FLIGHT AND TUNNEL TEST RESULTS OF THE MDC MECHANICAL JET NOISE SUPPRESSOR NOZZLE

R. D. FitzSimmons, R. A. McKinnon and E. S. Johnson
McDonnell Douglas Corporation

SUMMARY

A flight and wind tunnel test program to determine the acoustic and performance effects of a mechanical jet noise suppressor nozzle mounted on an engine of an HS-125 airplane has been completed.

The flight test program was jointly sponsored by McDonnell Douglas Corporation (MDC), Rolls-Royce, Ltd. (RR), British Aerospace (BAe) and the Royal Aircraft Establishment (RAE). To achieve as high an ideal jet velocity as possible to simulate a supersonic transport engine, Rolls Royce supplied a unique uprated Viper engine. Flyover noise measurements were made with microphones mounted on top of a 137.5-m (450-ft) tower of the Severn River Bridge at Bristol, England. Data were recorded from more than 400 passes of the HS-125 test aircraft over the bridge. Seven nozzle configurations - including two references nozzles, two suppressors and three ejector inlets - were tested. Acoustics results were obtained for all nozzles. The suppressor nozzle of interest for an advanced supersonic transport (AST), the MDC suppressor/treated ejector, achieved a measured noise reduction of 14 EPNdB relative to a conventional conical reference nozzle at the highest pressure ratio tested (approximately 2.5).

The wind tunnel test program was jointly sponsored by NASA, MDC, RR and BAe. The unique engine nacelle, flight hardware and nacelles from the HS-125 flight test program combined with a simulated HS-125 fuselage were tested in the NASA Ames 40 x 80 foot wind tunnel and in the outdoor Ames test facility. Both propulsion and acoustic data were recorded. Preliminary thrust data results from the wind tunnel tests are available and are summarized and compared to other mechanical suppressor test results. Nozzle performance results, including lined ejectors, are shown to be the best obtained to date in industry.

The test results indicate that a noise reduction of at least 16 EPNdB would be possible for the MDC suppressor/ejector nozzle scaled to typical AST engine size with a 5% thrust loss at a typical takeoff climb speed.

INTRODUCTION

NASA-sponsored studies of advanced engines intended for application to future AST aircraft have identified several potential engine cycles as candidates - low bypass ratio turbofan engines (leaky turbojets) and variable cycle engines. (References 1 to 4). The low bypass ratio turbofan engines require significant jet noise reductions to meet anticipated noise level requirements for a typical four engine transport configuration. The variable cycle engines employ inverted velocity profiles to reduce jet noise, but also require additional jet noise suppression to meet similar noise level requirements.

In the past, mechanical jet noise suppressors which have been designed and built have demonstrated significant levels of noise reduction statically, but dramatically lost effectiveness with forward velocity. (Reference 5). Others have shown large thrust losses in achieving significant noise reductions. (Reference 6). Designers of jet noise suppressor nozzles attempt to achieve significant noise reductions at minimum in-flight thrust losses. ICAO Working Group E Jet Suppressor Subgroup, after a careful examination of then-available test data worldwide, recommended 12 PNdB jet noise reduction for 10 percent thrust loss be used for mechanical-suppressor parametric studies (Reference 7). Previous model scale results indicated that an MDC mechanical-suppressor configuration had the potential of achieving a level of greater than 11 PNdB jet noise reduction for 5.5 percent thrust loss at AST engine design nozzle pressure ratios. However, this performance level was based on acoustic test results from the Rolls Royce (RR) spin rig at Aston Down, England (Reference 8) and unpublished thrust performance results from an MDC facility. Measured levels in the NASA Ames 40 x 80-ft wind tunnel (Reference 9) were significantly different from the measured spin rig noise reductions. To resolve the discrepancy, flight test results were required to verify the actual noise levels.

Accordingly, a joint flight test program was defined by MDC, RR, and BAe. An RAE HS-125 aircraft was modified by BAe to accept an uprated RR Viper 601 engine and an acoustically treated ejector. With NASA support, the uprated Viper 601 engine, the flight nacelle and the test nozzles were subsequently mounted on a simulated fuselage in the NASA Ames Research Center 40 x 80-ft wind tunnel to obtain thrust performance at forward velocity and also to obtain additional acoustic data. This paper presents the pertinent acoustic results from the flight test program for the AST applicable nozzles and thrust performance results from the Ames tunnel tests.

BACKGROUND

Development of an integrated engine/exhaust system meeting airport noise requirements is one of the pacing items for a new supersonic transport and it is most important to define the jet noise suppression at the earliest possible date. To expedite this activity MDC, with NASA support, since June 1974 has used a baseline configuration as the vehicle for detailed integration studies of the advanced technology engines and noise suppression schemes being derived by the major U. S. engine manufacturers under NASA contract. The analyses of the engine conceptual configurations include determination of the engine size (for noise and takeoff thrust requirements), selection of the proper inlet and nozzle design, calculation of installed engine performance, determination of structural impacts and configuration geometry changes, and determination of the overall range for each type engine/exhaust system combination. In all of these studies, noise suppresion schemes and suppression data as provided by the engine companies have been used. These studies led directly to the effort described herein which is necessary in order to provide data for the mechanical-suppressor program.

As part of the technology updating, MDC reviewed the results of the previous mechanical-suppressor testing programs prior to the design of the nozzle suppressor/ejector/reverser configuration for the conceptual MDC baseline 2.2M cruise vehicle. The design had to integrate with the airplane without any cruise performance penalty. The design for an MDC exhaust system is shown in Figure 1. The design for the HS-125 test is an exact duplication of the design shown in the figure.

FLIGHT TESTS

The flight test program was instituted jointly to obtain in-flight acoustic data on two conical reference nozzles and two mechanical jet noise suppressor nozzles with and without a treated ejector. In any flight research program, two of the major elements are the selection of the test aircraft and the test engine.

Aircraft/Engine Selections

In the choice of an aircraft/engine combination, it was desired to choose an engine with the highest possible jet velocity to simulate as closely as possible the jet velocities projected for low bypass ratio AST engines at takeoff and cutback. Turbojet engines operate at higher jet velocities than turbofans and are therefore logical candidates for a jet-noise oriented flight test. Use of a multiengine aircraft instead of a single engine aircraft minimizes the safety and airworthiness demonstrations required for a test engine and experimental parts to be flown.

Rolls Royce was able to identify an uprated Viper 601 engine as an excellent test engine because of its high nozzle pressure ratio and the HS-125 aircraft as an attractive test vehicle. The test engine provided ideal jet velocities up to 719.3 m/s (2360 ft/sec), which compares favorably with the anticipated maximum jet velocity of 762.0 m/s (2500 ft/sec) for a projected low bypass ratio AST engine. RR had a lined tailpipe from a previous test program (Reference 10) which was available and was installed on the test engine for all flights in this program. RAE provided an HS-125 research aircraft, Figure 2, from the Bedford Systems Group which was made available for the test program and BAe agreed to modify the test aircraft as needed for instrumentation, nozzle mounting and ejector attachment.

Site

Following the selection of an RAE HS-125 research aircraft as the test vehicle, RR proposed the use of a tower on the Severn River Bridge as the microphone location based on their successful use of this location previously. (Reference 11.) One of the desirable features of this test site is the height of the microphones above the water surface (approximately 137.2 meters - 450 feet) which assures a minimum of ground surface interference and reflection. Reflections from the bridge cables, the road surface and tower roof surface have been found negligible. Figure 3 shows the test aircraft flying past the test site with one of the seven nozzle configurations installed.

Configurations

The seven nozzle configurations tested are illustrated schematically in Figure 4. Two conical reference nozzles - one with a conventional entrance angle (RR-1) and one with a steep entrance angle (DAC-1) to simulate the primary nozzle of a supersonic cruise engine exhaust system - are included, as are two mechanical jet noise suppressor nozzles, one intended for subsonic aircraft research (RR-2) and the other for the AST (DAC-2). The suppressor nozzles can be fitted with a treated ejector to increase the noise reduction. As shown in Figure 4, three ejector inlet designs (DAC-3, DAC-4 and RR-3) are provided to achieve a total of seven configurations. Figure 2 shows the test aircraft with the uprated Viper engine and the DAC-4 nozzle configuration installed, and Figure 5 is an end view of this configuration

Instrumentation

Two acoustic recording systems are employed to provide redundancy. In each system two B&K 12.7 mm (1/2-inch) diameter type 4133 microphones are mounted vertically upward on poles about 6.1 meters (20 feet) above the roof, approximately 137.2 m (450 ft) above the water surface. Wind screens are used. Acoustic data are recorded on Nagra IV SJ portable tape recorders which are operated at a tape speed of 19 cm (7.5 inch) per second. The center track (FM) is used to record voice information between flights and IRIG B time code data during the flight recording.

Tracking of the aircraft flight path is done by an RR photographic system which is comparable to a mini kinetheodolite system. The method uses a camera to take numerous photographs of the test aircraft as it flies past the test site. Camera elevation and tilt are encoded on one channel of a Nagra IV SJ tape recorder, camera shutter contact pulses on the second channel and voice and time code (IRIG B) on the FM center track.

