher exhaust velocities and thus more noise for supersonic aircraft than for subsonic aircraft.

The exhaust nozzle for a supersonic cruise aircraft could either be an ejector or a plug design since both types are capable of providing high levels of efficiency during supersonic cruise. Variable geometry is required to decrease the nozzle exit area for subsonic operation to prevent flow overexpansion and thrust losses. This makes the selection of the nozzle design quite difficult because a trade-off must be made between aerodynamic performance and system mechanical complexity. Other factors which must be considered in the design of the nozzle are the pumping of cooling air around the engine and the requirement for thrust reversal. An additional factor is the noise characteristics of the different designs.

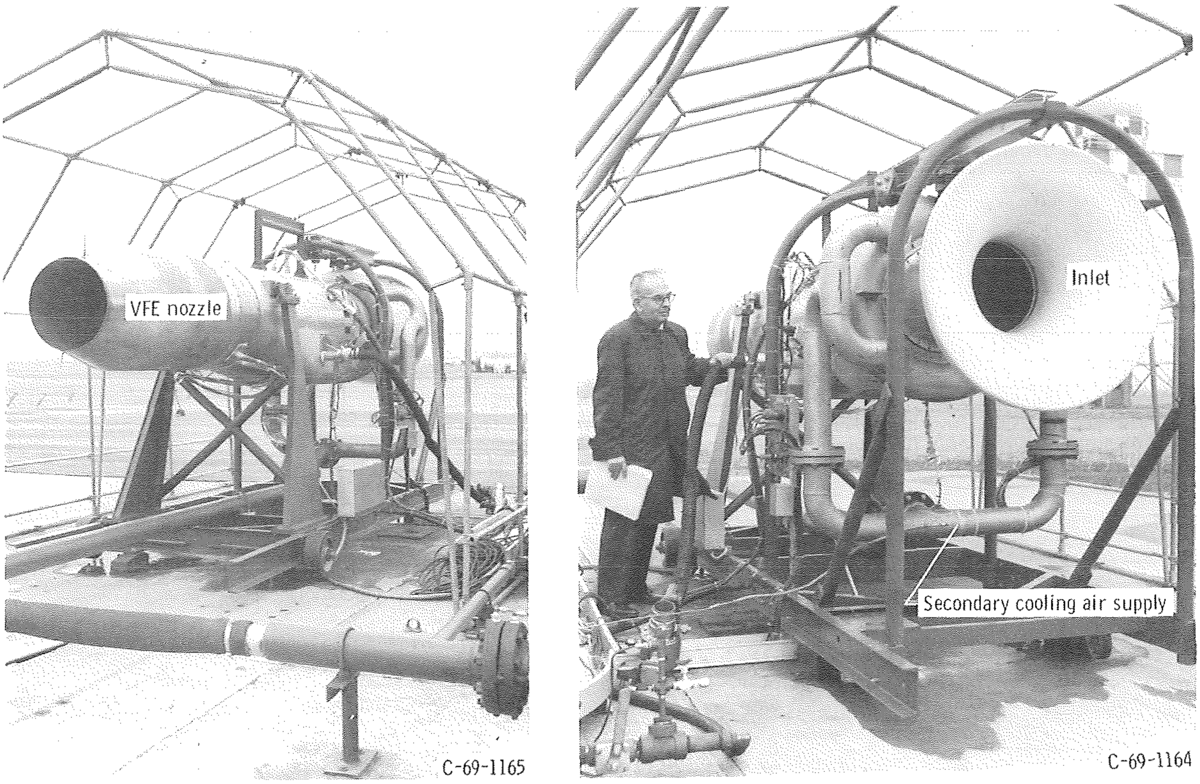
In a comprehensive airbreathing propulsion program, the Lewis Research Center is studying the performance of various types of exhaust nozzles designed for supersonic cruise aircraft. Nozzle performance is influenced by the flow field of the airplane on which it is installed. In the transonic speed range, a combined wind tunnel and flight research program is being conducted. The flight program (ref. 1) uses an F-106 aircraft modified to carry underwing podded engine nacelles housing J-85 afterburning turbojet engines. An engine nacelle and three exhaust nozzles built for the flight tests were used in the present noise evaluation program. The nozzles were a variable flap ejector, an auxiliary inlet ejector, and a low-angle conical plug nozzle. The results were compared to the noise characteristics of a simple convergent nozzle. The results of the tests in a sea level static stand are presented herein.

