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Abstract

The purpose of the experimental program reported herein was to evaluate the acoustic suppression capability of bulk absorber material designed for use in the fan exhaust duct walls of the QCSEE UTW (under-the-wing) engine and to compare it with other means of acoustic suppression. The paper includes comparison of the acoustic suppression to the original design for the QCSEE UTW engine fan duct which consisted of phased SDOF (single-degree-of-freedom) wall treatment and a splitter and also with the splitter removed. The method of approach consisted of mounting the UTW engine on the test stand of the Lewis Engine Noise Facility with an appropriate array of far-field microphones in order to measure the acoustic levels of the various configurations. Peak suppression was about as predicted with the bulk absorber configuration, however, the broadband characteristics were not attained. Post-test inspection revealed surface oil contamination on the bulk material which could have caused the loss in bandwidth suppression.

Introduction

Previous engine tests using "bulk absorber" acoustic treatment[1] for inlet suppression have shown excellent results when compared to single-degree of freedom (SDOF) liners. Other bulk absorber results have been reported in references 2 and 3. Much interest has been engendered by these inlet results and other applications have been suggested. As a result, a bulk absorber fan exhaust duct liner was designed and built for the Under-the-Wing (UTW) Quiet Clean Short Haul Experimental Engine (QCSEE). Reported herein are the results of the acoustic tests at the LeRC Engine Noise Facility.

The acoustic design of the bulk absorber suppressor is based on reference 4. The objective of this investigation was to evaluate the effectiveness of this design and compare it to the original fan exhaust duct suppressor design of the QCSEE UTW engine (phased single-degree-of-freedom (SDOF)) with and without an acoustic splitter. The scope of the investigation also included testing the bulk absorber configuration with (1) the upstream half of the absorber covered with aluminum tape and (2) the fan duct completely taped (hardwall). The engine was tested over a range of fan speeds from 81 to 95 percent of rated.

The fan blade angle was varied from $+5.2^{\circ}$ to -7.6° and the exhaust nozzle area was varied from 1.52 m^2 (2350 in^2) to 1.87 m^2 (2900 in^2) in order to simulate both approach and takeoff power conditions. Both far-field and in-duct acoustic measurements were used to evaluate the suppressors.

The QCSEE UTW had previously been tested at the contractor's test site. The engine design is reported in reference 5 and acoustic performance results obtained by the engine contractor are reported in reference 6.

Apparatus and Procedure

UTW Experimental Propulsion System

The UTW experimental propulsion system, shown in figure 1, features. a composite structure high Mach (accelerating) inlet; a gear-driven, variable-pitch fan with composite fan blades; a composite fan vane-frame; an acoustically treated fan duct with an acoustic splitter ring; a variable-geometry fan exhaust nozzle, an advanced (F101) core and low pressure turbine; an acoustically treated core exhaust nozzle; top-mounted engine accesories; and a digital electronic control system combined with a hydromechanical fuel control.

The fundamental design criterion which established the engine design was the fan engine cycle required to meet noise objectives. The fan and core exhaust pressure ratios were dictated by jet-flap noise constraints.

The fan is a low pressure ratio (1.27)†, low tip speed (289.6 m/sec, 950 ft/sec)† configuration sized to provide 405.5 kg/sec (894 lb/sec)† of corrected airflow. The fan contains 18 composite, variable-pitch fan blades with flight-weight disks and blade supporting system. The fan is driven by the F101 low pressure turbine through a main reduction gear. The reduction gear is a six-star epicyclic configuration with a gear ratio of 2.465 and a takeoff power rating of 9806 kW (13 145 hp).

The fan is capable of blade pitch change from forward to reverse thrust through either flat pitch or stall pitch. Two variable-pitch fan actuation systems were developed for the UTW experimental engine. A cam/harmonic drive system developed by the Hamilton Standard Division of United Technology Corporation under subcontract to the General Electric Company and a ball spline actuation system developed by GE. The rotary motion power required to drive both systems was provided by hydraulic motors. Both systems were designed to move the blades from their forward thrust position to reverse in less than 1 second.

The fan frame is a flight-weight composite structure containing integral acoustic treatment, outer casing blade containment, and fan tip treatment. The 33 integral outlet guide vanes also act as structural struts. The outer casing of the frame provides both inner and outer nacelle flow paths. Core inlet flow path and mounts for the forward bearings, gears, radial drive, etc, are also integrally provided.

