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Comparison of NASA and Contractor Results from Aeroacoustic Tests of QCSEE OTW Engine

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SUMMARY

The over-the-wing (OTW) Quiet, Clean, Short-Haul Experimental Engine (QCSEE) was tested both at the NASA Lewis Engine Noise Facility and at the contractor's facility. A boilerplate (nonflight-weight), high-throat-Mach number, acoustically treated inlet and a D-shaped OTW exhaust nozzle with variable position side doors were used in the tests. Both aerodynamic and acoustic results of the tests are presented. Some acoustic directivity results for the type "D" nozzle and acoustic effects of variations in the nozzle side door positions are included. The results indicate good agreement with the results previously obtained at the contractor's test site.

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INTRODUCTION

As a part of a broad-based NASA program to provide a technology base for future propulsion requirements for powered-lift aircraft, the Quiet, Clean, Short-Haul, Experimental Engine (QCSEE) Program was initiated by the Lewis Research Center in 1974 (ref. 1). Two propulsion systems were designed and built under this contracted program. One propulsion system was designed for an under-the-wing (UTW) externally blown flap application; the other was configured for over-the-wing (OTW) upper-surface blowing. Aerodynamic and acoustic results from tests on both systems are reported in reference 2. The OTW design was reported in references 3 and 4. The initial buildup of the OTW engine was tested at the contractor's test site and reported in reference 5. The engine was inspected, refurbished, and delivered to NASA Lewis Research Center in June 1977 for further testing. Other results of testing with the UTW engine at Lewis are presented in references 6 and 7. In reference 6 is an evaluation of a fan exhaust bulk absorber acoustic treatment and in reference 7 an acoustic test of the powered lift (engine and wing-flap) system.

The engine was tested at the NASA-Lewis Engine Noise Test Facility. A boilerplate, high-throat-Mach number, acoustically treated inlet was installed and a D-shaped OTW exhaust nozzle which had variable position side doors was used in the tests which are reported herein.

The 93 408 N (21 000 lb) thrust engine incorporated many low noise design features in addition to the "hybrid" (high-throat-Mach number, acoustically treated) inlet. It has wide rotor-stator spacing, frame treatment and treated vanes, stacked treatment in the core to attenuate both high-frequency turbine noise and low-frequency core noise, and removable fan exhaust wall panels and a splitter. Details of the acoustic design are contained in references 8 and 9. The QCSEE in-flight noise goals (fig. 1) for a 152.4-m (500-ft) sideline required all of the aforesaid treatment for a 610-m (2000-ft) runway. Another acoustic configuration, designated the "914-m (3000 ft) runway" configuration, was tested and is the only configuration reported herein. The fan duct acoustic splitter was removed, and the core treatment was simplified by removing the very deep, low-frequency treatment. The engine was run over a range of powers from flight idle to takeoff rating at two exhaust nozzle side-door positions. The purpose of this report is to compare NASA and contractor results of the engine-alone aeroacoustic tests and to show some test facility and instrumentation details and test procedures. A secondary purpose is to discuss the ground-reflection correction used throughout the QCSEE tests, both with and without the wing and flaps.

APPARATUS AND PROCEDURE

OTW Experimental Propulsion System Description

The OTW experimental propulsion system (fig. 2) featured a high Mach number (accelerating) inlet, a gear driven fan, a fan and stator vane-frame made of composite material, a treated fan duct with a removable splitter ring, a variable geometry confluent flow exhaust nozzle, an advanced (F-101) core and low pressure turbine, a removable treated-core exhaust, top-mounted engine accessories, and a digital electronic control system.

The fundamental design criterion was the engine cycle required to meet the noise objective. Acoustic design parameters are presented in table I. The fan and core exhaust pressure ratios were dictated by jet-flap noise constraints and by the powered lift requirements of an over-the-wing installation.

The fan was a low-pressure-ratio (1.34), low-tip-speed (350.5 m/sec; 1150 ft/sec) configuration sized to provide 405.5 kg/sec (894 lb/sec) of corrected airflow at takeoff conditions. The fan's 28 titanium blades were of an aerodynamic contour capable of conversion to composite material in a flight system. The fan was driven by the F-101 low-pressure turbine through a main reduction gear with a gear ratio of 2.0617.

The fan frame was a flight-weight composite structure composed of integral acoustic treatment, casing, containment ring, and fan tip treatment. Thirty- three integral outlet guide vanes also acted as structural struts. Core inlet flowpath and mounts for the forward bearings, gears, radial drive, etc., were integral with the frame.

The nacelle components included a hybrid inlet providing acoustic suppression by means of a high throat Mach number (0.79) and integral acoustic treatment. The boilerplate fan duct and the core cowl were hinged from the pylon to provide access for engine maintenance. The D-shaped confluent flow exhaust nozzle (fig. 3) incorporated side doors to vary the area from takeoff (25° open) to cruise conditions The tests reported herein included door angles of 11-1/2° and 25° open. No actuation system was provided for the experimental engine, so that exhaust areas had to be preset before starting the engine. A blocker type thrust reverser is shown in figure 3, but it was not used in these tests.

Engine fuel flow for this program was controlled by a hydromechanical control, which scheduled core stators and provided starting, acceleration, and deceleration schedules. Major engine accessories were mounted on a boilerplate gearbox on top of the fan frame.

Test Facility

The engine test stand (figs. 4 and 5) was designed specifically for tests of the QCSEE engines. Each engine was tested alone and also with appropriate unswept wing and flap segments properly located to simulate the powered-lift system of an aircraft in flight. Wing and flaps were mounted with spans vertical to minimize flow field ground interference. Since this report deals only with the OTW engine alone results, the photographs (fig. 4) show the D nozzle in a position 90° from the normal horizontal orientation. Specific attention was made to provide as much clearance as practical from the inlet to ground plane to minimize distortion of the inlet flow which cause high blade stress and extra noise. However, no inlet flow control device was provided. The engine centerline was 4.6 m (15 ft) above grade. A compact A-frame upper structure straddled and held the engine (top mounts) and all its accessories. The stand was designed to enable measurement of forward, reverse, and side loads. The engine upper stand structure was hung from flexure plates and steady-state thrust was measured by load cells with an estimated accuracy of ±1 percent of full scale.

Instrumentation, Data Reduction, and Test Procedure

Two microphone systems were employed in the test program, a ground plane system and an overhead system. The 14 ground microphones were positioned at 10° increments on a 45.7-m (150 ft) radius arc. These ground plane microphones provided flyover plane noise data for the case in which the aircraft flies directly over an observer on the ground. The flyover plane is shown in figure 6 as the plane AA'B'B. In this plane the angle θ_F is measured from the engine centerline AA' to the flyover observer at point O_F. The QCSEE inflight noise goals, however, are specified for a 152-m (500-ft) sideline flyby (as shown in fig. 1). That sideline plane is the plane AA'C'C in figure 6. The angle θ_S is measured in the sideline plane from the engine centerline to the sideline observer at O_S. To obtain sideline noise data, five microphones were hung from a cable suspended from two towers, all lying in a plane 90° to the engine axis (fig. 5). The microphones were spaced to correspond to angles between a sideline observer and an aircraft at altitudes of 0, 30.5, 61.0, 91.4, and 122 m (0, 100, 200, 300, and 400 ft). A sixth microphone was located to represent a sideline observer at 120° from the engine inlet with the aircraft at at altitude of 61.0 m (200 ft), which is the estimated location of maximum sideline flyby noise (both takeoff and landing). In this paper data obtained by the ground plane microphones relate to the flyover plane, and those obtained by the overhead microphones relate to the sideline flyby geometry.

Bruel and Kjaer 1.27-cm (0.5-in) diameter condenser microphones equipped with windscreens were used. The ground plane microphones were secured to 1.2 by 1.2 m (4 by 4 ft) hard boards with microphones pointed nominally toward the noise source. The paved asphalt test area surface was painted white, except for the region within 15.2 m (50 ft) of the engine center, to minimize acoustic refractions due to temperature gradients near the asphalt surface.