A second photographic method is employed as a backup for estimating the aircraft position and altitude. A camera with a lens of known focal length is mounted at the test site and the aperture pointed upward. As the aircraft flies overhead, a photographer clicks the shutter which triggers a one-half second 20 kHz pulse onto the center track of one of the Nagra IV SJ acoustic data recorders. After the film is developed, the wingspan and offset are measured. The altitude can be estimated as the aircraft wingspan in feet times the ratio of the focal length in millimeters to the measured wingspan dimension in millimeters. Similarly, the offsets - aircraft position before and after overhead and on or off line - can be estimated in feet as the aircraft wingspan in feet times the ratio of the offset in millimeters to the measured wingspan in millimeters.

Wet and dry bulb air temperatures, wind velocity and direction data are obtained at the tower test site. The air pressure is derived from measurements at the Filton Airfield nearby. Surveys of the air conditions between the test aircraft flight paths and the test site are made in a Tiger Moth aircraft in which wet and dry bulb temperatures, air pressure and wind velocity are measured. The Tiger Moth surveys are conducted before and after each flight test.

The aircraft flight recorder is programmed to record engine rpm, jet pipe temperature, jet pipe static pressure, ejector total and static pressures and total temperature, ambient air temperature and pressure, airspeed, altitude, run number and test identification data. Synchronization between the data from the aircraft flight recorder, the Nagra IV SJ recorder of the aircraft tracking system and the Nagra IV SJ recorders of the acoustic data acquisition system is by the IRIG B time code which is recorded on all three systems.

Procedure

Prior to each flight test, the test aircraft is ferried from Bedford to Filton Airfield. At the test site, a pink noise signal (200 mV) from a pseudo random noise generator is recorded on each tape for each microphone installation. The signal is applied at the preamplifier (cathode follower) for 45 seconds. Pistonphone calibrations are conducted at the beginning and end of each test. The signal is 124 dB at 250 Hz and recorded for 30-45 seconds. Ambient noise is recorded prior to the test and at selected intervals during the test. When the noise recording crew has completed the installation and pre-test calibrations, the test aircraft is flown over the test site with a minimum of three passes for each test point. Table 1 lists the desired test conditions. The majority of the flights are made with the flight path in a direction parallel to the bridge, but a limited number of flights are made with the flight path normal to bridge. Again the majority of the flights are performed with the non-test engine operating at idle power. A limited number of "control" flights are performed with the test engine at idle power and non-test engine at takeoff power. The test passes are flown at constant airspeed and altitude to achieve a desired altitude over the test site of 152.4m, but the aircraft's altitude is allowed to increase or decrease as needed for a given power setting. Noise data recorded from the "control" flights when compared to previous data serve as a check on the validity of the recording system.

Limitations

The tests are conducted with the following weather limitations:

Precipitation	None
Wind Speed	not more than 10 knots*
Humidity	not less than 50 percent not greater than 90 percent

*Initial goal - subsequently modifed to 15 knots

ACOUSTIC RESULTS AND DISCUSSION

The acoustic results for the two reference nozzles, the MDC suppressor nozzle and the MDC suppressor nozzle with ram and flush ejectors, are presented in terms of the variation of peak perceived noise levels (PNLM) and effective perceived noise levels (EPNL) with ideal jet velocity, PNL directivity and one-third octave band sound pressure level (1/3 OBSPL) spectra at the peak noise angle and selected angles of 90° and 150° to the inlet.

The variation of peak PNL with relative jet velocity is shown in Figure 6 for the conventional reference and the AST applicable nozzles. The noise levels produced by the two conical nozzles (RR-1 and DAC-1) are substantially the same; therefore RR-1 is used as the reference nozzle for subsequent comparisons. The noise reductions provided by the mechanical jet noise suppressor (DAC-2) are clearly evident at high engine powers, but decrease to zero at the low end of the engine power range tested. It can be observed that the treated ejector is effective in providing additional noise reduction throughout the power range tested. It can be noted that the suppressor/ejector configuration with the ram scoop inlet (DAC-3) produced noise levels similar to the flush (flight type) inlet configuration (DAC-4). Both configurations produced measured noise reductions of approximately 14 EPNdB. Thus, previous questions of differences between the two configurations were answered. The ram scoop inlet configuration was included in the test program because all model scale tests had included the ram scoop inlet, but not the flush inlet.

The corresponding variation of EPNL with relative jet velocity is shown in Figure 7. It can be observed that the pattern of variation for the nozzles with EPNL is substantially the same as for peak PNL, which means essentially that the mechanical suppressors and the treated ejector did not have an effect on the duration correction factor component of EPNL. The beneficial effects of the treated ejector in providing additional noise reduction over the entire engine power range tested are apparent. Again, DAC-3 noise levels are not substantially different from DAC-4 noise levels.

In the analysis that follows, two typical cases are considered: one at a supercritical nozzle pressure ratio (2.2 NPR nominal) and one at a subcritical nozzle pressure ratio (1.6 NPR nominal). All data presented are for level flight 152.4m (500 ft) above the microphone and 172 knots airspeed. The tone corrected PNL (PNLT) directivity patterns are illustrated for the supercritical case in Figure 8 and for the subcritical case in Figure 9. For the sake of clarity, data are shown for the conventional reference and the AST applicable nozzles only. Since DAC-3 results are substantially the same as DAC-4, only DAC-4 results are shown. In Figure 8 the hump in the noise levels of the reference nozzle in the region of 40° to 70° is attributed to shock cell associated noise and the hump in the rear arc is jet noise. In Figure 8, the anticipated trend of the suppressor to move the angle of peak noise more forward is apparent. This trend is continued with the treated ejector attached.

From Figure 9, it can be observed that the MDC suppressor alone is ineffective in reducing the noise level below that of the reference nozzle at subcritical nozzle pressure ratios. However, the addition of the treated ejector does provide noise reductions, particulary from 80° aft. No definite change in the peak noise angle with the ejector fitted is apparent.

One-third octave band sound pressure level spectra for the 24 center-band frequencies beginning at 50 Hertz are presented in Figures 10 to 12 for the 2.2 NPR case at selected angles of peak noise, 90° and 150° to the inlet, respectively. Similar data for the 1.5 NPR case are given in Figures 13 to 15.

From Figure 10, the reference nozzle (RR-1) spectral shape for 2.2 NPR at the peak noise angle (approximately 135°) appears to be primarily due to jet noise. Source separation techniques are available (Reference 12, for example) to separate core and jet noise, but they have not been applied to the HS-125/Viper 601 flight data to date. It can be observed that the MDC suppressor (DAC-2) reduces the low frequency noise levels. The treated ejector with the flush inlet (DAC-4) reduced the low frequency noise levels a little more, but reduced the high frequency noise levels significantly. From Figure 13, however, one can postulate the presence of core noise at 1.6 NPR influencing the reference nozzle peak SPL at 630 Hertz. The secondary peak at 315 Hertz could well be jet noise for this reduced power setting. The MDC suppressor reduced the low frequency noise levels but increased the high frequency noise levels compared to the reference nozzle. Such behavior has been demonstrated by previous mechanical suppressors. When the treated ejector with the flush inlet is added to the mechanical suppressor, noise reductions relative to the reference nozzle are provided throughout the spectrum. The beneficial effect of the treated ejector is again apparent.

At 90° to the inlet and 2.2 NPR, Figure 11 illustrates noise reduction in the low frequencies by the suppressor alone and noise reductions in the high frequencies by the treated ejector with no further reduction in low frequency noise levels. Similarly at 1.6 NPR, Figure 14 indicates modest reductions in low frequency noise levels by the suppressor but a slight increase in high frequency noise levels. Addition of the treated ejector reduced the frequency noise levels, with no change in low frequency noise levels.

At 150° to the inlet and 2.2 NPR, Figure 12 indicates significant mid-frequency noise level reductions (approximately 20 dB) and substantial high frequency noise level reductions (about 8 dB) by the suppressor and additional high frequency noise level reductions by the treated ejector. Similarly at 1.6 NPR, (Figure 15) significant low to mid-frequency noise level reductions are obtained by the suppressor but with slight increases in high-frequency noise levels which are subsequently lowered by the treated ejector.

The noise reduction provided by the DAC-4 configuration relative to the conventional reference nozzle was remarkably independent of aircraft speed, as shown in Figure 16.

WIND TUNNEL TESTS

Purpose

The purpose of the wind tunnel tests is to determine propulsion and acoustic characteristics of the seven configurations tested in flight on the HS-125 airplane. Since this HS-125 test aircraft is not instrumented to determine engine thrust, net thrust measurements of each configuration at forward speed are particularly important. These data will allow the deduction of net thrust in flight based on engine RPM. Near field acoustic measurements (in conjunction with outdoor static acoustic data) will allow a prediction and comparison of actual flight data.

Configuration

At the conclusion of the flight testing the engine, inlet, nacelle and nozzle test parts were removed from the HS-125 airplane and shipped to the NASA Ames Research Center, Moffett Field, California. The installation in the NASA Ames 40 x 80-foot wind tunnel is shown in Figure 17. A portion of the HS-125 airplane fuselage was simulated in order to provide as close a representation of the flight configuration as possible. Since all of the acoustic measurements in flight were taken below the aircraft, it was decided to rotate the engine/simulated fuselage 90° clockwise (looking forward) for the tunnel tests. In addition, the vertical and horizontal tail surfaces were simulated for test purposes, Figure 18. The engine exhaust centerline at the reference nozzle exit was located 3.96 m (13 ft) above the floor. As on the aircraft, the engine centerline is 5.5° down from the airplane centerline and 2° out from the fuselage. The entire assembly was mounted on a force table so as to obtain net thrust. Two of the configurations utilized inlet and exit fairings, Figure 19, in order to determine the drag tare. One additional configuration, only run statically, was with a calibrated bellmouth to determine engine airflow. This configuration was run at the start and at the end of the test period. The seven configurations flown on the test aircraft were run statically, at 0.2 M and 0.26 M in the wind tunnel.