The nacelle components include a lightweight composite hybrid inlet providing acoustic suppression at takeoff power by means of a high throat Mach number (0.79) and integral acoustic treatment. The composite fan duct, acoustic splitter, and core cowl are hinged from the pylon to provide access for engine maintenance. The core exhaust nozzle and noz-

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†Takeoff power setting.

zle plug are acoustically treated to reduce aft radiated noise. The fan exhaust nozzle is a variable-area, four-flap design capable of area change from takeoff to cruise, as well as opening to a flared position to form an inlet in the reverse thrust mode. The nozzle flaps are hydraulically actuated.

Engine fuel flow, blade pitch angle, and exhaust nozzle area are controlled by a digital electronic control. Major engine accessories are mounted on a boiler plate gearbox on top of the fan frame.

The UTW experimental propulsion system was designed to provide 81 400 N (18 300 lb) of uninstalled thrust and 77 400 N (17 400 lb) of installed thrust at takeoff on a 305.6 K (90° F) day.

Engine Acoustic Design Features

Table I lists the acoustic design parameters of the engine. Table II lists "as tested" values of pertinent parameters.

Figure 2 summarizes the main acoustic features of the engine. A high inlet throat Mach number (0.79) is used to suppress inlet noise at takeoff. Wall treatment having a length equal to 0.74 fan diameters is added to provide suppression at approach and in reverse thrust. The rotor-stator combination has 1.5 tip chords spacing and a vane-blade ratio selected to reduce second harmonic noise due to rotor-stator interaction. Fan exhaust suppression utilizes inner and outer wall treatment with varying thickness to obtain increased suppression bandwidth. A treated 101.6 cm (40 in.) splitter is necessary to obtain the required suppression level. A major concern in the aft duct is noise generated by flow over the created surfaces, struts, and splitter. To keep these sources below the suppressed fan noise, the average duct Mach number is limited to 0.47. The core suppressor is a stacked design having combination low frequency absorption cells for combustor noise reduction with thinner treated panels on the inner and outer walls to reduce the high frequency turbine noise. Treatment is also applied in the core inlet passage to reduce forward radiated compressor noise. Schematics showing acoustic design details for the inlet, fan exhaust duct and the core exhaust are presented in figures 3(a), (b), and (c), respectively.

Acoustic Configurations

The phased SDOF configurations embodying all of the design features shown in detail in figure 3 are shown schematically in figure 4. Splitter-in fully suppressed configuration (1) and splitter-out configuration (2) are shown in the bottom and top halves, respectively. The substitution of the bulk absorber treatment designated configuration 3 in the fan duct for the phased SDOF treatment is detailed in figure 5. The bulk absorber panels were constructed as follows: (Z) sections and channels were bonded to a solid back face. An advanced aramid fiber, Dupont "Kevlar 29" which was treated to have low moisture absotpion was installed in the 2.5 cm deep cavities to a nominal bulk density of 56 kg/m^3 (3.5 lb/ft^3). An 0.075 cm thick perforated face plate was then bonded and riveted to the top of the (Z) sections and channels. The perforated face plate had 0.15 cm diameter holes with an open area of about 30 percent. The other acoustic treatment shown previously in figure 3 was also used in this series of configurations. Taping the front half of the fan duct treatment was denoted configuration (4). Complete taping of the fan duct and the nozzle flaps was called hard-wall configuration (5).

Facility Description

The test program was performed at the Engine Noise Test Facility located at Lewis Research Center. The facility is shown schematically in figure 6 and photographically in figure 7.

Both ground placed microphones and overhead microphones were used in this investigation; the ground microphones were spaced every 10° from the inlet axis to 150° on a 45.7 meter (150 ft) radius. They were oriented towards the sound source and taped to 1.9 cm (3/4 in.) thick hardboard panels. Engine operation was controlled from the flight research building where the noise instrumentation and analysis equipment were located.

Experimental Methods

Aerodynamic and acoustic data were obtained over a range of corrected fan speeds from 81 to 95 percent of rated. The fan blade angle was varied from +5.2° to -7.6° and the exhaust nozzle area was varied from 1.52 to 1.87 square meters in order to simulate both approach and takeoff power conditions.