The data acquisition system used a minicomputer to control the noise and aerodynamic data scanners. Noise data from each microphone were analyzed on-line by an automated 1/3-octave-band spectrum analyzer (ref. 10). Sound pressure level spectra (referenced to 2×10^{-5} Pa) were measured over the frequency range from 25 Hz to 16 kHz. The digitized noise data were transmitted to the computer. Three samples for a given corrected fan speed were reduced separately. The arithmetic average was then adjusted to standard acoustic day atmospheric conditions (77° F, 70 percent relative humidity). The analog noise signals were also recorded on FM tape for later off-line data reduction.

Perceived noise levels (PNL's) on a 152-m (500 ft) sideline flyby with the aircraft at different specified altitudes were calculated using data from the overhead microphone system and the method of reference 11.

The measured ground-plane microphone data were corrected to free field by application of a -6-dB correction to each 1/3-octave-band SPL value. For the overhead microphones a nominal -2-dB free-field correction had been previously determined from both analytical and empirical studies. The ground-reflection characteristics of each of the overhead microphones were unique, and a spectral correction for each was empirically determined and applied in all cases for this report. These corrections (table II) were significant and are discussed in the appendix.

During a typical acoustic test the engine was run over a range of powers from flight idle to takeoff rating at two exhaust nozzle side-door positions. At each steady-state condition, the aerodynamic and environmental data were sampled periodically during the noise data acquisition scan and also transmitted to the computer. These data included engine fan and core speeds, fuel flow, engine pressures and temperatures, engine thrust, wind speed and direction, ambient and dew-point temperatures, and barometric pressure. Instrumentation stations are shown in figure 7. Data from the multiple aerodynamic and environmental scans were averaged and used by the computer in the calculation of engine operating parameters. At the conclusion of the test point, the noise data and calculated engine operating parameters were imprinted on a line printer. Data stored in the test and site computer were transmitted on command to a large central computer for storage and detailed analysis.

Total-pressure recovery of the inlet was measured at the fan face (station 2, fig. 7) by means of two traversing pressure probes. The results from traverses in and out were averaged and flow-area-weighted by means of an offline computer program separate from the on-line program referred to earlier. The resulting total pressure was then divided by the ambient pressure to yield recovery. These tests were done before acoustic testing.

RESULTS AND DISCUSSION

The aerodynamic results for the high-Mach-number inlet are presented in terms of recovery factor as a function of one-dimensional throat Mach number. The aerodynamic performance of the engine is shown as corrected air flow and corrected net thrust as functions of percent rated corrected fan speed and corrected specific fuel consumption as a function of corrected net thrust.

The acoustic comparison of NASA and contractor results are displayed as 500-ft sideline 1/3-octave SPL spectra and as 500-ft sideline OASPL directivity plots. The D-nozzle directivity is presented in terms of 100-ft radius OASPL and in 1/3-octave-band comparisons of flyover and sideline planes. The acoustic effects of nozzle door position on directivity are presented in terms of OASPL and 100-ft radius 1/3-octave-band spectra.

Aerodynamic Performance

The high-Mach-number inlet performance is presented in figure 8 in terms of inlet recovery factor as a function of average throat Mach number. Inlet recovery is defined as the integrated average of the fan face total pressure divided by the ambient pressure. The contractor's data (ref. 5) are shown as a dashed line. The data taken during this investigation are shown for the nozzle areas (1.577 m^2 and 1.90 m^2). The line drawn through these data points falls below the contractor's data by 0.1 to 0.2 percent. A possible reason for this very small disagreement might be that the ambient wind direction during the program for the aerodynamic tests reported herein was from the rear quadrant which can result in greater distortion of inlet flow distribution and, hence, lower inlet recovery.

Corrected engine inlet airflow is presented in figure 9 as a function of percent of rated corrected fan speed. Again the contractor's data (ref. 5) are shown as a dashed line for both exhaust nozzle areas. The data taken during this investigation agree remarkably well with the contractor's data except at high fan speeds. At 95 percent of rated corrected fan speed, the large-area (1.901 m^2) nozzle data fall about 1 percent below the contractor's data. The small-area nozzle data (1.577 m^2) fall about 1.5 percent below the contractor's data. This probably is also due to the aft quadrant ambient wind causing greater distortion at the high fan speeds during this investigation.

Corrected axially measured net thrust is shown in figure 10 as a function of percent of rated corrected fan speed. Again the contractor's data (5) are shown as dashed lines for both exhaust nozzle areas. The data for both large and small nozzles fall higher than the contractor's data in this case; the data fall about 3 percent higher than the contractor's data at 95 percent rated corrected fan speed.

A possible reason for this increased thrust for the tests reported herein is as follows: During early checkout tests for this investigation, it was discovered that fan discharge air was leaking from the D-nozzle transition joint (see fig. 3) over the range of fan speeds, particularly at high fan speeds. The leakage problem was then corrected for the data which is presented. However, it is possible that leakage occurred during those tests made by the contractor and resulted in lower thrusts.

Corrected specific fuel consumption based on axially measured net thrust is presented in figure 11 as a function of corrected axial net thrust. In this case the individual points are presented for the contractor's data as well as the faired dashed lines. The 1.901 m^2 nozzle area data for this investigation fall about 3 percent below the contractor's data (as expected from the preceding figure). The data for the small nozzle area (1.577 m^2) agree with the contractor's data. However, this agreement is based on only two data points.

Acoustic Performance: Comparison of Contractor and NASA Results

A rather comprehensive report of the OTW engine acoustics was made by the contractor in reference 5. This report treats mainly comparisons of NASA and contractor's data. However, because of the differences between the NASA and contractor's sound arenas and engine mounting orientation (see figs. 4 and 5 and 18-20 from the appendix), only one direct comparison can be made.

The NASA tower microphone directly over the engine referred to as the 30.5-m altitude microphone and the contractor's 90°, 12.2-m high pole microphone are both at an angular location 90° from the engine center line and about 7° below the plane of the flat side of the D nozzle. Shown in figure 12 is the comparison of the 152-m sideline 1/3-octave spectra corrected to free-field conditions for these microphones at two engine speeds, 95 and 86 percent of rated corrected fan speed. The nozzle doors were set at 11-1/2° open for both sets of data. As can be noted, the comparison of the two sets of data is excellent for the frequencies where jet noise is dominant and fairly good for the fan noise frequencies for both power settings. It is feasible that differences in inlet turbulence contribute to the discrepancies in fan tones. Estimated jet noise by the contractor (ref. 5) is shown in figure 12 for reference. Their estimate was based on extensive model and full-scale engine nozzle tests. It should be noted that the noise spectra is jet-noise dominated at frequencies below 630 Hz.

D-Nozzle Directivity

Because the microphone arrangements at the contractor's facility and the NASA facility were markedly different and because a comparison of matching microphone data had been good (fig. 12) a unique opportunity presented itself to compare D-nozzle directivity effects without wing shielding utilizing both sets of data. The contractor's array of 12.2-m pole microphones (figs. 19 and 20) represents the sideline plane and the NASA ground microphones (fig. 5) represent the flyover plane in relation to the D-nozzle mounting orientation at the two facilities. These two sets of 152-m sideline OASPL corrected data are compared in figure 13 for two engine speeds, 95 and 86 percent of rated corrected fan speed. The nozzle doors were set at 11-1/2° open. For both engine speeds the differences between the OASPL data are the greatest at 110° from the engine inlet. The flyover plane (NASA data) noise is greater than the sideline plane (contractor's data) by about 5 to 6 dB. The general shape of the curves indicates a propulsion system that is aft jet noise dominated. The flyover plane is noisier mainly because the 11-1/2° open doors create openings in the nozzle which face the flyover plane. Secondly, the D-nozzle directs the jet about 14° downward from the engine centerline toward the engine flyover plane.

The fact that the noise in the flyover plane is greater can be seen also in figure 14 where the noise data (corrected for ground reflection) from the sideline microphones at 90° from the engine inlet are shown on a polar plot with the data from the 90° flyover microphone.