Propulsion and acoustic data were obtained for a total of 13 configurations. The acoustic array consisted of two microphones (at a lateral distance of 8 and 12 nozzle diameters) on a traverse from 27° to 166° and four fixed microphones 6.1 m (20 ft) to the side as shown in Figure 20. In order to decrease the reverberant characteristics of the 40 x 80-foot test section, acoustic foam was installed on the floor and part way up to the side nearest the fixed microphones.

Instrumentation

In addition to the microphone array and thrust system described above, instruments were utilized on the engine and within the test section. Tables 2 and 3 describe this instrumentation.

Test Procedure

After calibration of the acoustic system the engine was started and stabilized at 40% RPM. The wind tunnel was started and stabilized at the desired speed. The engine was then set at various speeds between 80% and 100% RPM. At each speed a microphone traverse from forward to aft was accomplished, recording data from the traverse and fixed microphones. Propulsion data and thrust/drag measurements were taken at the start, middle and end of the traverse cycle. After shutdown of the engine and wind tunnel a calibration of the acoustic system was accomplished.

Various critical engine parameters (RPM, JPT, JPPS, oil pressure, bearing temperatures, oil temperature, fuel flow and engine vibration) were visually monitored during each run to insure that the engine was operating satisfactorily. Engine data were printed out immediately following each run.

Results and Discussion

The data from the wind tunnel tests are presently being reduced and analyzed. Initial and final engine calibration, utilizing an instrumented bellmouth inlet and a conical nozzle, have been checked and agree with the calibration data run by RR.

Figure 21 presents the results of previous MDC tests with a 15.24 cm (6-inch) model of the 12 lobe-24 tube suppressor/treated ejector over a wide range of nozzle pressure ratios and flight Mach numbers. Predicted propulsion results for the DAC-4 configuration in the NASA Ames Viper 601 engine test are shown and preliminary test results are indicated. The agreement between the predicted and the measured test results at NASA Ames is very close at forward speeds (C_v within 0.2%). Statically, however, the agreement between predicted and measured test results varies from 0 to 1.2% lower than the previous data.

IMPLICATIONS TO ADVANCED SUPERSONIC TRANSPORTS

The results of the combined flight and wind tunnel tests should have significant implications to future advanced supersonic transports. They demonstrate that a mechanical jet noise suppressor/treated ejector nozzle exhaust system can be designed to provide large noise reductions with acceptable thrust losses. The two results - noise reductions and thrust performance are discussed in order.

The 152.4-meter, level flight data at Viper 601 engine test conditions were scaled to a nozzle size of 95.25 cm (37.5 in.) equivalent diameter and projected to typical AST anticipated flyover/cutback and sideline slant range distances of 381 m (1250 ft) and 731.5 m (2400 ft), respectively (applicable to the FAR Part 36 (Stage 2) and ICAO Annex 16 Chapter 2 takeoff and sideline measuring conditions for 4-engine aircraft). The results are presented in Figure 22, and indicate a noise level reduction of 16 EPNdB at the takeoff power setting.

Currently, only preliminary results of the thrust performance of the MDC mechanical suppressor/treated ejector nozzle are available from the Ames 40 x 80-foot wind tunnel tests (Figure 21). The thrust data taken in the wind tunnel tests are being processed and reduced to obtain the thrust coefficients for all nozzles. After the wind tunnel data reduction is complete, the in-flight thrust performance will be deduced. Based on the excellent agreement shown in unpublished results of 15.24 cm (6 in.) equivalent diameter nozzle tests in an MDC facility, it is estimated that the in-flight thrust loss for a typical AST suppressor/ejector nozzle configuration (95.25 cm equivalent diameter) would be 5.4 percent at takeoff power and 6.6 percent at cutback power settings.

Since the deduced flight thrust performance results are not available, the increments shown in Figure 22 are for equivalent ideal jet velocities and are not at equivalent thrust levels for the two nozzles. The noise suppression levels will be adjusted to equivalent thrust levels when the flight thrust loss estimates are available.

The recommendation made by the ICAO Working Group E Jet Suppressor Subgroup, taken from Reference 7, is presented in Figure 23. The Subgroup's recommendation of the variation of noise reduction in PNdB with percent gross thrust loss is the centerline of the three. This variation was recommended for the Working Group E parametric studies. Also shown on Figure 23 is the estimate for the MDC mechanical suppressor/treated ejector configuration at a typical takeoff power setting applicable to the sideline noise measuring condition.

CONCLUDING REMARKS

Results of a joint MDC/RR/BAe/RAE flight test program in which an HS-125 research aircraft was fitted with an uprated Viper 601 engine and seven nozzle configurations show that significant noise reductions (up to 16 EPNdB) can be achieved by mechanical jet noise suppressor/treated ejector configurations relative to a conical reference nozzle. Preliminary results of thrust performance measurements taken in the NASA Ames 40 x 80-ft wind tunnel indicate good agreement of the Viper 601 size MDC mechanical suppressor/treated ejector configuration with previous unpublished results of 15.24 cm (6 in.) equivalent diameter nozzle tests in an MDC facility. Flight and tunnel test results of a mechanical suppressor have shown that a low-bypass turbofan-powered AST could be built to meet FAR Part 36 (Stage 2) noise levels.

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TABLE 1. - HS-125 FLIGHT TESTS

SEVERN RIVER BRIDGE

ITEM	LEVELS	NOZZLE CONFIGURATIONS
NOZZLE PRESSURE RATIO	1.6, 1.8, 2.0, 2.2 AND MAX	ALL CONFIGURATIONS
FLIGHT SPEEDS:	140 KNOTS	RR-1
	172 KNOTS	ALL CONFIGURATIONS
	250 KNOTS	RR-1, DAC-4

TABLE 2. - ENGINE INSTRUMENTATION

INSTRUMENTATION	RANGE	ACCURACY
Engine RPM	0 to 110% (40% Ground Idle)	± 50 RPM
Engine JPT	0 to 900°C (436°C Ground Idle)	± 3°C
High Pressure Comp. P_{S3}	103.4 to 620.6 $\frac{kN}{m^2}$ (15 to 90 PSI)	± 0.25%
Jet Pipe Static Pressure JP_{PS}	103.4 to 310.3 $\frac{kN}{m^2}$ (15 to 45 PSI)	± 0.25%
Oil Pressure	0 to 275.8 $\frac{kN}{m^2}$ (0 to 40 PSI)	± 5%
Bearing Temp. 1	0 to 300°C	± 2%
Bearing Temp. 2	0 to 300°C	± 2%
Intake Venturi (P_S5, P_S6, P_S7, P_S8)	0-152.4 cm (0 - 60 in.) H_2O	± 0.5%
Turbine Overheat Temp	0 - 400°C	± 2%
Oil Temperature (Redlined at 117°C)	0 - 140°C	± 2%
Ejector Static Pressure	89.6-103.4 $\frac{kN}{m^2}$ (13 - 15 PSIA)	± 0.25%
Total Pressure	89.6-117.2 $\frac{kN}{m^2}$ (13 - 17 PSIA)	± 0.25%
Total Temperature	10 - 48.8°C (50 - 120°F)	± 2%
Ejector Acceleration	0 - 5 G	± 2%
Engine Vibration	0 - 10 MILS	± 1%

TABLE 3. - FACILITY INSTRUMENTATION

INSTRUMENTATION	RANGE	ACCURACY
Engine Thrust (Tunnel Balance System)	0 to 17793N (0 to 400 lb.) 956N (215 lb.) Ground Idle	± 0.25%
Tunnel Speed	0 to 94.5 m (0 to 310 ft)/sec	± 1.5 m (5 ft)/sec
Tunnel Temperature - Total	10° to 48.8° C (50° to 120° F)	± 0.56° C ± (1° F)
Tunnel Humidity	20% to 100% RH	± 5%
Fuel Inlet Pressure	0 to 310.3 $\frac{kN}{m^2}$ (0 to 45 PSI)	± 1%
Fuel Inlet Temperature	10° C to 48.8° C (50° F to 120° F)	± 2.8° C ± (5° F)
Tunnel Static Pressure	93.1-103.4 $\frac{kN}{m^2}$ (13.5 - 15 PSIA)	± 0.1%
Fuel Flow	0-2041 kg (0-4500 lb)/Hr. ≈ 277 kg/Hr. (500 lb/Hr) Flight Idle	± 0.25%
Tunnel Total Pressure	93.1-103.4 $\frac{kN}{m^2}$ (13.5 - 15 PSIA)	± 0.1%