SYMBOLS

AIE	auxiliary inlet ejector
A_p	area of primary nozzle exit, in.^{2} (cm^2)
A_s	area of ejector nozzle exit, in.^{2} (cm^2)
D_p	diameter or primary nozzle, in. (cm)
D_s	diameter of ejector nozzle, in. (cm)
L	length between exit planes of primary and ejector nozzles, in. (cm)
PN	perceived noise level, dB
S	length between primary nozzle exit and ejector nozzle throat, in. (cm)
VFE	variable flap ejector

APPARATUS AND PROCEDURE

The test stand is shown in figure 1. The test engine was mounted within the nacelle and was supplied with smooth inlet flow by the bellmouth. Secondary cooling air around



(a) Rear view of variable flap ejector nozzle installed. (b) Front view.

Figure 1. - Engine test stand for nozzle noise evaluation tests.

the engine was supplied by the manifold system shown at the front of the nacelle. The tubular structure appearing around the test stand was used to support a work tent between runs. During a run, it was completely removed.

The test stand was located in an open area as a free nonreverberant sound field. There were no reflections from buildings which would affect the data by more than 1/2 decibel. Sound measurements were made with 1/2-inch (1.27-cm) diameter condenser microphones mounted on stands in a horizontal plane through the engine centerline at an elevation of 60 inches (152.4 cm). Frequency response of these microphones for normal incidence was flat to within 1 decibel over the frequency range used. The microphones were calibrated prior to each test with a stable 121-decibel battery-driven speaker. The microphones together with their preamplifiers were located on a 150-foot (45.8-m) radius around the engine at 10° increments as shown in figure 2. Sound pressure levels (in dB) for each microphone, were recorded and analyzed into 1/3 octave frequency components.

The turbojet engine used was a General Electric J85-13 with a mechanically actuated, converging, variable, primary nozzle attached to the afterburner. This engine is of single spool design with an eight-stage axial flow compressor and a two-stage turbine. Its

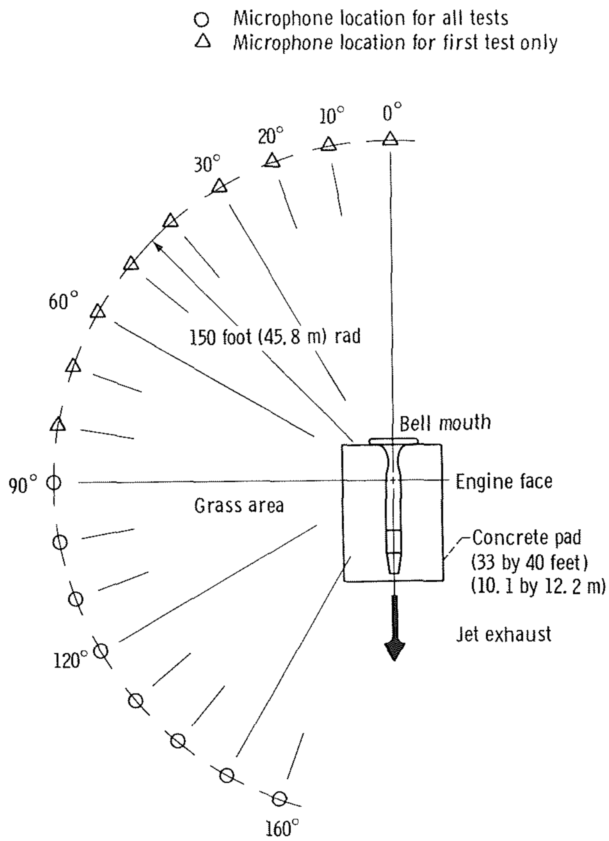
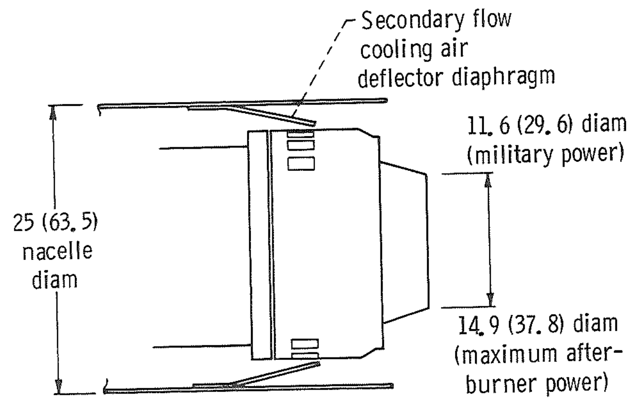


Figure 2. - Microphone locations.