The OASPL (30.5-m lossless) data are presented for three engine speeds: 95, 81, and 65 percent of rated corrected fan speed. The orientation of the D-nozzle is shown for reference. Note that the OASPL gradually increases from the sideline to the flyover direction. For example, at 95 percent of rated fan speed the OASPL increases from 105.6 at the sideline at 180° to 111.4 for the flyover plane at 83°. At the two lower speeds the increase is not quite as much. The PNL directivity is essentially the same as the OASPL directivity.

The 1/3-octave-band spectra for the points at 180° and 83° are presented in figure 15 for the three engine power conditions. The estimated jet noise (ref. 5) at the sideline plane is also shown for 95 and 81 percent rated fan speed. At 65 percent the jet noise does not contribute substantially to the spectra levels. As can be noted the sieline data follows the jet noise estimate for 95 and 81 percent of rated fan speed at frequencies up to 800 Hz. Fan noise predominates above 1000 Hz. This general result had been previously noted in figure 12(a). The flyover plane noise data, however, are of higher magnitude. This result is due to the orientation of the nozzle door openings, which increase the noise in some 1/3-octave-bands as much as 7 to 10 dB at the two higher power conditions. At 65 percent of rated fan speed, the increases are less, from a fraction of a decibel to 4 dB.

Effect of Nozzle Door Angle

Data for a 25° door angle were obtained to compare with the data for a door angle of 11-1/2°. These data are presented in figure 16 on a polar plot format like figure 14. The effect on OASPL of opening the doors from 11-1/2 to 25° is very small, less than 1 dB for all the data presented. Opening the doors has two opposite effects on noise. The jet velocity is reduced slightly, lowering the noise and perhaps shifting the frequency. However, as the opening is enlarged, apparently more fan machinery noise and, at low speeds, more core noise are able to reach the microphones. The net result is that there is little difference in OASPL at 90° from the inlet over the range of engine speeds investigated. At 120° from the engine inlet in the flyover plane, the increase in OASPL for the 25° door angle is measurable (about +1 dB in OASPL and PNdB). Presented in figure 17 are 1/3-octave-band spectra for 95 percent (part (a)) and 65 percent (part (b)) rated fan speed. At 95 percent rated fan speed noise at the blade passing frequency and its harmonic and fan broadband noise contribute to the increase in OASPL for the 25° door angle position. At 65 percent rated fan speed what could be core noise at the low frequency bands up to 315 Hz is mainly responsible for the increase in OASPL. The fan broadband noise at frequencies above 1600 Hz may also contribute. It should be remembered, however, that this increase in noise is of somewhat academic interest since the D-nozzle was designed to have a wing shielding the noise in the flyover plane. References 6 and 8 have shown that the wing shielding can result in a reduction of 1.6 to 2.8 PNdB in the approach and takeoff power cases, respectively, for an OTW installation. It should be noted by nozzle designers, however, that even small gaps in exhaust nozzles can produce measurable increases in aft radiated noise.

SUMMARY OF RESULTS

The results of the QCSEE OTW engine alone aeroacoustic tests conducted at the NASA Lewis Engine Noise Facility can be summarized as follows:

1. The engine aerodynamic performance results essentially agreed with the results obtained previously by the contractor.

2. A comparison of the acoustic data obtained at Lewis and at the contractor's facility was good.

3. The D-nozzle shape (without the wing) causes up to 6 dB greater OASPL in the flyover plane than in the sideline plane.

4. Even small gaps in nozzles can produce measurable increases in aft radiated noise. Increasing the nozzle angle from 11-1/2° to 25° resulted in some increases in measured fan noise.

5. Ground reflection corrections for tower microphones over hard surfaces can be significant. Application of the perfectly reflected ground plane model did not provide sufficient correction for the data contained in this report.

APPENDIX A - GROUND REFLECTION CORRECTIONS

QCSEE Overhead Microphone System

The overhead microphone array is the key portion of the QCSEE acoustic measurement system since it provides the basic input for the calculation of QCSEE in-flight noise levels for rating acoustic performance in relation to the specified QCSEE sideline noise goals. This overhead array was also useful in determining the noise asymmetry of the engine-nozzle system (and wing and flap systems used in other QCSEE tests). The QCSEE engine and wing tests provided a distributed source relative to the small microphone distances. The QCSEE engine noise spectra also included very significant low-frequency contributions from combustors, jet and jet-flap noise, with jet-flap noise peaking well below 50 Hz. Thus, spectral distortion due to ground reflections for very low frequencies could not be ignored.

A computer program of the analytical model of reference 12 was employed by Bruce Clark of NASA to correct the overhead microphone data for a variety of source distributions. This model assumed a perfectly reflecting ground plane. These calculations indicated that the net effect of the reflected signal would be an increase of 1.9 dB for the entire spectrum. However, for the specific comparisons to be made in this report, data were available from tests with the UTW engine so that an empirical correction could be made. This engine is axisymmetric with the possible exception of the four-flap variable exhaust nozzle and an inlet slip ring strut, neither of which should have more than a slight effect on symmetry about the engine axis of rotation. Corrections derived from these data include complicated effects that might be due to the engine itself, the engine test stand structure, and the presence and location of peripheral support equipment (see fig. 2).

The total acoustic system, in addition to the five overhead microphones in a plane perpendicular to the engine axis at 90° from the inlet, had a microphone also at 90° from the engine inlet in the ground plane array. A free-field spectrum was provided by subtracting 6 dB from the measured ground plane SPL values over the entire spectrum. The spectral correction for each overhead microphone was then obtained by subtracting each 1/3-octave-band SPL value from the corresponding free-field value obtained from the 90° ground plane microphone.

From UTW engine alone acoustic tests, six representative tests points were selected in which engine power settings varied from approach to takeoff conditions and for which postcalibration tests indicated high quality data for the overhead system and for the 90° ground plane microphone. Correction values for the five overhead microphones which are given in table II are the arithmetic means of the corrections from the six test runs. Also listed is the probable error of the mean values. The measured correction values above 1000 Hz for the 61.0- and 91.4-m (200- and 300-ft) altitude microphones are larger than the expected average correction of about -2 dB, and may indicate the presence of additional reflection paths.

Tabulated corrections are given in table III for PNL and OASPL for representative takeoff and approach power settings. As can be seen, the ground reflection corrections vary from 0.2 to 2.8 from OASPL and from 0.9 to 3.7 on a PNL basis. These corrections were then used for the results presented herein.

Contractor's Microphone System

The contractor's test installation (fig. 18) was somewhat different than the NASA Engine Noise Facility installation. The engine centerline was 3.96 m (13 ft) above the ground and the D-nozzle was oriented with the flat section at the top contrasting to the NASA installation where the engine centerline was 4.6 m (15 ft) and the flat section (bottom) of the nozzle was oriented sideward toward the sound field (figs. 1 and 2).

The contractor's test arena (fig. 19) consisted of a leveled semicircle of approximately 76-m (250-ft) radius with a crushed rock surface composed of rock sizes of approximately 2.5 to 7.5 cm (1 in. to 3 in.) diameter. The standard far-field microphone setup for forward thrust tests consisted of microphones located at acoustic angles of 10° through 160° at 10° increments, on permanently fixed towers located on a 45.7-m (150-ft) arc and centered near the fan rotor plane. Standard microphone height was 12.2 m (40 ft) above ground level, or 8.2 m (27 ft) above engine centerline height of 4.0 m (13.0 ft), with a distance from the arc center to microphone location of 46.5 m (152.4 ft). The 12.2 m (40-ft) microphone height was chosen in the early 1970's to simulate the ground reflection effects experienced during flyover testing with a 1.22 m (4-ft) microphone height.

Additional far-field microphones were used during forward thrust testing to monitor D-nozzle asymmetry effects. Three microphones were located on the 90°, 120°, and 150° poles at engine centerline height. A fourth was located on the 150° pole at a height of 7.8 m (25.6 ft). The locations of these microphones are shown in figures 19 and 20. Measurements from these microphones were reported by the contractor, but only the 12.2-m (40-ft) data were used in this report.

The corrections for ground reflections were determined by the contractor and are presented in table IV for the 12.2-m (40-ft) high microphones.