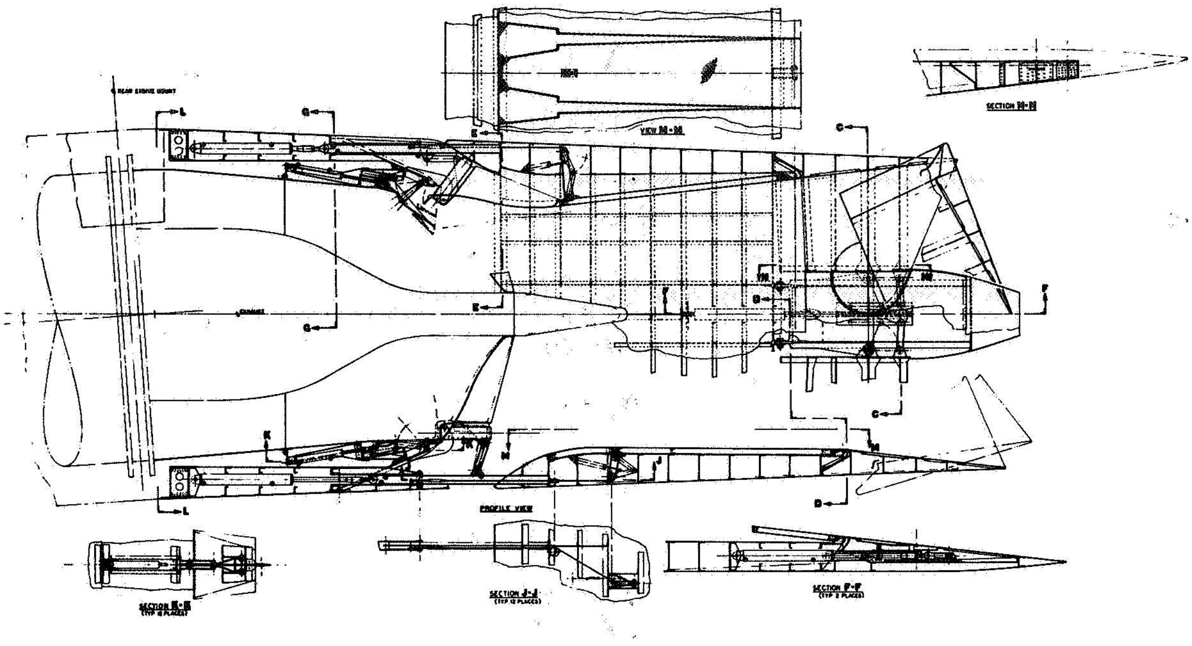

Figure 1.- MDC AST exhaust system design.

Figure 2.- HS-125 test aircraft.

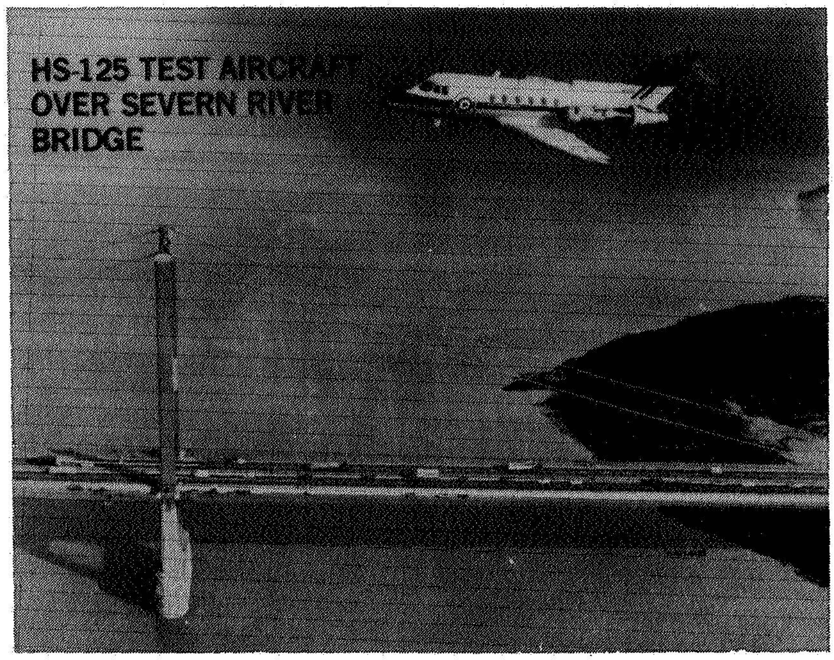

Figure 3.- HS-125 test aircraft over Severn River bridge.

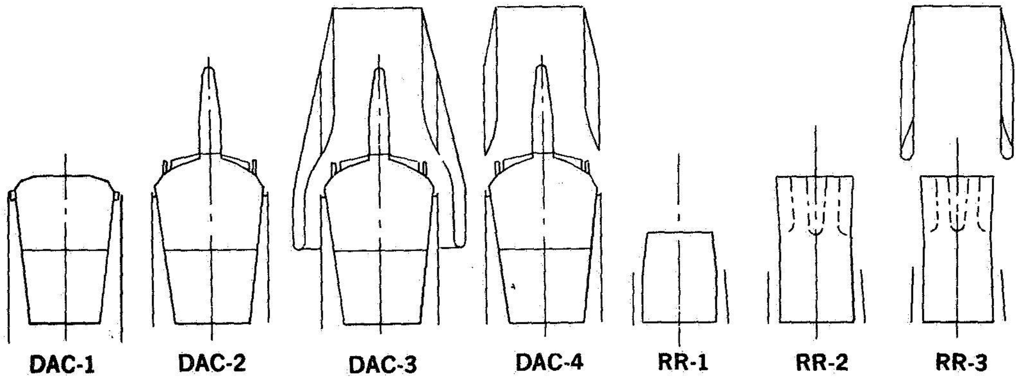

Figure 4.- HS-125 flight test configuration summary.

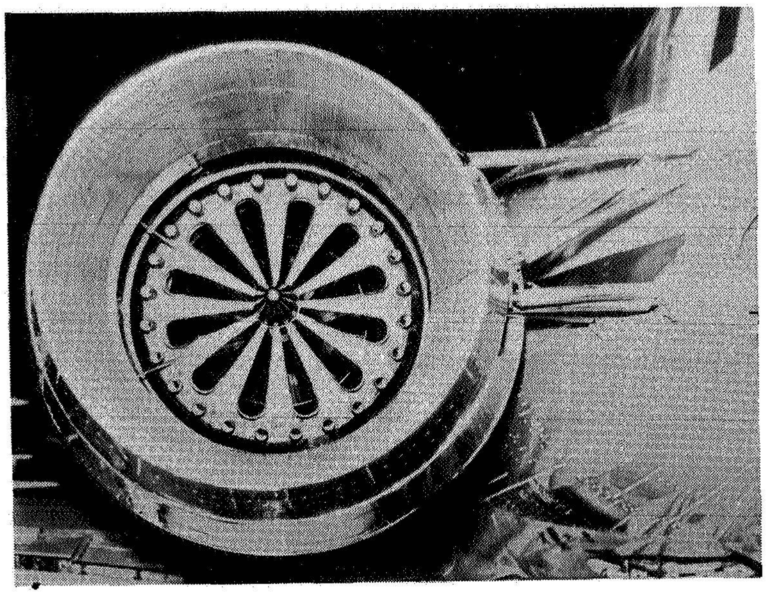

Figure 5.- Aft end view of MDC suppressor/ejector.

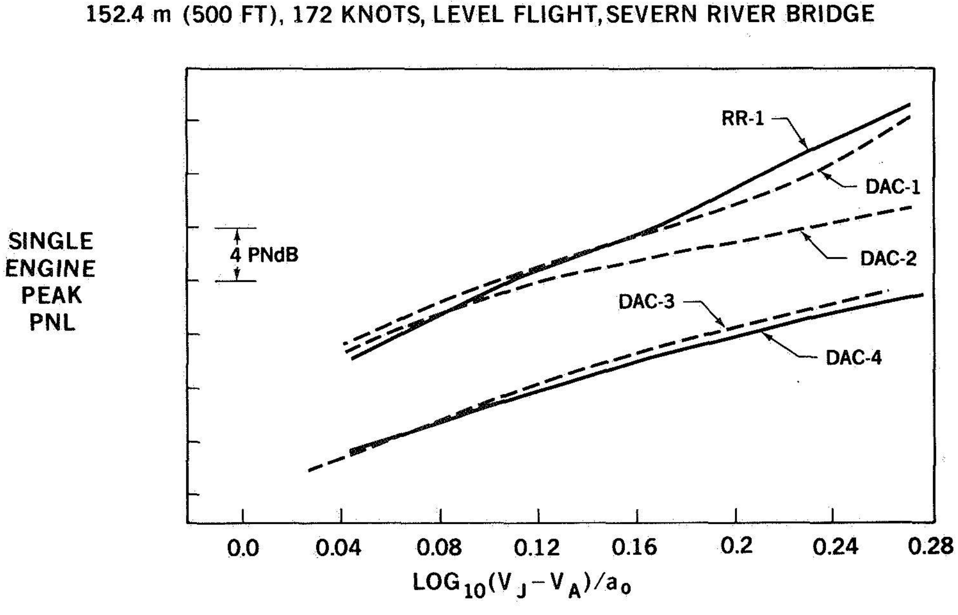

Figure 6.- Variation of peak PNL with relative jet velocity.