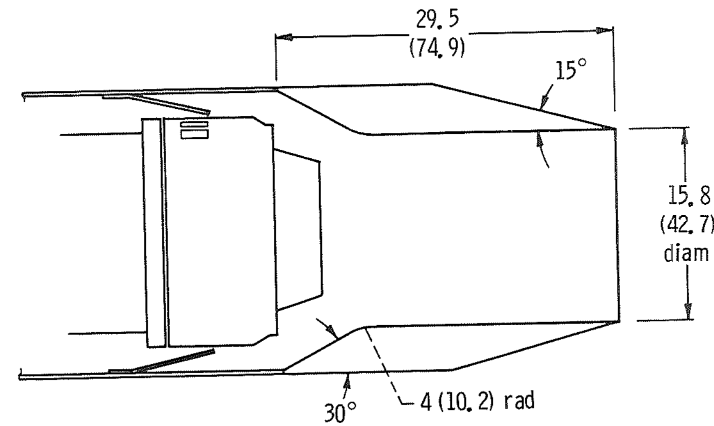
weight is approximately 600 pounds (270 kg). At sea-level standard conditions it is rated as follows: air consumption, 44 pounds per second (20 kg/sec); nozzle pressure ratio, 2.3 to 1; military power thrust, 2720 pounds (12 100 N); maximum thrust with afterburner on, 4080 pounds (19 100 N). The engine nozzle flow parameters (from ref. 2) are given in table I.

TABLE I. - J-85GE-13 TURBOJET NOZZLE FLOW PARAMETERS

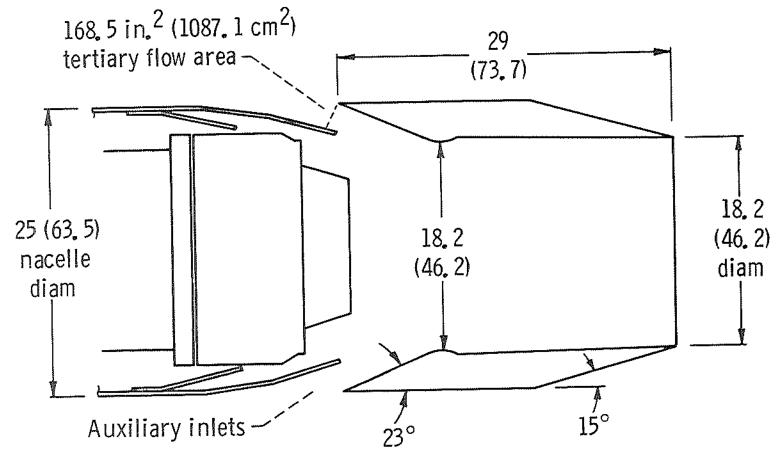
	Ratio absolute nozzle pressure to ambient pressure	Exhaust gas temperature		Primary weight flow rate		Primary area	
		^{o}R	K	lb/sec	kg/sec	in.^{2}	cm^2
Military power	2.29	1785	991	44	20	107	690
Maximum afterburner power	2.13	3640	2022	44	20	174	1124



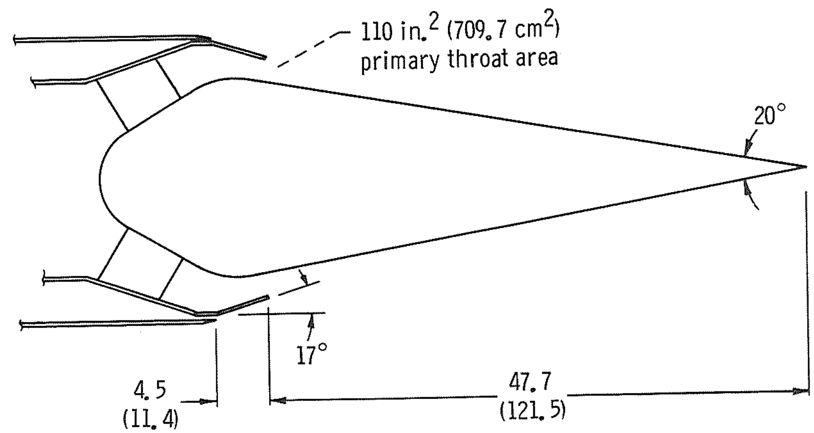
(a) Primary nozzle.



(b) Variable flap ejector nozzle (VFE).



(c) Auxiliary inlet ejector nozzle (AIE).



(d) Plug nozzle.

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Figure 3. - Nozzles used in noise evaluation test. (All dimensions are in inches (cm).)