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TABLE 1. - ACOUSTIC DESIGN PARAMETERS

	OTW engine
Fan diameter, cm (in.)	180.4 (71)
Number of fan blades	28
Number of stator vanes	33 (32 + pylon)
Vane to blade ratio	1.18
Inlet treatment length to fan diameter ratio, L/D	0.74
Rotor-stator spacing, rotor tip chords	1.93
Takeoff conditions:	
Fan speed (rpm)	3738
Fan tip speed, m/sec (ft/sec)	350.5 (1150)
Fan pressure ratio	1.34
Fan weight flow (corrected), kg/sec (lbm/sec)	405.5 (894)
Core weight flow (corrected), kg/sec (lbm/sec)	35.7 (78.6)
Fan and core exhaust area (total), m^2 (in^2)	1.802 (2794)
Fan exhaust velocity, m/sec (ft/sec)	219 (720)
Core exhaust velocity, m/sec (ft/sec)	328 (1077)
Bypass ratio	10.3
Uninstalled thrust, SLS, kN (lbf)	93.4 (21 000)
Installed thrust, SLS, kN (lbf)	90.3 (20 300)
Fan blade passing frequency, Hz	1744
Aircraft speed, m/sec (knots)	41.2 (80)
Approach conditions:	
Fan and core exhaust area (total), m^2 (in^2)	1.802 (2794)
Fan exhaust velocity, m/sec (ft/sec)	180.4 (592)
Core exhaust velocity, m/sec (ft/sec)	229.8 (754)
Aircraft speed, m/sec (knots)	41.2 (80)
Installed thrust, SLS, kN (lbf)	58.0 (13 042)

TABLE II. - MEASURED TEST AREA REFLECTIVITY CORRECTIONS FOR

QCSEE OVERHEAD MICROPHONE SYSTEM

Frequency	Simulated 152.4 m (500-ft) sideline altitude									
	0		30.5 m (100 ft)		61.0 m (200 ft)		91.4 m (300 ft)		121.9 m (400 ft)	
	ΔdB	P.E.	ΔdB	P.E.	ΔdB	P.E.	ΔdB	P.E.	ΔdB	P.E.
25	-2.1	0.7	-0.9	0.6	1.3	0.3	-0.7	0.3	-1.2	0.4
31.5	-2.1	.2	-1.2	.4	.5	.2	-1.5	.2	-1.9	.6
40	-1.3	.3	-.6	.5	.7	.5	-.3	.4	-.8	.4
50	-1.2	.4	-1.3	.5	.6	.4	.3	.4	-.9	.3
63	-0.9	.2	-1.1	.4	-.2	.5	-.7	.4	-3.0	.4
80	-.9	.3	-.9	.5	-.5	.4	-.6	.2	-1.8	.3
100	.5	.4	-.1	.4	-.0	.4	-.6	.3	-1.0	.2
125	-.4	.2	-1.0	↓	-.6	.3	-1.3	.3	-1.5	.2
160	.5	.4	-.4	↓	-.6	.3	-1.0	.4	-2.2	.3
200	1.7	.4	1.0	↓	.9	.4	.3	.5	.0	.4
250	-.5	.2	-.5	.3	-1.5	.4	-1.6	.3	-2.2	↓
315	-.4	.2	-.5	.1	-1.7	.3	-1.8	.3	-2.6	↓
400	.6	.1	-.1	.1	-2.0	.2	-1.8	.2	-2.6	↓
500	-1.7	.2	-1.5	.2	-2.7	.1	-3.3	.3	-3.9	↓
630	-.9	.1	.2	.2	-1.2	.1	-2.0	.2	-2.4	.1
800	.9	.2	.1	.2	-1.0	.2	-1.1	.2	-2.3	.3
1 000	-.7	.4	-.7	.5	-2.4	.4	-3.2	.4	-3.3	.5
1 250	.6	.2	-.1	.1	-1.5	.2	-2.3	.1	-3.1	.2
1 600	-1.4	.3	-2.0	.2	-2.9	.2	-3.5	.2	-4.0	.2
2 000	-1.8	.2	-2.7	↓	-3.9	.3	-4.4	.3	-4.9	.4
2 500	-2.2	↓	-2.8	↓	-3.3	.3	-4.6	.4	-4.8	.3
3 150	-1.3	↓	-2.6	↓	-2.7	.2	-4.0	.3	-4.6	.3
4 000	-.8	↓	-1.9	.3	-1.8	.2	-3.8	.3	-4.3	.4
5 000	-1.3	↓	-3.0	.1	-1.9	.1	-4.2	.2	-4.6	.1
6 300	-1.2	↓	-3.4	.2	-1.6	.2	-4.9	.2	-4.6	.2
8 000	-.8	↓	-3.8	.2	-1.3	.2	-5.5	.1	-4.9	.2
10 000	-.4	.1	-4.3	.1	-.3	.2	-5.7	.1	-5.5	.1

TABLE III. - EFFECT OF GROUND REFLECTION CORRECTION ON MEASURED OASPL AND PNL AT TAKEOFF POWER

Simulated altitude of overhead microphone system, m (ft)	Correction in OASPL, ΔdB	Correction in PNL, ΔdB
0	-0.2	-0.9
30.0 (100)	-1.1	-1.8
61.0 (200)	-1.3	-2.0
91.4 (300)	-2.2	-3.3
121.9 (400)	-2.8	-3.7

TABLE IV. - GROUND REFLECTION CORRECTIONS FOR 12.2-m (40-ft) HIGH MICROPHONE

[Corrections are to be added to measured spectra.]

Frequency, Hz	Correction, dB	Frequency, Hz	Correction, dB
50	+3.0	800	-0.7
63	+5.1	1 000	-.6
80	+2.3	1 250	-.7
100	-1.4	1 600	-.6
125	-3.1	2 000	-.7
160	-0.8	2 500	-.4
200	+2.7	3 150	-.6
250	-2.6	4 000	-.6
315	+1.3	5 000	-.5
400	-1.4	6 300	-.6
500	-.9	8 000	-.5
630	-.3	10 000	-.6

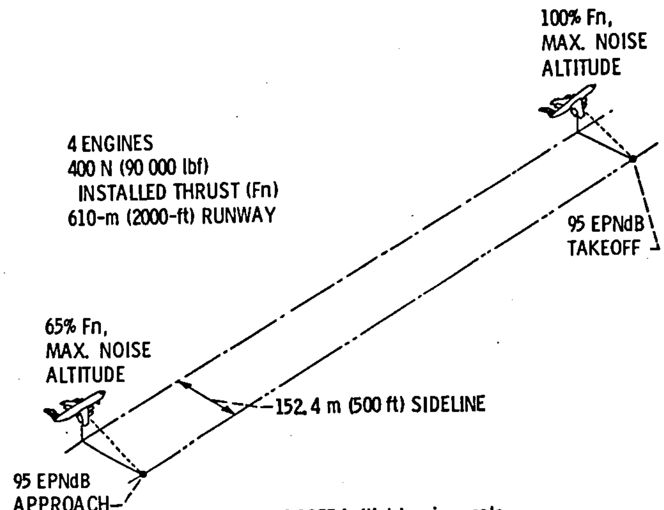


Figure 1. - QCSEE inflight noise goals.

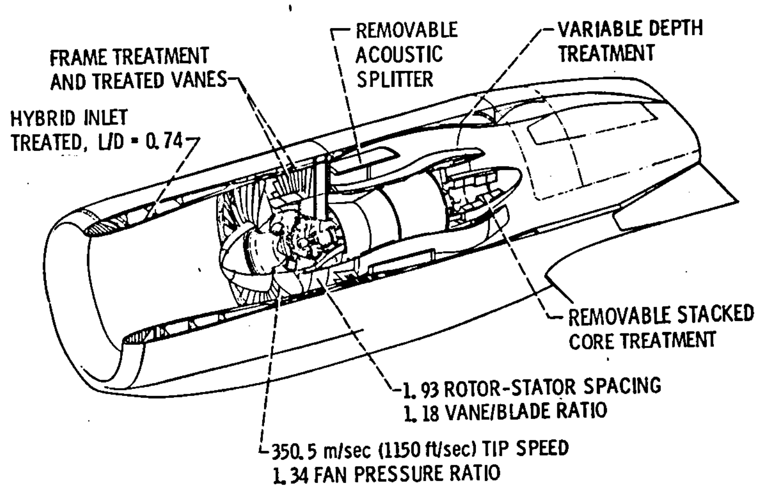


Figure 2. - OTW Engine acoustic design features.