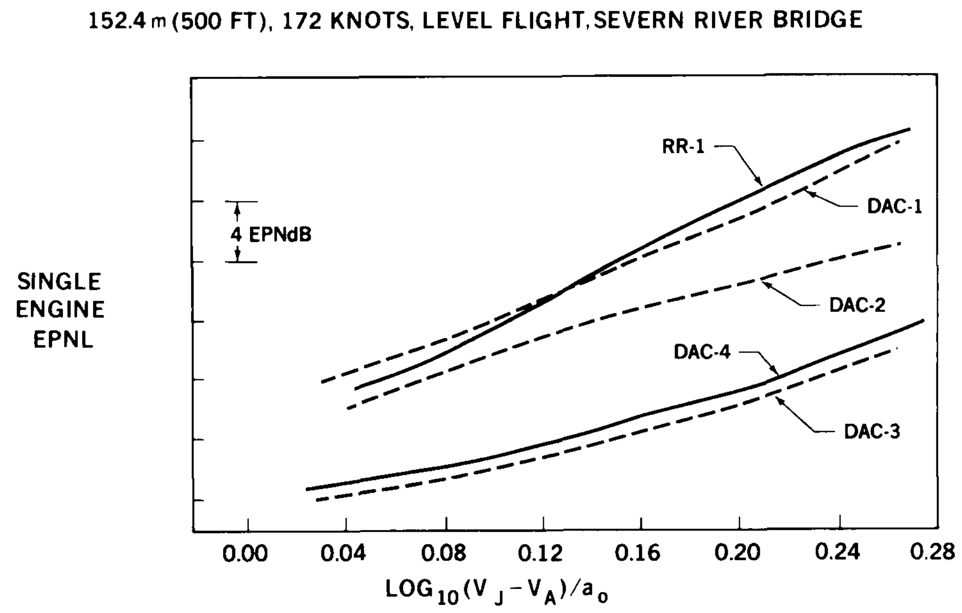

Figure 7.- Variation of EPNL with relative jet velocity.

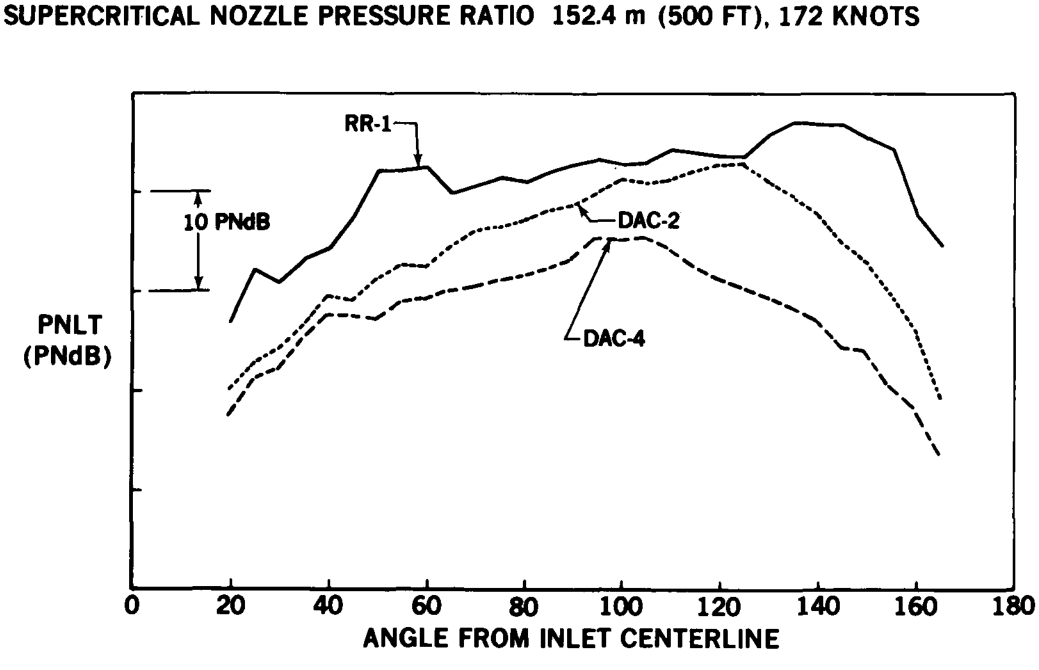

Figure 8.- PNLT directivity patterns at a typical supercritical nozzle pressure ratio.

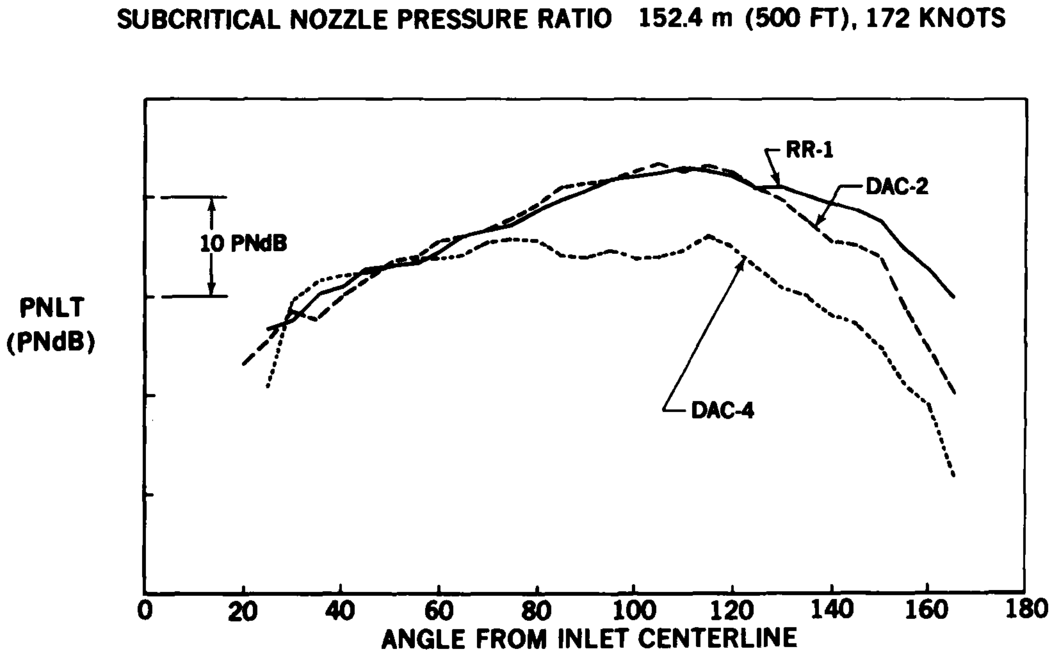

Figure 9.- PNLT directivity patterns at a typical subcritical nozzle pressure ratio.

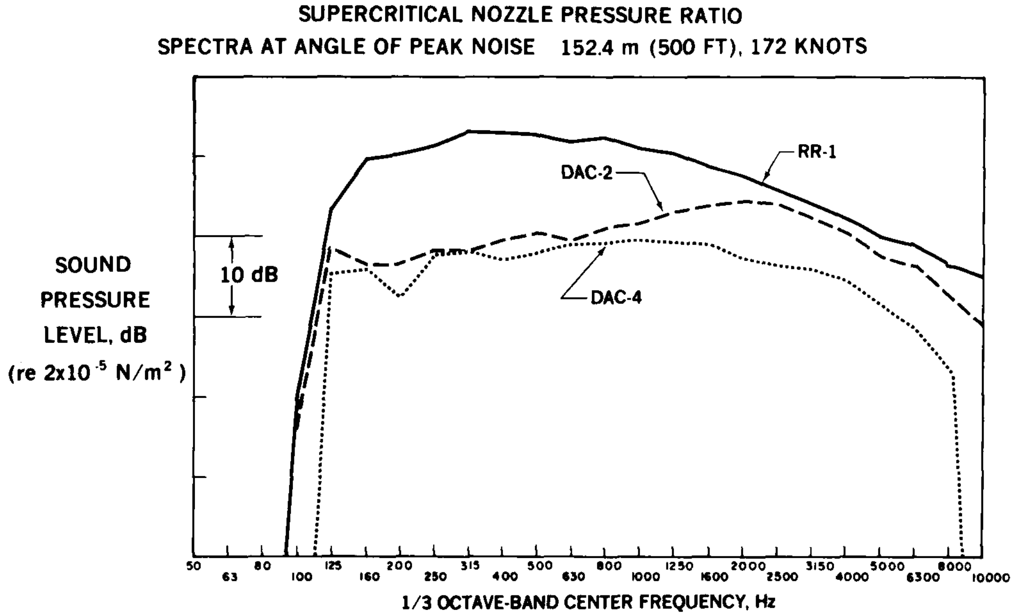

Figure 10.- Peak noise angle SPL spectra at a typical supercritical nozzle pressure ratio.