Power condition	% Rated speed	Exhaust nozzle area		Fan blade angle, deg
		m^2	in^2	
Approach	95	1.87	2900	+5.2
Takeoff	95*	1.52	2350	-7.6

*Takeoff percent rated speed was limited by turbine inlet temperature.

The acoustic instrumentation and data recording system had a flat response over the frequency range of interest (25 to 16 000 Hz). Data signals were FM recorded from all channels simultaneously on magnetic tape. Each of the three samples for a given corrected fan speed was reduced separately by using a 1/3-octave-band analyzer and a 4-second average time. The resulting sound pressure levels were arithmetically averaged, adjusted to standard day atmospheric conditions and side-line perceived noise levels were calculated using the standardized procedures presented in reference 7.

Ground microphone data are corrected to free-field conditions by subtracting 6 dB at all frequencies up to 16 000 Hz. This correction accounts for the effect of ground reflected signals. Theory predicts a 6-dB correction for a perfect reflecting surface and calibration tests of the acoustic arena have verified this conclusion. Narrow band data are presented in uncorrected form. Some engine performance data (such as thrust, fuel flow, and wall static pressures) along with final data on air flow, Mach number, corrected thrusts, and specific fuel consumption were processed in the facility minicomputer.

Results and Discussion

Narrow band data is presented first, followed by corrected 1/3-octave band data for all the configurations at takeoff and approach power at their respective peak noise aft angles. PNL directivity plots for the same engine conditions are then introduced. Sound pressure level (SPL) suppression is then compared to contractor data and contractor's predicted suppression. Finally, comparisons of Sound Power Level suppression data for the various configurations are made.

Narrow Band Data

Presented in figure 8 are narrow band spectra at takeoff power for configurations 1, 2, and 3, each compared to the hard wall configuration 5. The bulk absorber, configuration 3 (fig. 8(a)) reduced the four tones an average of about 8 dB compared to the hard wall. Although the design turning frequency was 1.6 KHz, the bulk absorber significantly reduced broad band noise below 3.0 KHz with values of about 14 dB between 2 and 3 BPF. The SDOF, splitter-out configuration (fig. 8(b)) reduced the four tones about 6 dB and the broad band noise between the second and third BPF about 8 dB. The SDOF splitter-in configuration, configuration 1 (fig. 8(c)) reduced the four tones about 12 dB along with significant broad band reductions over a wide range of frequencies, probably because of the multiple design turning frequencies (1.25, 1.6, 2.0, and 2.5 KHz).

At approach power, figure 9, only one comparison is shown. The bulk absorber reduced the noise compared to the hard wall about the same amount as at takeoff (fig. 8(a)). The entire noise level of both configurations is about 4 dB lower at approach than at takeoff.

One-Third Octave Spectra

Presented in figure 10 are 1/3-octave band spectra at 110° from the inlet adjusted to 30.5 m (100 ft) for takeoff and approach power conditions.

In general, the results indicate the configurations can be grouped in ascending order of loudness as follows: SDOF with splitter-in (quietest), SDOF with splitter-out, bulk absorber, half taped bulk absorber, and the hard wall (loudest). An exception to this is the frequency range from 400 to 1250 Hz where SDOF w/splitter-out is about as good as SDOF w/splitter-in. With the splitter out, all of the tuning frequencies are lowered (fig. 3(b)), which may account for its "good" low frequency suppression. Another exception is at the 2000 Hz frequency where the bulk absorber (3) resulted in the lowest noise at approach power but was slightly noisier than configuration 1 at takeoff power.

Perceived Noise

Presented in figure 11 are PNL directivity plots for takeoff and approach power conditions. With an aft-noise dominated engine such as this, the fan duct suppression is extremely important as it also affects the front noise. For both engine conditions, the SDOF splitter-in (1) configuration is least noisy at all angles. In ascending order of increasing PNL's are configurations 2, 3, 4, and 5, respectively. Configuration 2 is a slightly better suppressor than 3 on a PNL basis. The few data points which do not fall in this sequence are within the accuracy of the data (+1.0 PNdB). At the peak noise aft angle of 110° for takeoff power, configuration 4 suppresses the hard wall noise 3.5 PNdB' configuration 2, about 4.5 PNdB; configuration 3, about 5 PNdB; and configuration 1, about 9.5 PNdB. At the peak noise aft angle of 120° for approach power the suppressions are as follows: configuration 4, 1.5 PNdB; configuration 3, 3.5 PNdB; and configuration 1, about 8 PNdB.