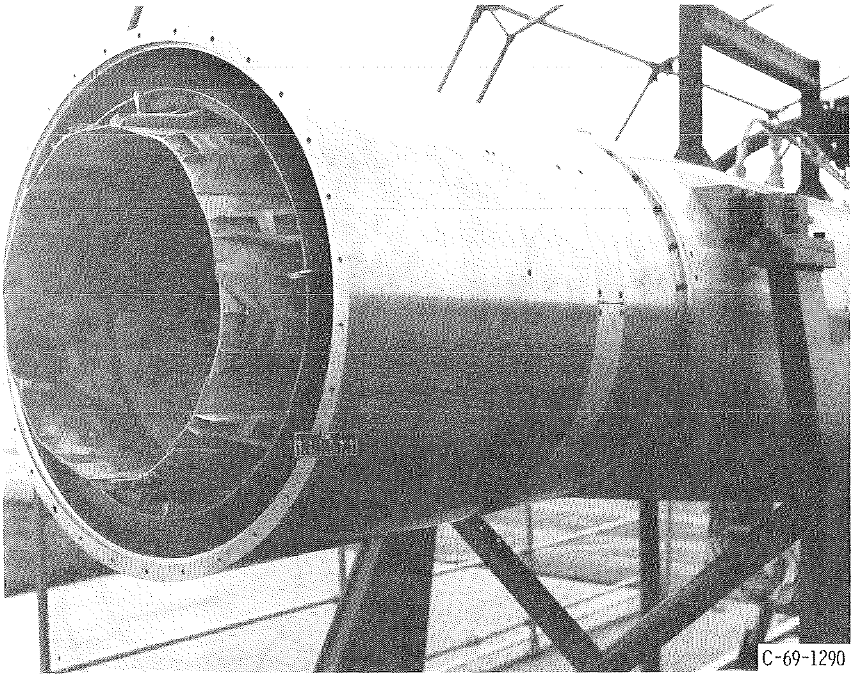

Figure 4. - Primary nozzle.

The engine primary nozzle is shown in figures 3(a) and 4. It was partially shrouded by a cylindrical extension of the nacelle. The exit area of the nozzle can be varied by translating leaves which also change the exit flow convergence angle. A flow diverter located in the secondary flow passage directs the cooling air over these leaves.

The variable flap ejector (VFE) nozzle is shown in figures 1(a) and 3(b). It is a fixed geometry version of a high Mach number (approx. 2.7) nozzle in the position appropriate for low speed operation. Further information on this nozzle as well as its static performance characteristics are given in reference 3. The ejector nozzle geometric parameters at military power and maximum afterburning are listed in table II.

The auxiliary inlet ejector (AIE) nozzle (figs. 3(c) and 5) consists of an ejector shroud which has flaps at the shroud exit and a series of auxiliary inlet doors located around the periphery of the external skin just ahead of the primary nozzle exit. It was a fixed flap configuration of a high Mach number (approx. 2.7) nozzle in the position appropriate for low speed operation. The 16 double-hinged doors, which in actual flight would float as balanced by air loads, were also fixed in the low speed position. Table II lists the nozzle geometric parameters for military power and maximum afterburning. Reference 4 gives further information on the nozzle including its static performance characteristics.

TABLE II. - EJECTOR NOZZLE GEOMETRIC PARAMETERS

Nozzle configuration	Power level	Ratio of secondary to primary nozzle diameter, D_s/D_p	Ratio of ejector length to primary nozzle diameter, L/D_p	Ratio of distance between primary and ejector throats to primary diameter, S/D_p	Ratio of ejector to primary nozzle flow areas, A_s/A_p
VFE	Maximum afterburning	1.13	1.75	0.26	1.27
	Military	1.42	2.06	.20	2.07
AIE	Maximum afterburning	1.22	1.93	0.56	1.49
	Military	1.56	2.32	.57	2.43

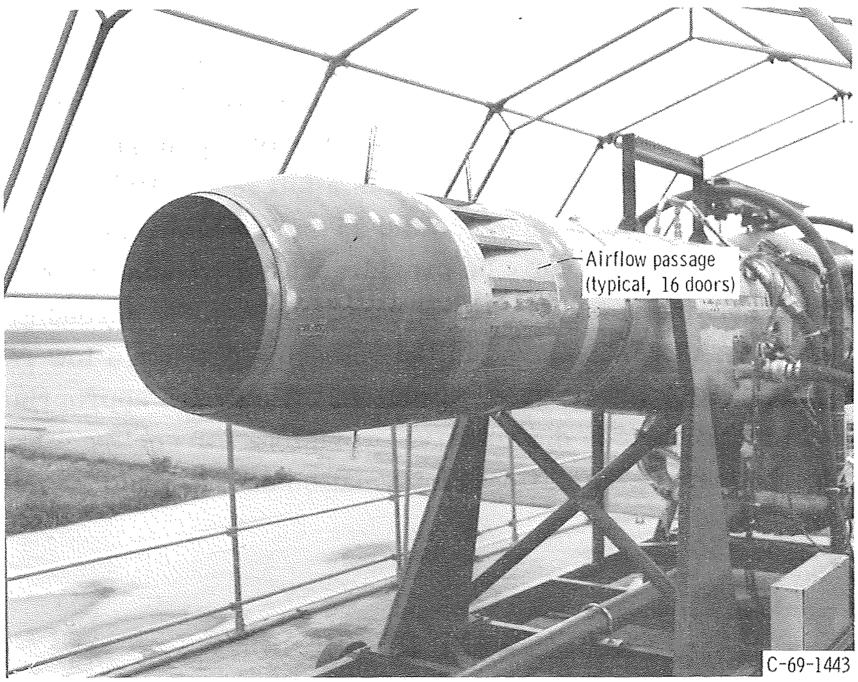

Figure 5. - Auxiliary inlet ejector nozzle.