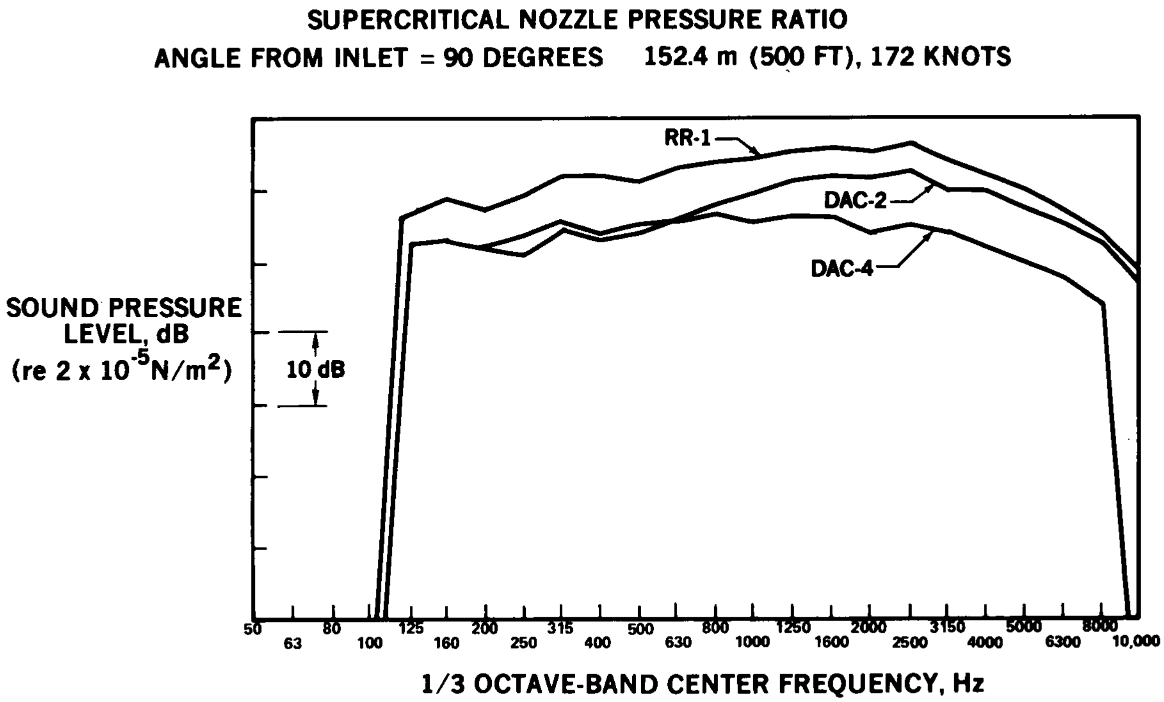
SUPERCRITICAL NOZZLE PRESSURE RATIO
ANGLE FROM INLET = 90 DEGREES 152.4 m (500 FT), 172 KNOTS

Figure 11.- SPL spectra at 90° for a typical supercritical nozzle pressure ratio.

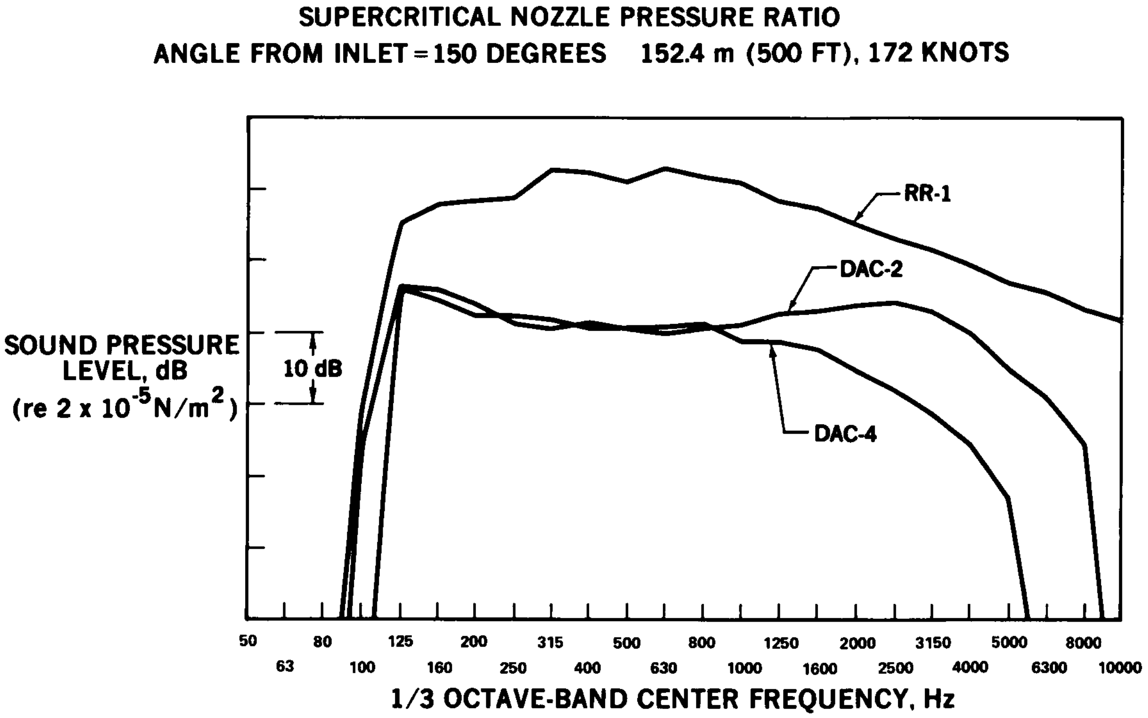
SUPERCRITICAL NOZZLE PRESSURE RATIO
ANGLE FROM INLET=150 DEGREES 152.4 m (500 FT), 172 KNOTS

Figure 12.- SPL spectra at 150° for a typical supercritical nozzle pressure ratio.

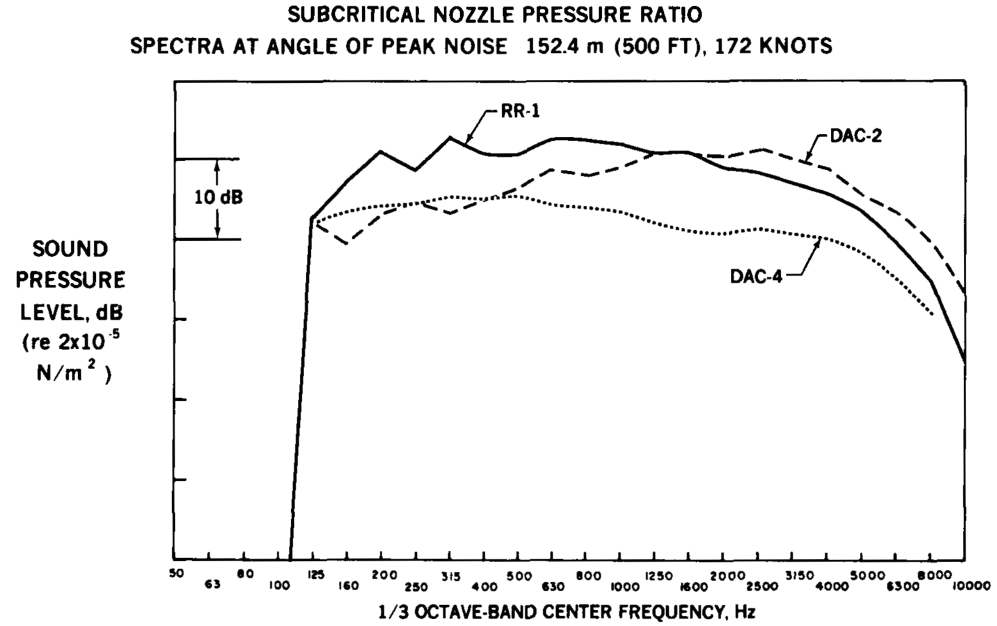

Figure 13.- Peak noise angle SPL spectra at a typical subcritical nozzle pressure ratio.

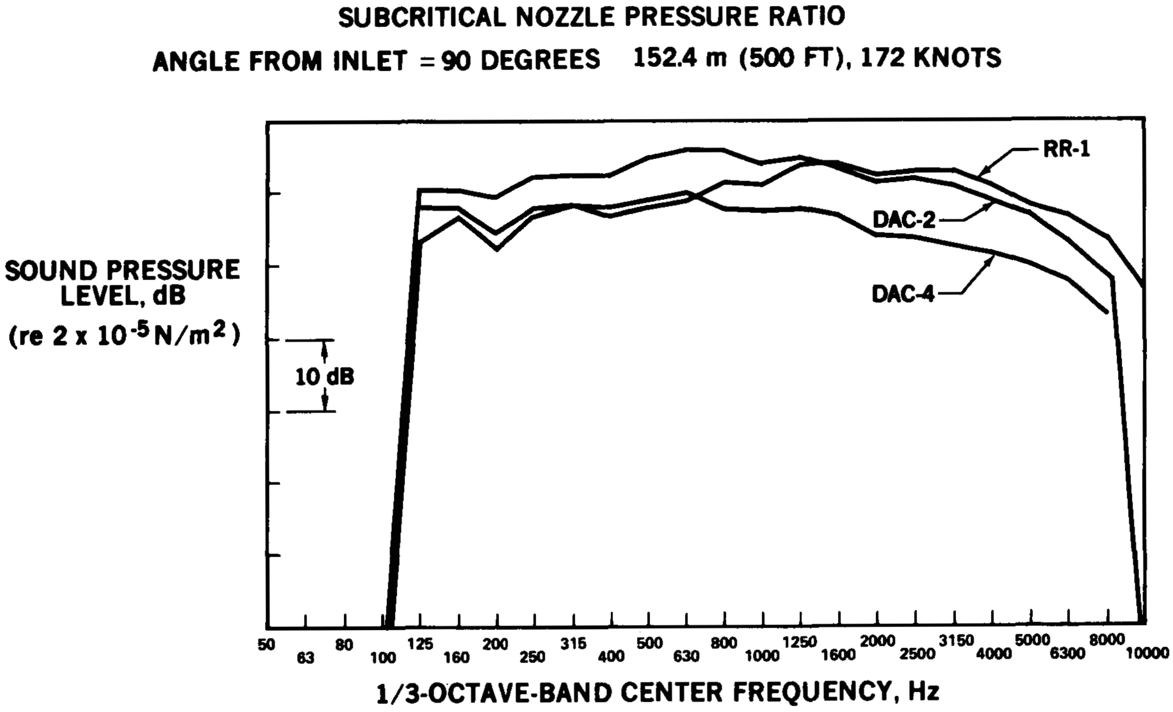

Figure 14.- SPL spectra at 90^o for a typical subcritical nozzle pressure ratio.