SPL Suppression Spectra

Presented in figures 12 and 13 are SPL suppression comparisons on a 1/3-octave basis at takeoff and approach power. Compared are data taken during this investigation and by the contractor.[6]

The suppression comparison at 110° from the inlet for configuration 1 (SDOF splitter-in, fig. 12) exhibits good agreement at takeoff power and only fair agreement at approach power. The suppression agreement for configuration 2 (SDOF splitter-out fig. 13) is also good with the exception of the peak suppression at 2000 Hz and takeoff power for the NASA data.

Presented in figure 14 is the SPL suppression comparison at 110° from the inlet between the bulk absorber (configuration 3) and prediction. The peak measured suppression matches the prediction at only one frequency band at takeoff power and two bands for approach power. Because of this poor comparison, an attempt was made to find possible configuration anomalies or discrepancies and several bulk absorber panels were disassembled following completion of the tests. The perforated face plate was removed from five panel sections of the outer cowl. The "Kevlar" material was removed from these 18×53 cm (7×21 in.) areas, inspected and weighed to check the bulk density. The bulk density of the material was about 38 kg/m^3 (2.4 lb/ft^3) compared to the design value of 56 kg/m^3 (3.5 lb/ft^3). This material had been treated with "Zepel" (similar to Scotch guard) to prevent wicking or absorption of oil or water.[8] However, a considerable amount of oil had soaked into the outer layers of Kevlar which had been adjacent to the face plate.† About 1 1/2 hours of engine time had been accumulated prior to the start of the acoustic evaluation of the bulk absorber and about 2 hours of additional engine time were required to complete the test. Tests of the hard wall and the half-taped configuration followed, each requiring an additional 2 hours. Before the bulk absorber material was inspected, an additional 25 1/2 hours of engine time was accumulated. It is known that fluid absorbed into bulk absorber materials can markedly affect the broad-banded acoustic suppression characteristics and could have produced the kind of acoustic results presented herein. The lower-than-design bulk density measured should not have affected the acoustic suppression characteristics to any degree, based on earlier evaluations of this material. The results suggest that surface oil film on the bulk absorber could have caused the loss in suppression bandwidth.

Sound Power

Rear quadrant Sound Power Levels were also examined. Data from six far-field microphones (100° through 150°) were used in these calculations. Presented in figure 15 are data for configurations 1 and 2 showing the effect of the splitter-on Sound Power Level reduction. Some of the peaks that were

†Note: The QCSEE UTW engine was an experimental engine and did exhibit a considerable oil leakage in the fan duct passage after each test run.

apparent at certain microphones in the SPL suppression data of figures 12 and 13 have now been averaged. The overall comparison is the same, however. The splitter-in configuration (1) is superior to the splitter-out configuration (2) over the frequency range from 1250 to about 7000 Hz. At 2500 Hz the Sound Power Level reduction is more than doubled at approach and takeoff power with the use of the splitter.

A comparison of the SDOF (2) and BULK (3) configurations without splitter-on a Sound Power Level basis is shown in figure 16. The use of six microphones does not eliminate the peaks observed in the bulk absorber data in figure 14. Peak suppression occurs at 2000 and 5000 Hz at approach and at takeoff power. At takeoff power, the sound power peak suppression occurred at 2000 Hz while the peak SPL suppression (fig. 14) at 110° occurred at 2500 Hz. Comparing figure 16 results with the performance of the SDOF splitter-in configuration (1) in figure 15, indicates less suppression for the SDOF and bulk configurations without splitter, especially in the frequency range between 2000 and 5000 Hz.

Summary of Important Conclusions

1. At the peak noise rear quadrant angle:

   120° for approach power: The hard wall unsuppressed aft fan noise was reduced 3 1/2 PNdB by the bulk absorber, 5 1/2 PNdB by the SDOF treatment without splitter, and 8 PNdB by the SDOF with splitter configuration.

   110° for takeoff power: The hard wall unsuppressed aft fan noise was reduced about 4 1/2 PNdB by the SDOF treatment without splitter, 5 PNdB by the bulk absorber, and 9 1/2 PNdB by the SDOF treatment with acoustic splitter.