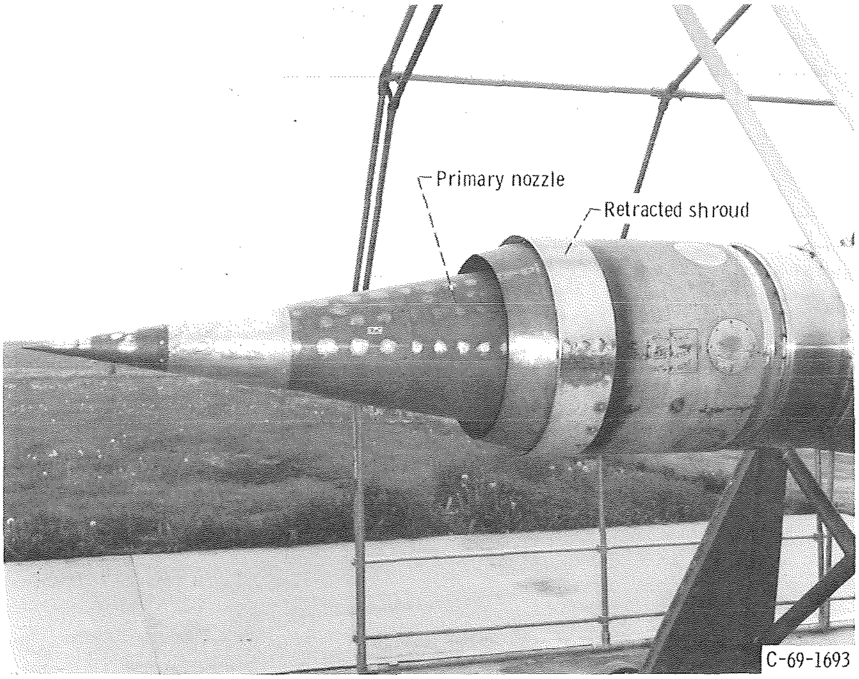

Figure 6. - Fixed-area 20° cone plug nozzle.

The plug nozzle is shown in figures 3(d) and 6. For this configuration, the afterburner was modified by removing the variable area primary nozzle and substituting a plug mounted within a fixed 17° half-angle conical nozzle creating an annular exit area of 110 square inches (710 cm^2). The plug itself was a full length 10° half-angle conical surface. It was supported by struts attached to the 25-inch (63.50-cm) diameter nacelle. A plug nozzle of this type would normally be provided with a translating outer cylindrical shroud to vary the expansion ratio. In the extended position the shroud gives a high expansion ratio for supersonic cruise, and in the retracted position a low ratio for subsonic operation. The nozzle had a short, fixed shroud in the position appropriate to low speed operation. Since the plug surface did not have provisions for cooling, it could not be tested with the afterburner on. Additional information on this plug nozzle configuration is given in reference 5.

RESULTS AND DISCUSSION

A full array of microphones covering both front and back quadrants around the engine (fig. 2) was used in the initial test. The microphones in the front quadrant were included so noise generated by the engine and propagated out the inlet could be evaluated for its effect on the total sound power and location of maximum perceived noise. Since the initial tests indicated that the noise measurements from the front quadrant microphones had negligible effects on these factors, they were not used in further tests and only rear quadrant data are presented.

The sound pressure measurements at the various microphone locations are presented in figure 7. Each point shown is the average of five readings of 1-second duration. They were taken approximately 8 minutes apart to minimize the effects of unavoidable background noise in the area. The total data-recording time, therefore, represented by each point is 5 seconds. For military power, the sound distributions were generally similar in shape despite the differences in exhaust nozzle configuration. There was a considerable spread between the data for the different nozzles at microphone locations from 90° to 120°. At these angles the VFE nozzle and the plug nozzle were the quietest, the primary nozzle was somewhat noisier, and the AIE nozzle was the noisiest. This high level for the AIE is believed to be due to sound being reflected out of the door openings. The sound levels radiated towards the more rearward located microphones (from 130° to 150°) were the highest, as is normal for jet aircraft. The level was about the same (about 125 dB) for the primary, VFE, and AIE nozzles and somewhat lower (an average of about 122 dB) for the plug nozzle. At angles greater than 150° the sound pressure dropped off in the normal manner as the exhaust jet axis was approached. When the engine was operated at full afterburner power the general