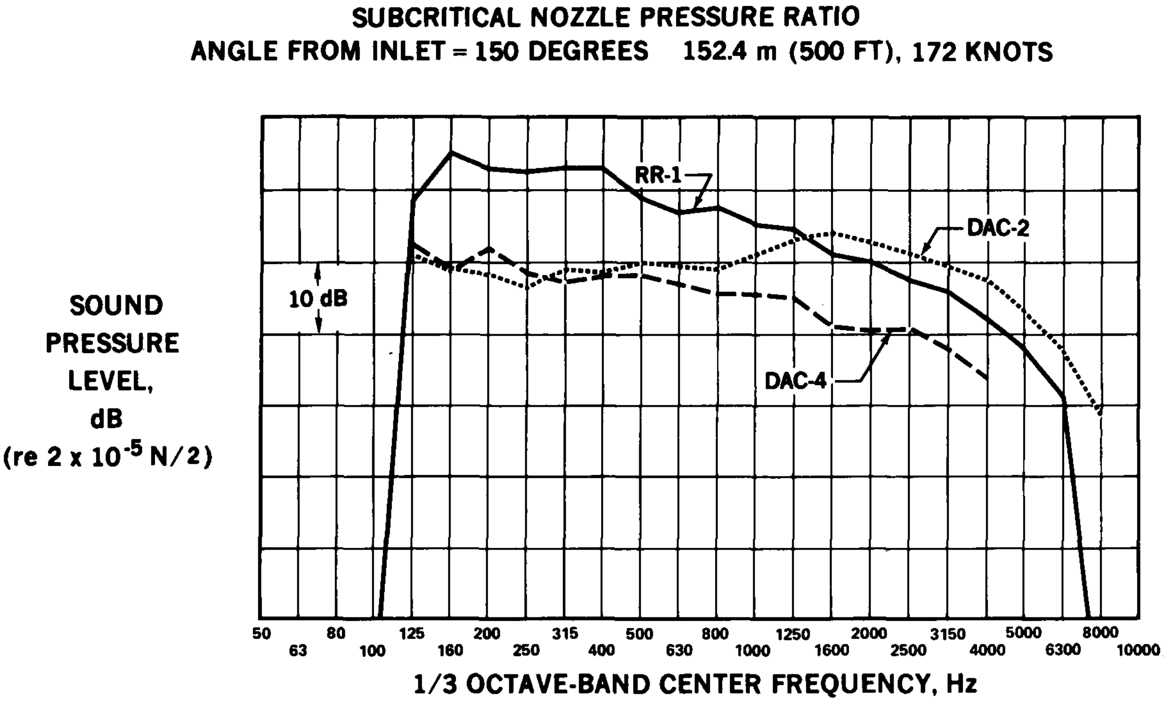

Figure 15.- SPL spectra at 150° for a typical subcritical nozzle pressure ratio.

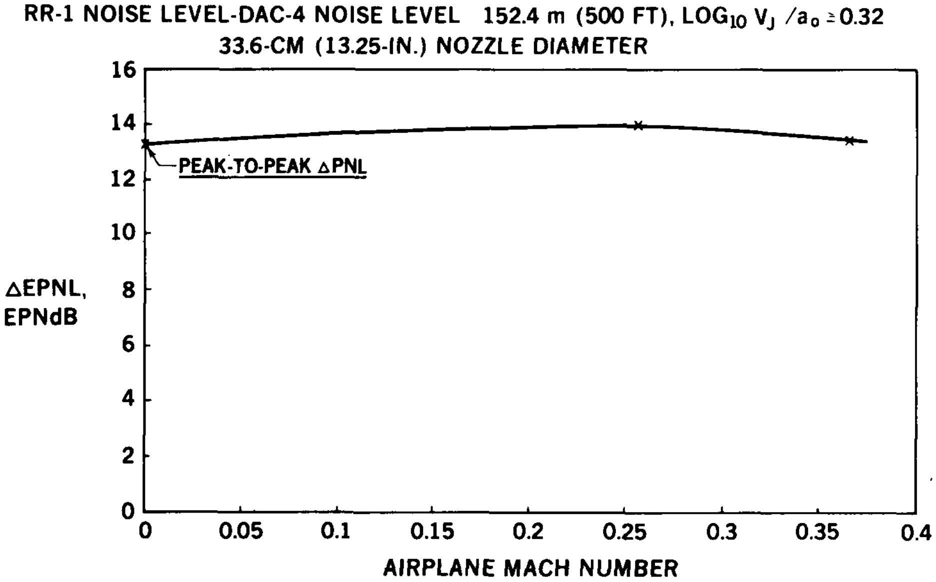

Figure 16.- Variation of noise suppression with airplane speed.

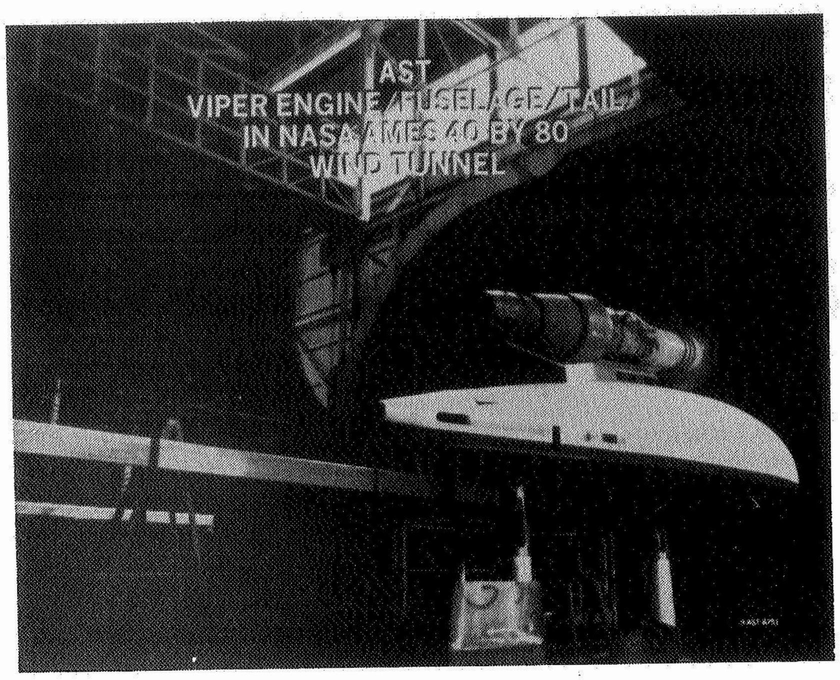

Figure 17.- Viper 601 engine and simulated HS-125 fuselage in NASA Ames 40- × 80-ft wind tunnel.

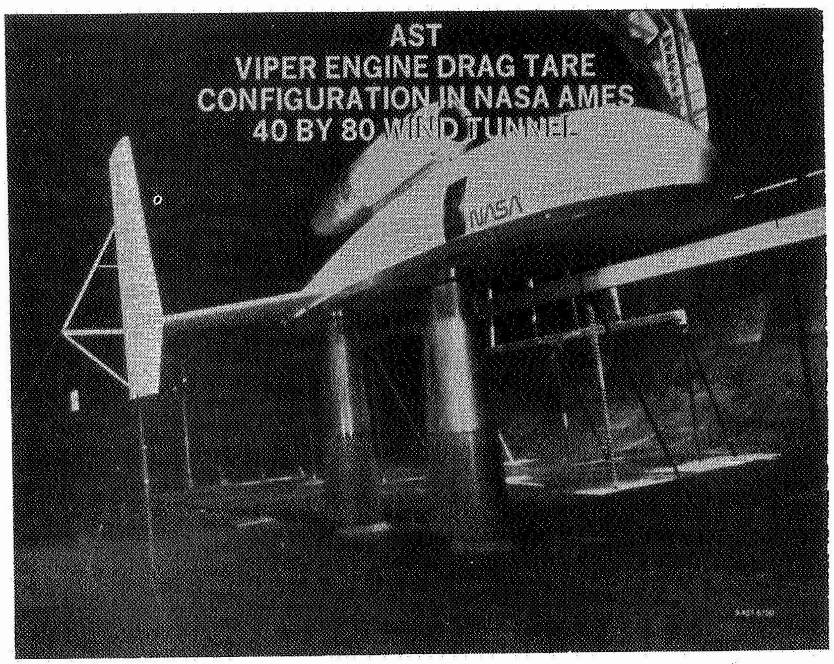

Figure 18.- NASA Ames 40- × 80-ft wind tunnel installation with simulated horizontal tail surface attached.