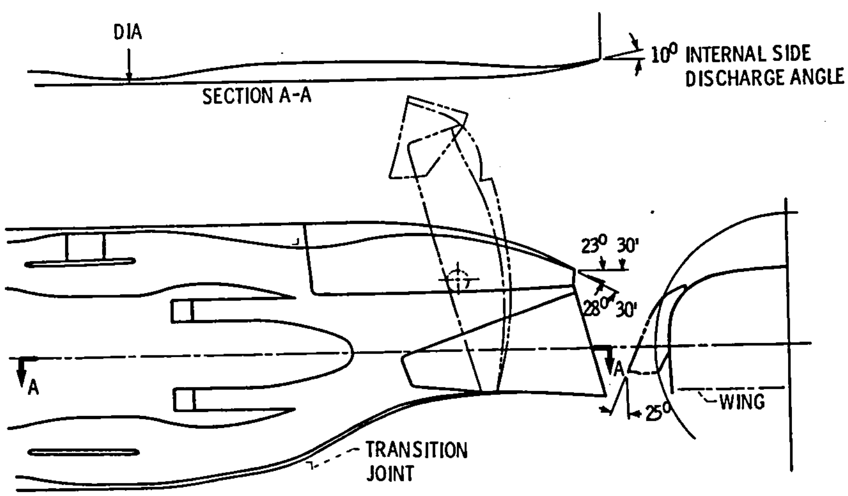
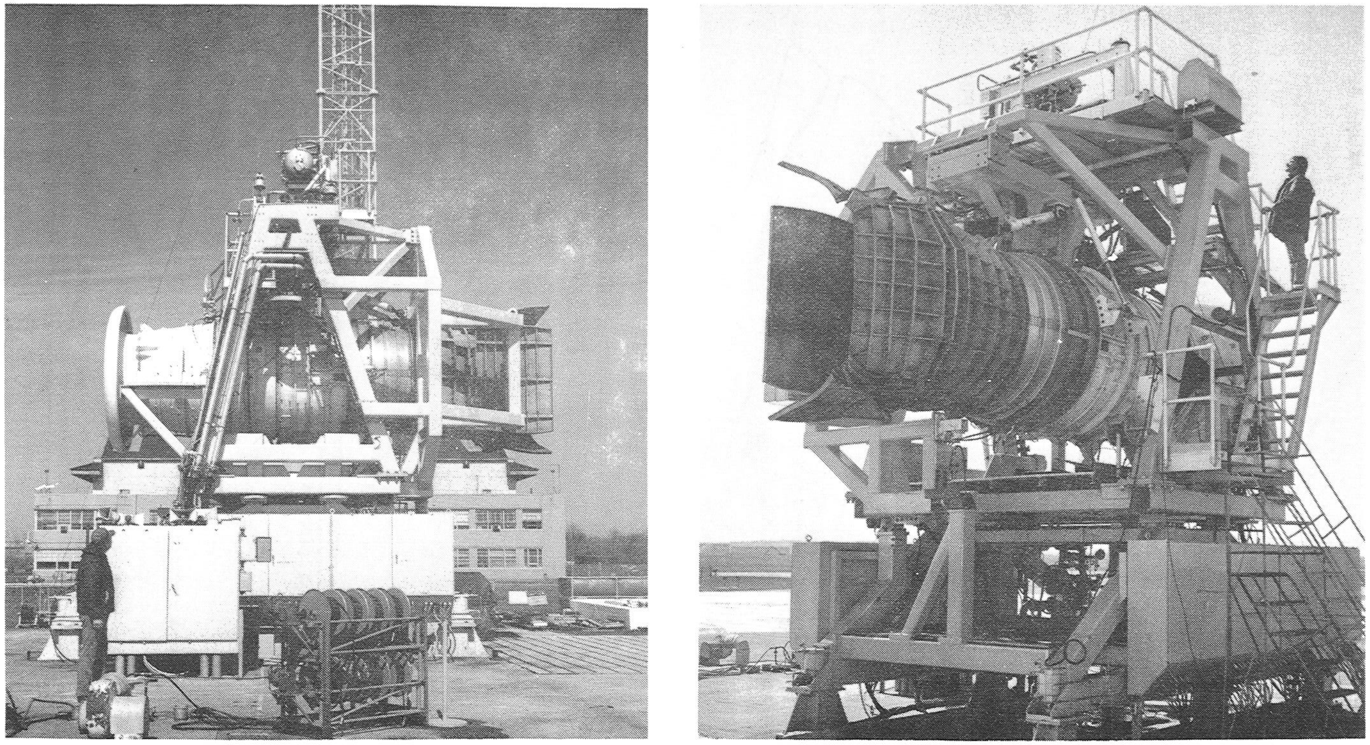


Figure 3. - D-shaped confluent exhaust nozzle.



(a) Bottom of D-nozzle. (b) Top of D-nozzle.

Figure 4. - Thrust stand installation with OTW engine.

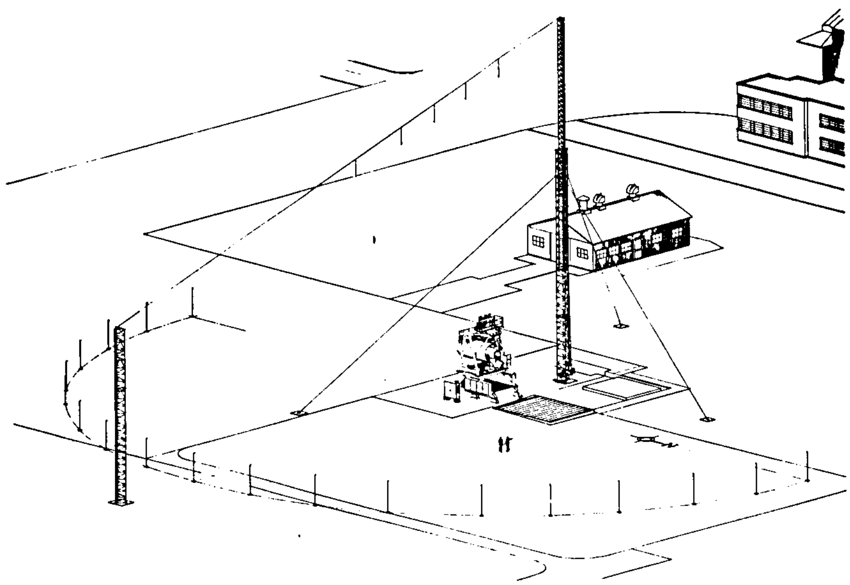


Figure 5. - Engine noise test facility showing QCSEE installation and microphone towers.

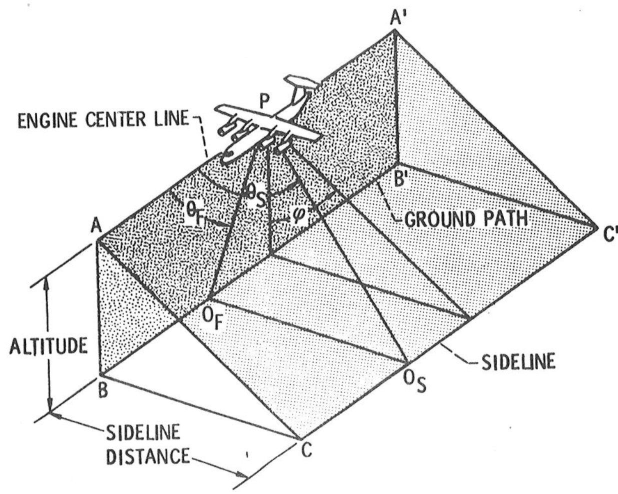


Figure 6. - Flyover and sideline flyby geometry.