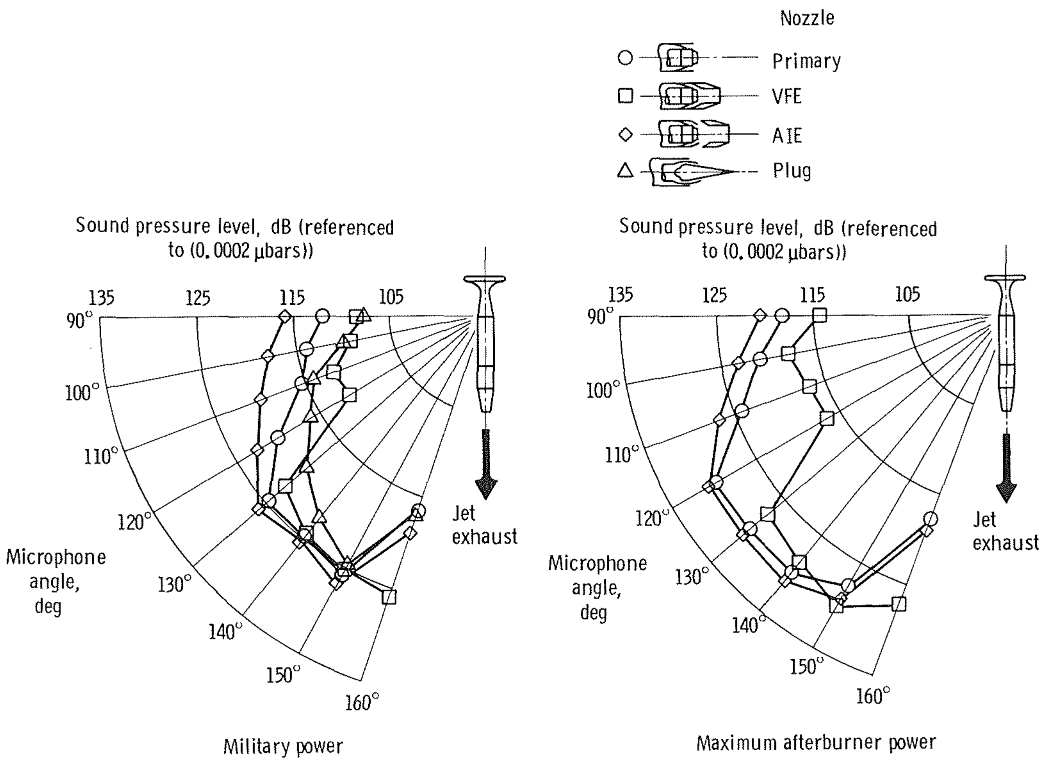

Figure 7. - Sound pressure levels at 150-foot (45.8 m) radius.

shape of the sound pressure level curves remained about the same although the region of high level broadened somewhat. The VFE nozzle remained the quietest and the AIE nozzle the noisiest throughout most of the angle range. Sound pressure levels for the three nozzles tested were about 5 decibels higher at full afterburner than at military power.

The sound pressure levels were converted to sound power level (PWL) for each 1/3 octave band center frequency using the measured sound pressure levels and the appropriate parts of the total spherical area. For this calculation the reference sound power level used was 10^{-13} watt. Results are shown in figure 8 for both military and

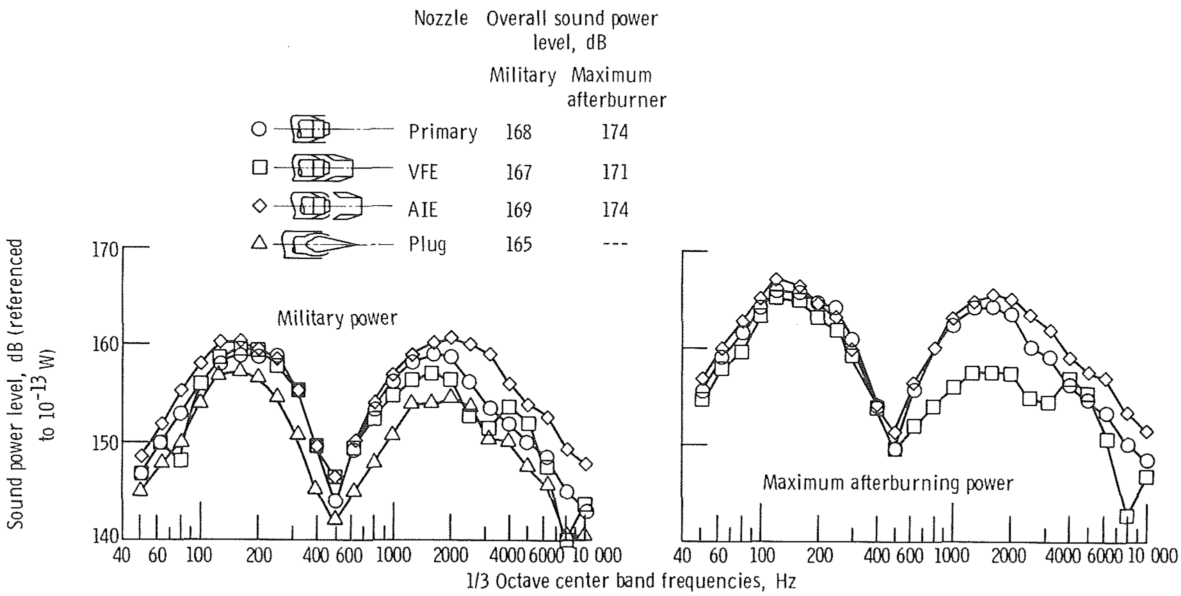

Figure 8. - Band frequency sound power levels.