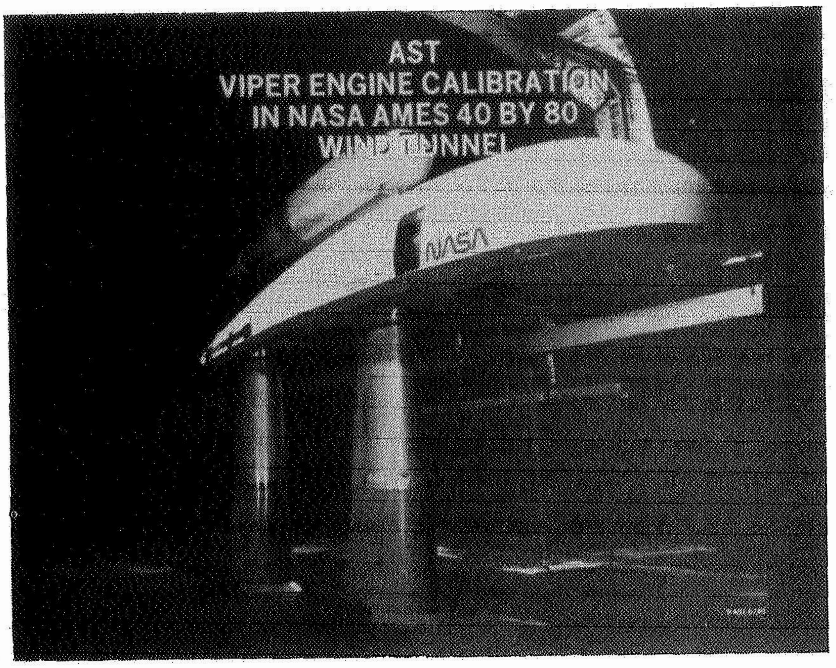

Figure 19.- Viper engine drag tare configuration, NASA Ames 40- × 80-ft wind tunnel

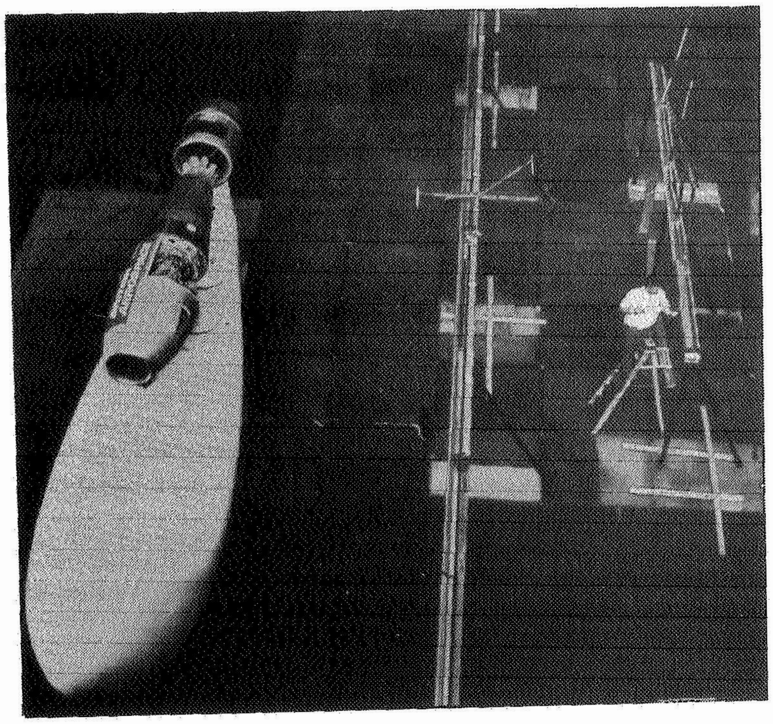

Figure 20.- NASA Ames 40- × 80-ft wind tunnel microphone array.

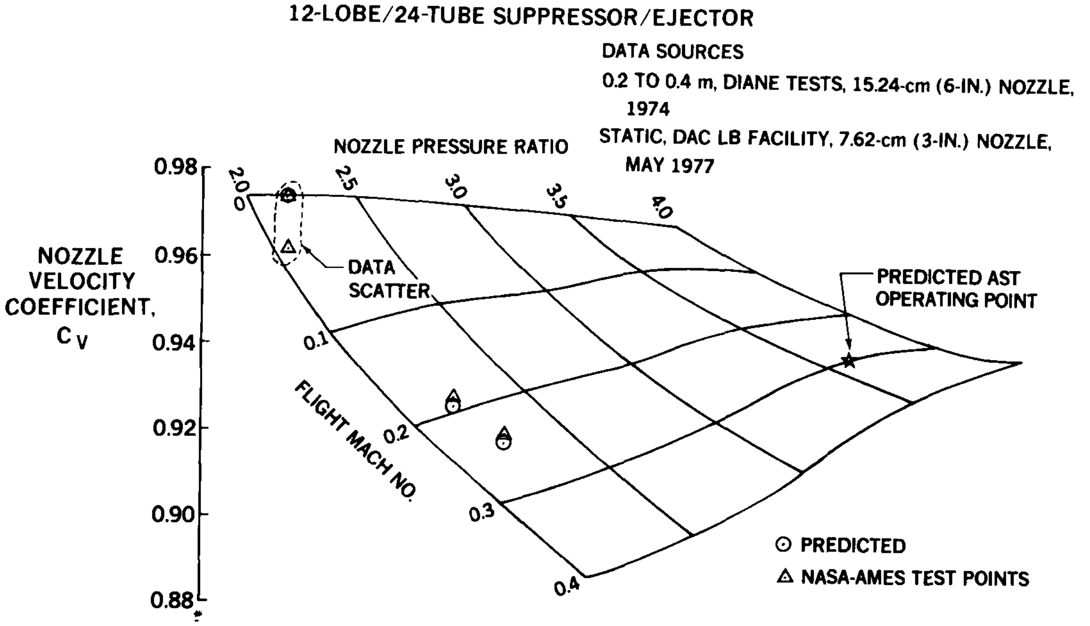

Figure 21.- MDC 12-lobe/24-tube suppressor/treated ejector nozzle performance.

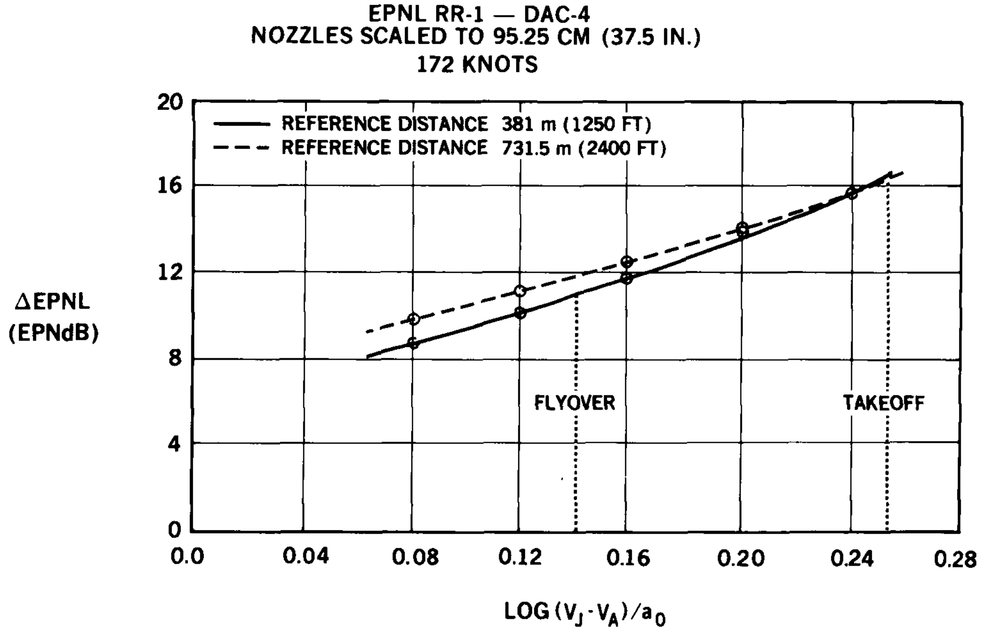

Figure 22.- Variation of noise suppression scaled to AST engine size with relative jet velocity.

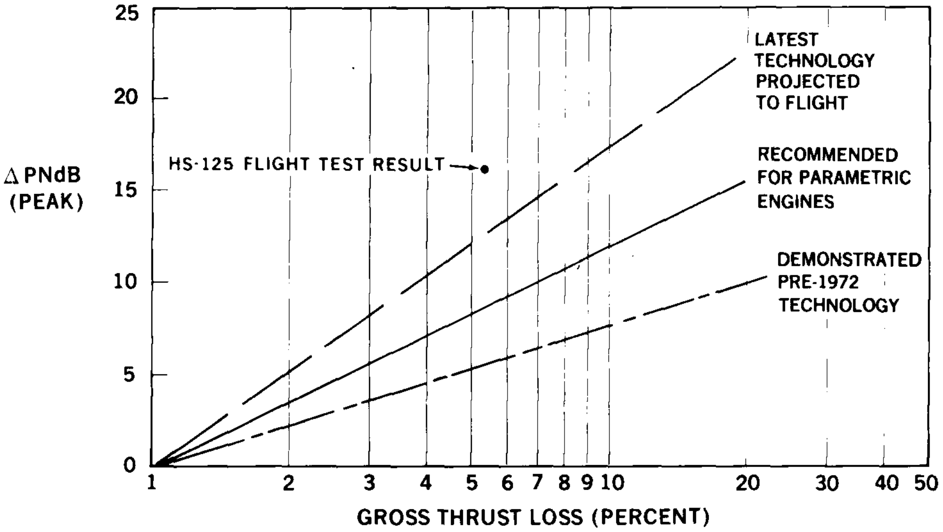

Figure 23.- Working Group E jet suppressor subgroup recommendation for trade-offs of noise suppression and thrust loss.