2. On a 1/3-octave basis at the peak noise rear quadrant angle, the peak suppression for the bulk absorber was about as predicted (13 dB). However, the broad band characteristics were not attained with the suppression confined primarily to the 2500 Hz 1/3-octave band. These results could have been due to the oil from the engine which had soaked the surface layers of the "Kevlar 29" bulk absorber material and partially due to the lower-than-design value of the density of the material.

3. The SDOF treatment with splitter configuration exhibited better suppression characteristics than the other configurations over the range of conditions tested.

References

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3. Kirk, J. J., "Extended Reaction Impedance Characteristics of Polyurethane Foam," Presented at the 88th Meeting of the Acoustical Society of America, St. Louis, MO, Nov. 4-8, 1974, Session X, Paper 8.

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6. Stimpert, D. L., "Quiet, Clean, Short-Haul Experimental Engine Under the Wing (UTW) Composite Nacelle Test Report. Vol. 2: Acoustic Performance," General Electric Co., Cincinnati, OH, R78AEG574-VOL-2, Nov. 1979. (Proj. FEDD, NASA CR-159472.)

7. Montigani, F. J., "Some Propulsion System Noise Data Handling Conventions and Computer Programs Used at the Lewis Research Center," NASA TM X-3013, 1974.

8. Smith, C.D. and Parrott, T. L., "An Experimental Study of the Effects of Water Repellant Treatment on the Acoustics Properties of Kevlar," NASA TM-78654, 1978.

TABLE I. - ACOUSTIC DESIGN PARAMETERS

[41.2 m/sec (80 knots) aircraft speed; 61 m (200 ft) altitude; takeoff conditions.]

Number of fan blades	18
Fan diameter, cm (in.)	180.4 (71)
Fan pressure ratio	1.27
Fan rpm	3089 (3244 at 100%)
Fan tip speed, m/sec (ft/sec)	289.6 (950)
Number of OGV's	33 (32 + pylon)
Fan weight flow (corrected), kg/sec (lbm/sec)	405.5 (894)
Inlet Mach number (throat)	0.79
Rotor OGV spacing	1.5 rotor tip aerodynamic chords
Fan exhaust area, m^2 (in^2)	1.615 (2504)
Core exhaust area, m^2 (in^2)	0.348 (540)
Gross thrust (SLS uninstalled), kN (lbf)	81.39 (18 300)
Blade passing frequency, Hz	927
Core exhaust flow, kg/sec (lbm/sec)	31.3 (69.1)
Fan exhaust velocity, m/sec (ft/sec)	197.8 (649)
Core exhaust velocity, m/sec (ft/sec)	238.9 (784)
Bypass ratio	12.1
Inlet treatment length/fan diameter	0.74
Van/blade ratio	1.83

TABLE II. - NOMINAL CONDITIONS (AS TESTED)

	Takeoff	Approach
Corrected fan speed, percent	95	95
Fan exhaust area, m^2 (in^2)	1.516 (2350)	1.870 (2900)
Core exhaust area, m^2 (in^2)	0.348 (540)	0.348 (540)
Fan blade angle (panel +28^o), deg	-7.6	+5.2
Corrected gross thrust (installed), kN (lbf)	77.39 (17 400)	55.42 (12 460)
Inlet throat Mach number (I-D)	0.79	0.63
Fan pressure ratio	1.25	1.14
Bypass ratio	11.7	12.9
Fan exhaust velocity, m/s (ft/s)	195 (640)	151 (495)
Core exhaust velocity, m/s (ft/s)	253 (830)	177 (580)
Mass average velocity, m/s (ft/s)	200 (655)	152 (500)

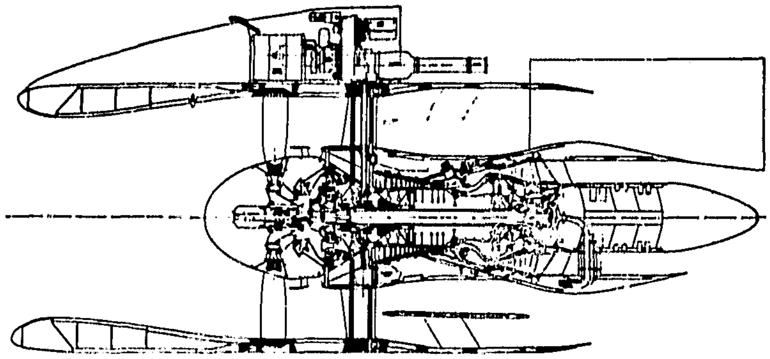


Figure 1. - UTW experimental propulsion system.