maximum afterburner power. The sharp dip in power level at approximately 500 hertz is believed to be due to selective absorption by the ground and/or destructive interference due to ground reflection. The ground area covered by grass is indicated in figure 2. At military power the AIE nozzle was the noisiest throughout the entire frequency range. It had an overall sound power level of 169 decibels. The sound power levels for the primary and VFE nozzles were somewhat lower than those for the AIE nozzle throughout essentially the whole frequency spectrum. The plug nozzle had an overall sound power level of 165 decibels, which was 4 decibels lower than the AIE nozzle. At maximum afterburner power, the sound power levels for the primary, VFE, and AIE nozzles increased by approximately 5 decibels except for frequencies in the range of the second broadband noise hump (500 to 3000 Hz) where the VFE nozzle noise output did not increase appreciably.

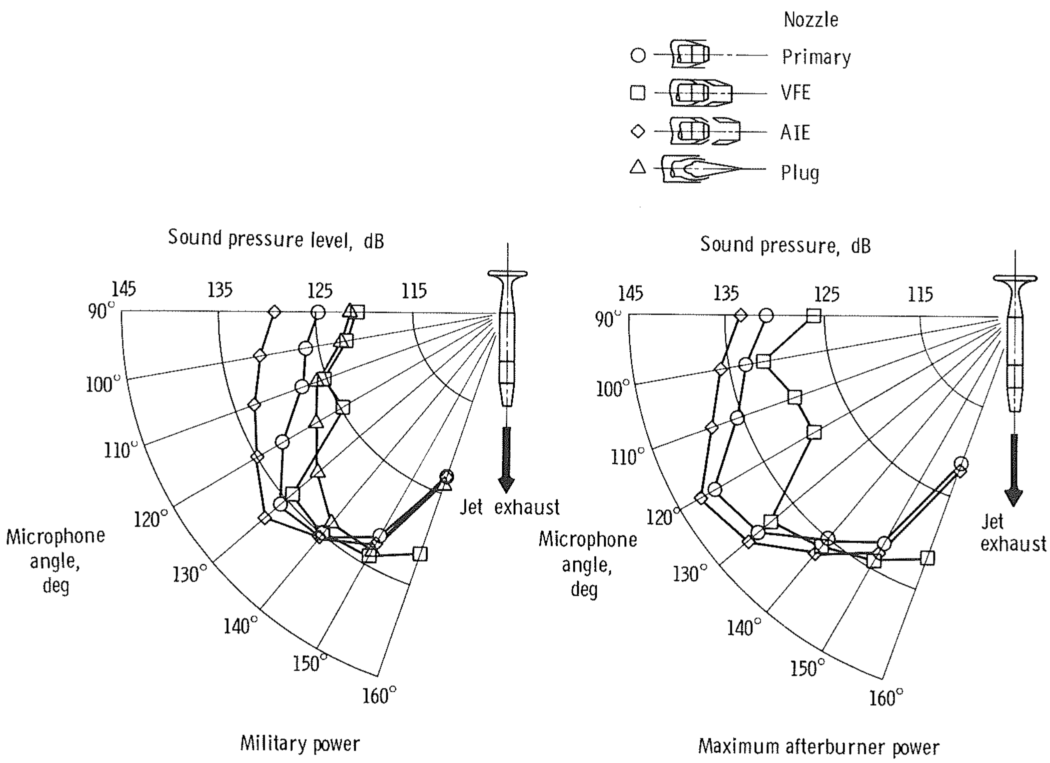

Figure 9. - Perceived noise level at 150-foot (45.8 m) radius.

Perceived noise level in decibels (a subjective noise annoyance rating) was calculated for each microphone location using the procedure of reference 6. The results plotted in figure 9 show that for military power the shapes of the perceived noise level curves remained essentially the same as those for sound pressure level. The perceived noise level was again highest for the AIE nozzle and reached a maximum value of 138 decibels at 130°. The highest level for the convergent nozzle was 136 decibels; for the VFE nozzle, 135 decibels; and for the plug nozzle, 134 decibels. When the afterburner was operated at maximum power, the perceived noise level increased to a maximum of 143 decibels for the AIE nozzle, 142 decibels for the primary nozzle, and 138 decibels for the VFE nozzle.