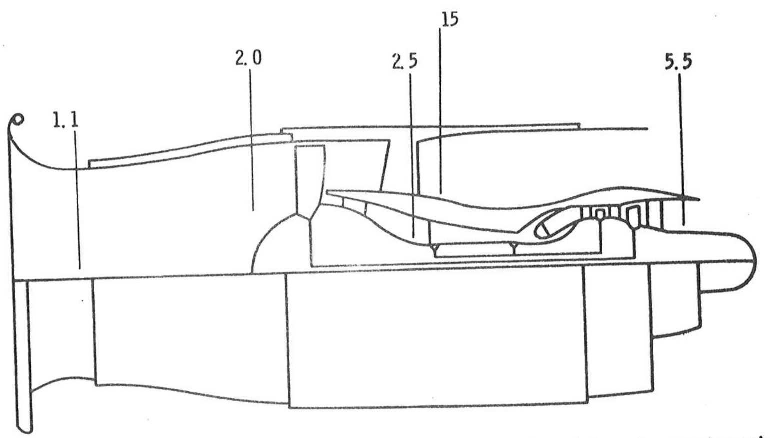


Figure 7. - QCSEE OTW engine sketch showing instrumentation stations for aerodynamic measurements.

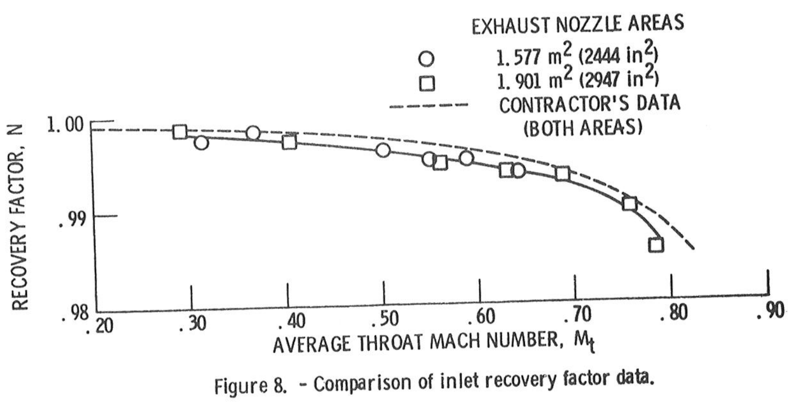


Figure 8. - Comparison of inlet recovery factor data.

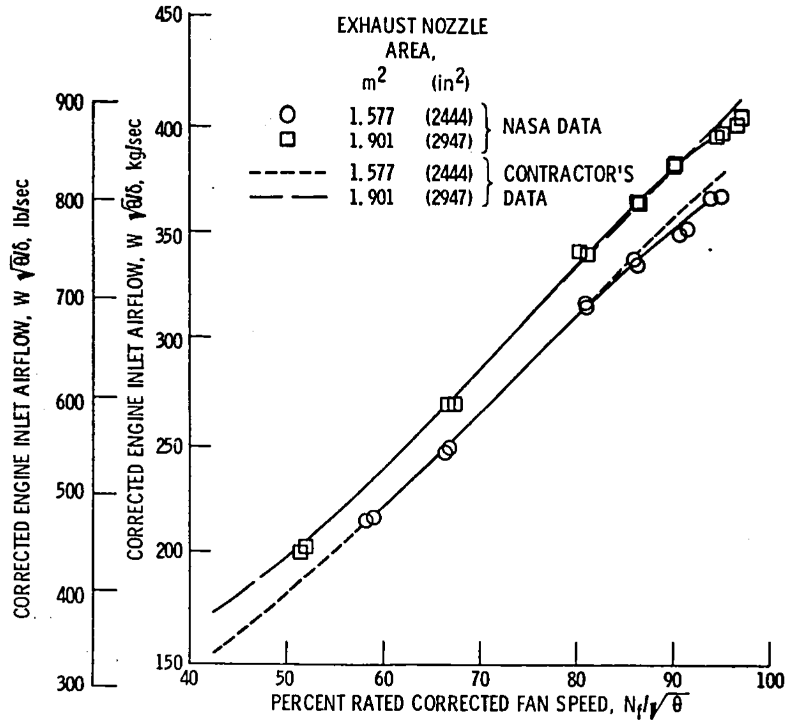


Figure 9. - Comparison of corrected airflow data.

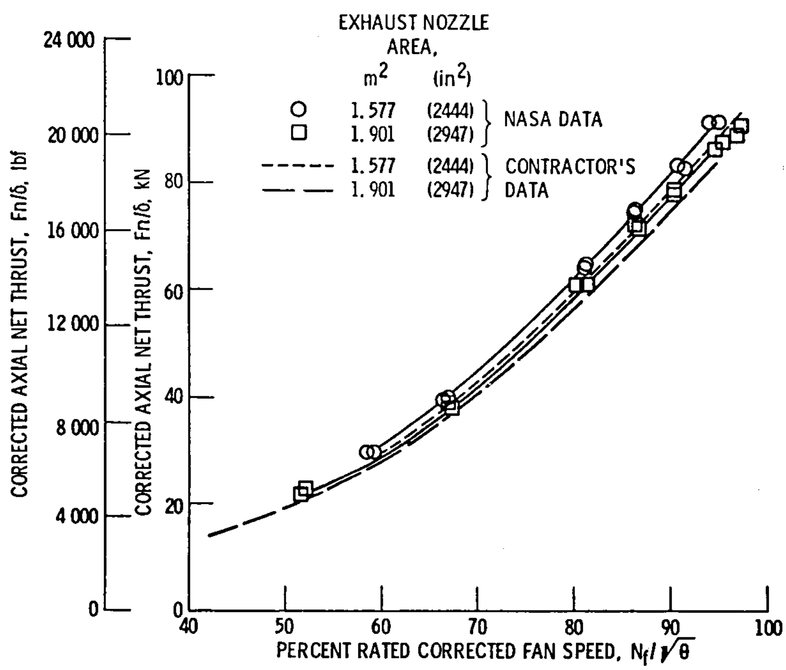


Figure 10. - Comparison of corrected axial net thrust data.

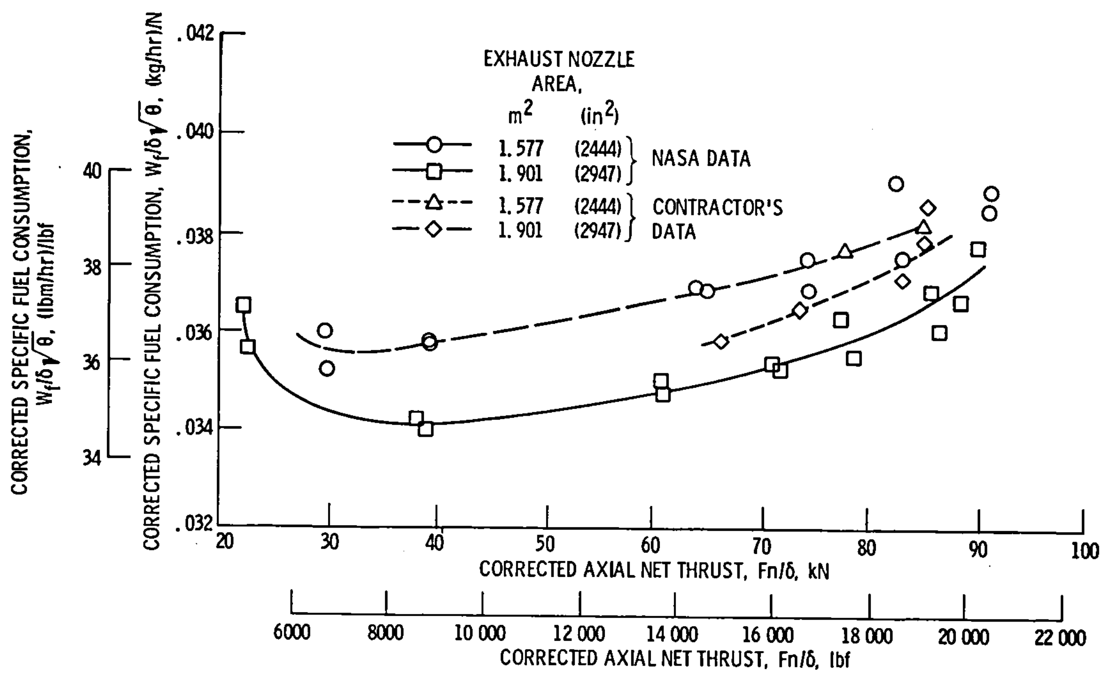


Figure 11. - Comparison of corrected specific fuel consumption data.