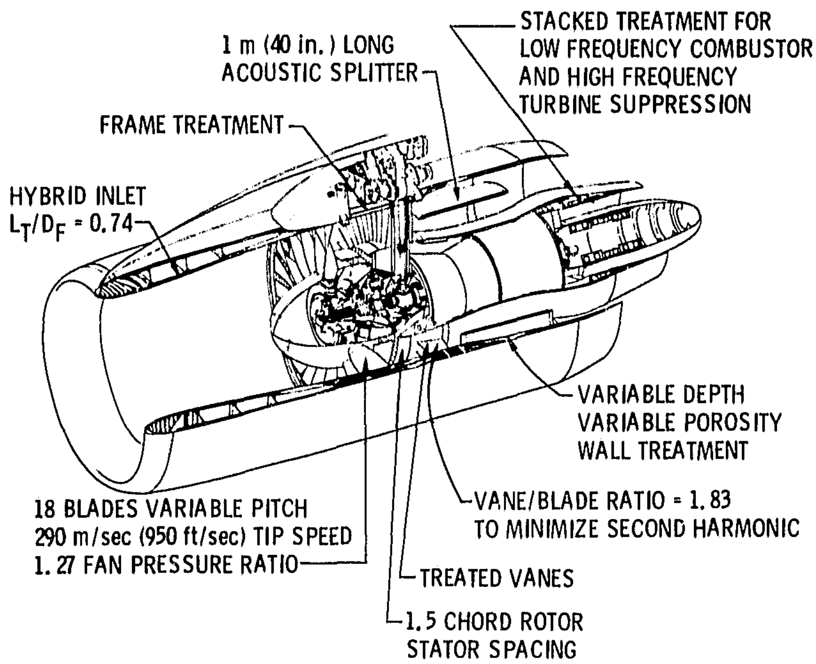
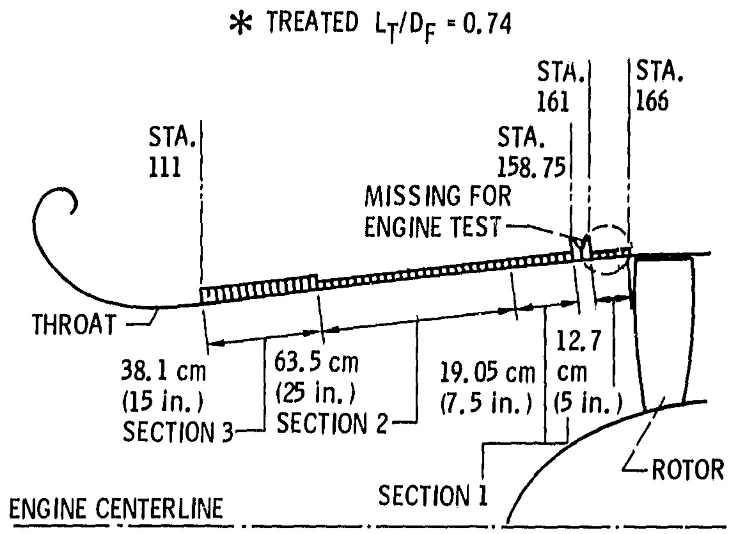


Figure 2. - Acoustic design features of QCSEE UTW engine.