The perceived noise levels on the ground for a sideline or flyover distance of 1000 feet (304.8 m) are given in figure 10. This calculation does not account for the variation in atmospheric attenuation at different frequencies as discussed in reference 7. For military power the AIE was most objectionable, and the plug nozzle was the least objectionable. The maximum perceived noise level was 119 decibels for the AIE nozzle with the airplane 820 feet (250 m) past the observer. For the VFE nozzle the maximum perceived noise level was 115 decibels at the same distance, and for the plug nozzle, 113 decibels at from 820 to 1200 feet (250 to 366 m) past the observer. The plug nozzle, therefore, was 6 decibels quieter than the AIE nozzle. This reduction was the result of

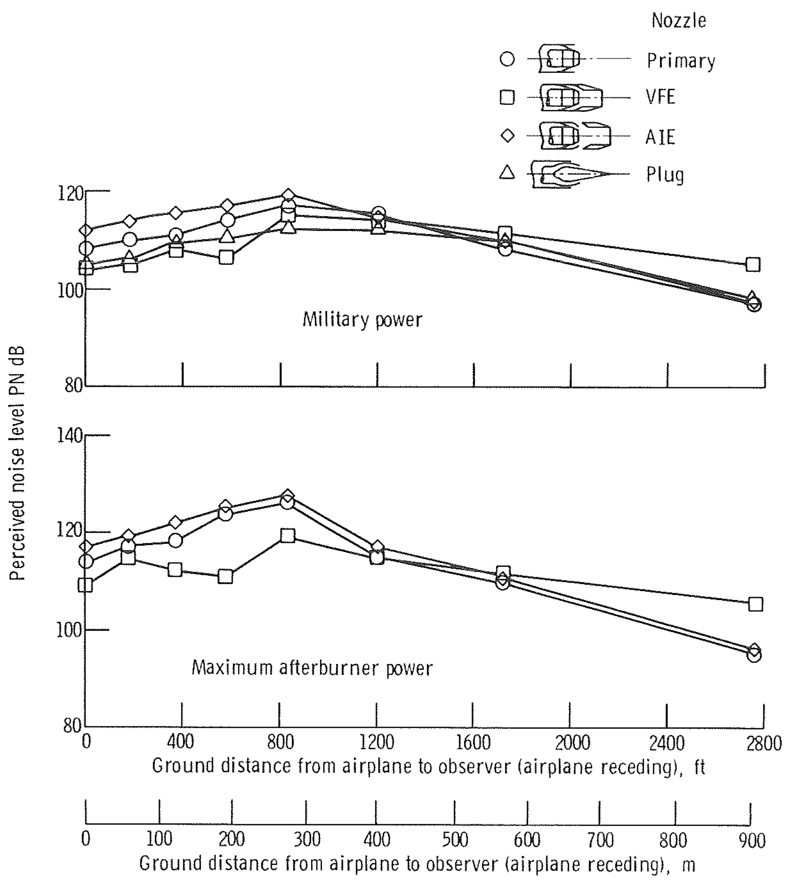

Figure 10. - Perceived noise in 1000-feet (304.8-m) altitude flyover.

the lower maximum noise level for the plug nozzle and the fact that this nozzle radiated most of its noise at angles further aft so the airplane was further away when this noise was directed to the observer.

Lower noise levels for a plug nozzle compared with a conic nozzle were noted in limited small scale tests reported in reference 8. The difference was attributed to the change in shock structure within the jet.

SUMMARY OF RESULTS

Sea level static tests were made of the jet noise characteristics of three different nozzle designs suitable for a supersonic cruise aircraft. A GE J85-13 afterburning turbojet engine was used as the gas generator. At military power, results obtained with a plug nozzle, a variable flap ejector, and an auxiliary inlet ejector were compared with that of a convergent primary nozzle. At full afterburning only the primary and two ejector nozzles were tested. The plug nozzle could not be tested when the engine was operating in the afterburner mode.

At military power the overall sound power level was lowest with the plug nozzle; and it increased as the configuration was successively changed to the variable flap ejector, the primary nozzle, and the auxiliary inlet ejector. The sound power level for the auxiliary inlet ejector was 4 decibels higher than that of the plug nozzle. At maximum afterburning the overall sound power level increased 5 to 6 decibels above that obtained at military power for each nozzle type. At maximum afterburning the auxiliary inlet ejector and the primary nozzle sound levels were about 3 decibels higher than that for the variable flap ejector.

For a flyover at 1000 feet (304.8 m) altitude, the maximum perceived noise level on the ground would be 6 decibels less with the plug nozzle than with the auxiliary inlet ejector.

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Cleveland, Ohio, February 18, 1970,
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