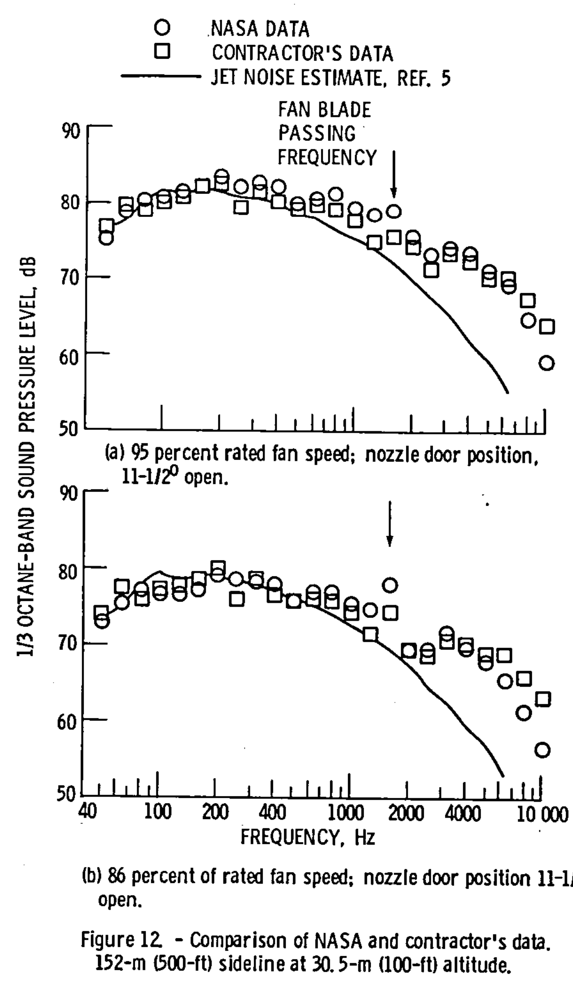


Figure 12. - Comparison of NASA and contractor's data. 152-m (500-ft) sideline at 30.5-m (100-ft) altitude.

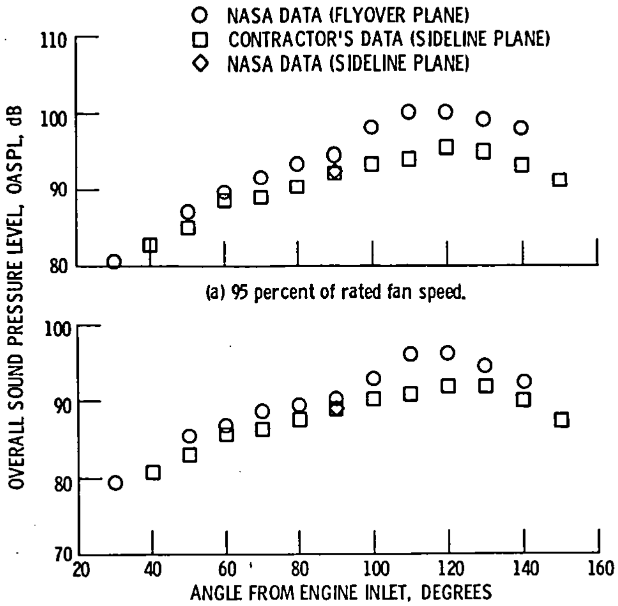


Figure 13. - D-nozzle directivity effect. 152-m (500-ft) sideline; nozzle door position, 11-1/2° open.

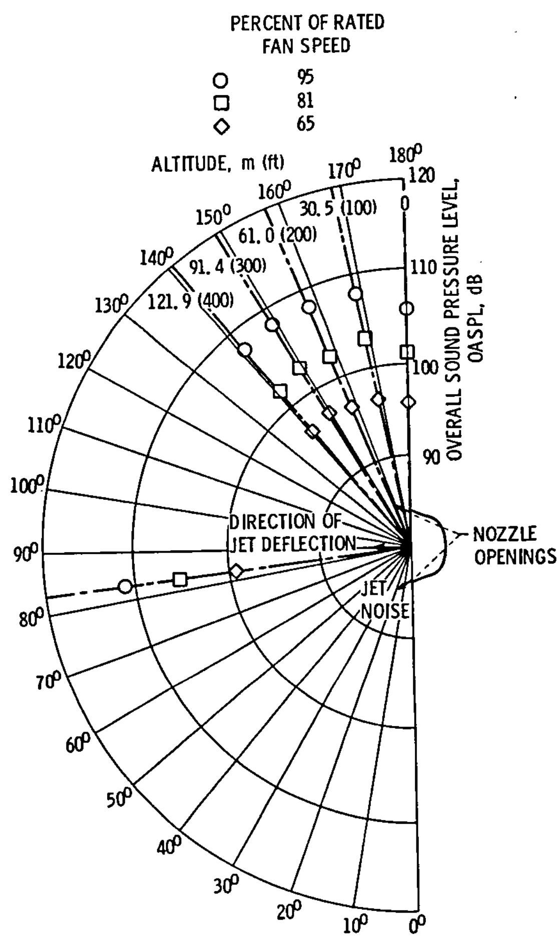
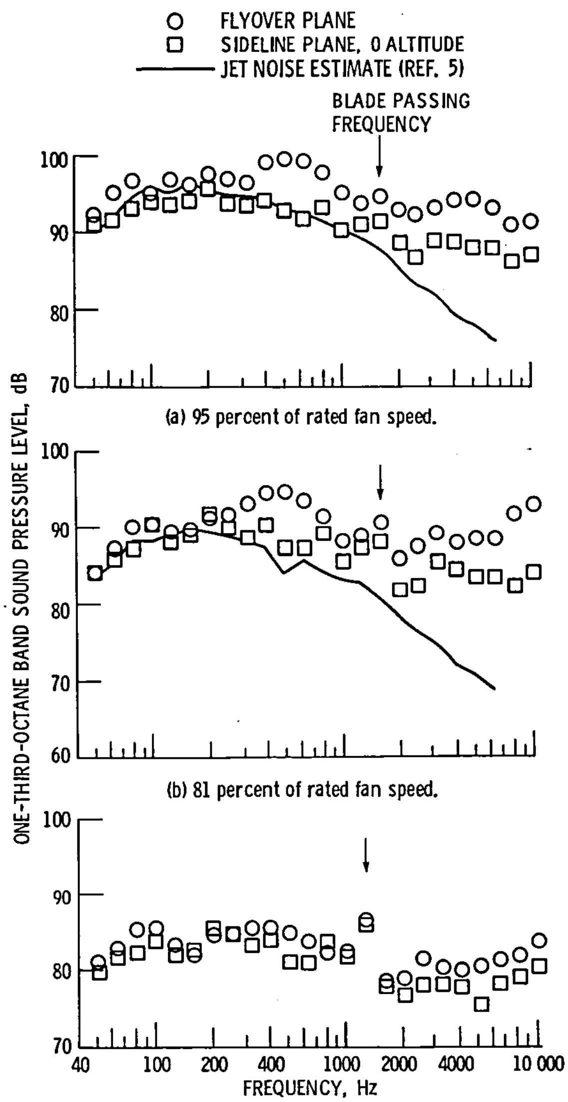


Figure 14. - Effect of engine speed on D-nozzle directivity in plane normal to engine axis at a distance of 30.5-m (100 ft). Nozzle door position, 11-1/2°.



(c) 65 percent of rated fan speed.

Figure 15. - Noise spectra comparison of flyover and sideline planes. 90^0 from engine inlet at a distance of 30.5-m (100 ft); nozzle door position, 11-1/2^0.

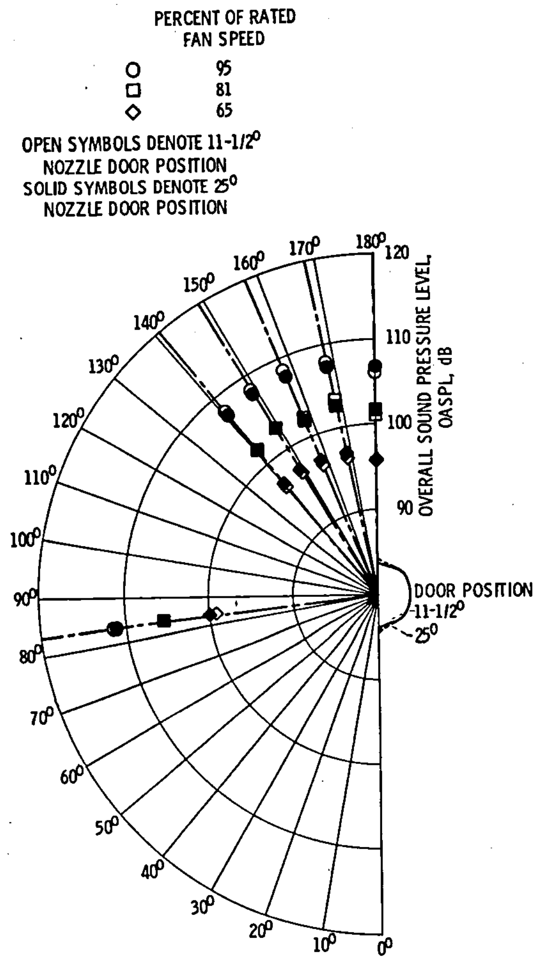
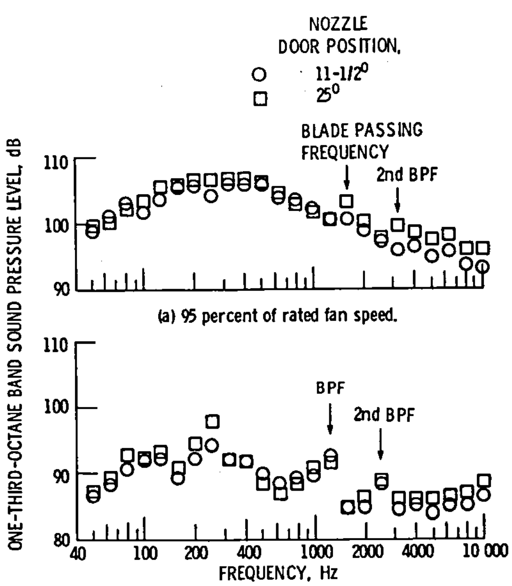


Figure 16. - Effect of nozzle door position at three fan speeds on D-nozzle directivity in plane normal to engine axis at a distance of 30.5-m (100 ft).



(b) 65 percent of rated fan speed.

Figure 17. - Effect of nozzle door position on noise spectra. Flyover plane data at an angle of 120° from the engine inlet and a distance of 30.5-m (100 ft).

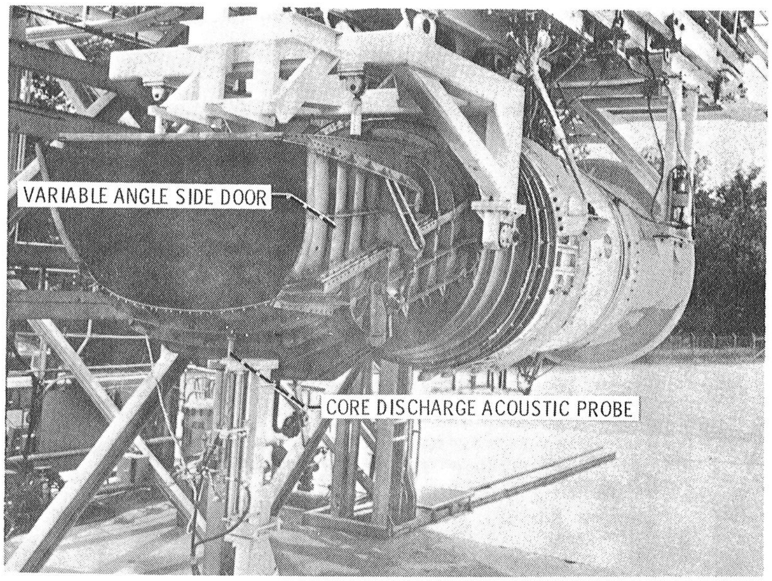
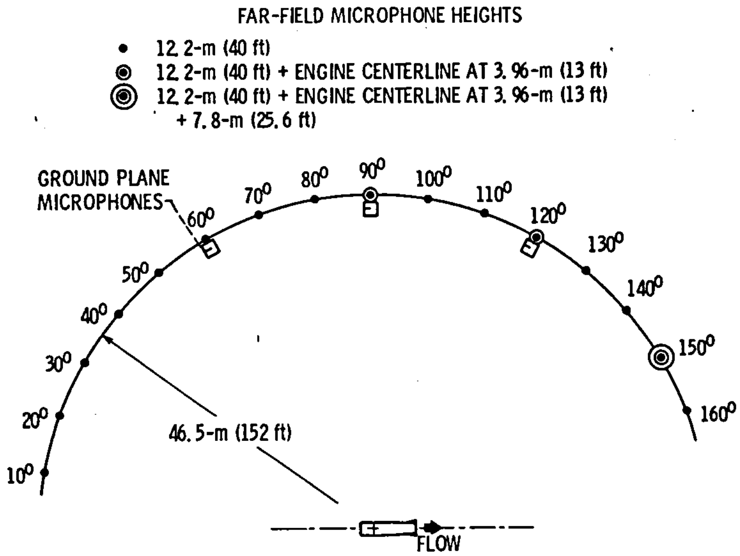
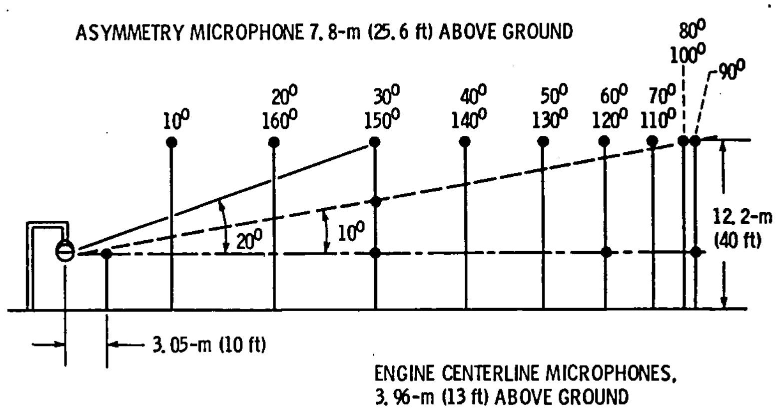


Figure 18. - OTW test installation at contractor's site showing D-nozzle orientation.



(a) Top view.



(b) Aft looking forward.

Figure 19. - Sound field acoustic instrumentation.

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16. Abstract

The over-the-wing (OTW) Quiet, Clean, Short-Haul Experimental Engine (QCSEE) was tested both at the NASA Lewis Engine Noise Facility and at the contractor's facility. A boilerplate (nonflight-weight), high-throat-Mach number, acoustically treated inlet and a D-shaped OTW exhaust nozzle with variable position side doors were used in the tests. Both aerodynamic and acoustic results of the tests are presented. Some acoustic directivity results for the type "D" nozzle and acoustic effects of variations in the nozzle side door positions are included. The results indicate good agreement with the results previously obtained at the contractor's test cite.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
QCSEE OTW; Powered lift; Aeroacoustics tests; Acoustic Suppression; Hybrid inlet; Ground reflection; "D" Nozzle directivity	Unclassified - unlimited STAR Category 07

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