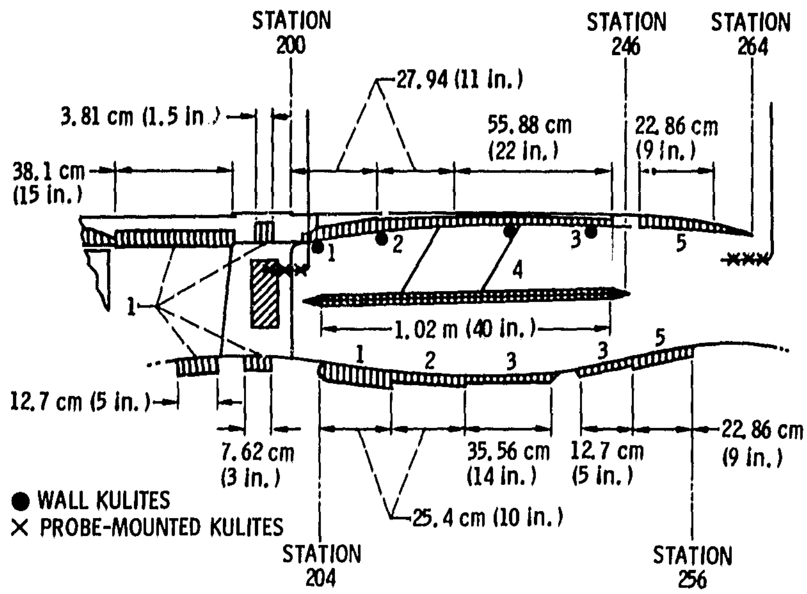
SECTION	HOLE SIZE, cm (in.)	POROSITY, %	CAVITY DEPTH, cm (in.)	FACEPLATE THICKNESS, cm (in.)
1	0.1589 (0.0625)	9.89	1.27 (0.50)	0.0813 (0.032)
2	0.1589 (0.0625)	9.89	1.91 (0.75)	0.0813 (0.032)
3	0.1589 (0.0625)	9.89	3.82 (1.50)	0.0813 (0.032)

DESIGN FREQUENCIES

SECTION	REVERSE THRUST, Hz	FORWARD THRUST, Hz
1	3150	2000
2	2500	1600
3	1600	1000

(a) INLET TREATMENT.

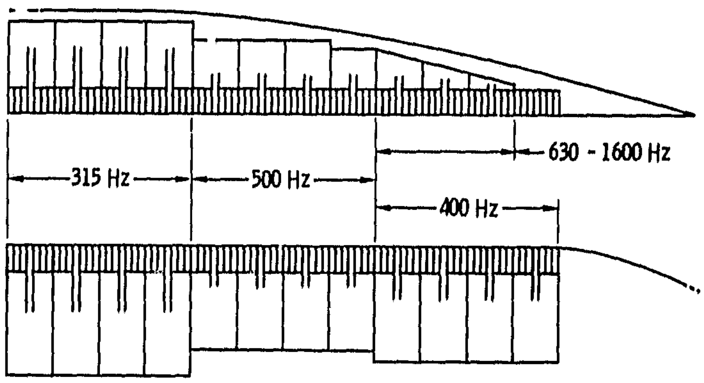
Figure 3. - Acoustic design details.



	DEPTH, cm (in.)	POROSITY, %	HOLE SIZE, cm (in.)	FACEPLATE THICKNESS, cm (in.)	FREQUENCY, Hz
			FAN FRAME TREATMENT		
SECTION 1	5.08 (2.0)	10	0.1589 (0.0625)	0.0869 (0.035)	1000
TREATED VANES	0.76 (0.3)	10	0.1589 (0.0625)	0.127 (0.05)	4000
			FAN EXHAUST TREATMENT		
SECTION 1	5.08 (2)	22	0.1589 (0.0625)	0.1016 (0.040)	1250
SECTION 2	2.54 (1)	15.5	0.1589 (0.0625)	0.1016 (0.040)	2000
SECTION 3	1.90 (0.75)	15.5	0.1589 (0.0625)	0.1016 (0.040)	2500
SECTION 4	1.27 (0.5)	11.5	0.198 (0.078)	0.2032 (0.080)	2500
SECTION 5	2.54 (1)	15.5	0.1589 (0.0625)	0.1016 (0.040)	1600

(b) COMPOSITE NACELLE FAN EXHAUST DUCT TREATMENT.

Figure 3. - Continued.



	COMBUSTOR						TURBINE
	INNER WALL			OUTER WALL			BOTH WALLS
TUNING FREQUENCY, Hz	315	400	500	315	500	630 - 1600	3150
NECK LENGTH (FACEPLATE THICKNESS cm (in.)	6.99 (2.75)	5.72 (2.25)	4.45 (1.75)	6.99 (2.75)	4.45 (1.75)	3.56 - 2.54 (1.4) - (1.0)	0.08128 (0.032)
CAVITY DEPTH, cm (in.)	10.2 (4.0)	8.89 (3.5)	7.62 (3.0)	7.62 (3.0)	4.32 & 5.08 (1.7) & (2)	4.06 - 0.51 (1.6) - (0.2)	1.905 (0.75)
POROSITY, %	10	10	10	7	7	7	10
TREATMENT LENGTH, cm (in.)	20.32 (8.0)	20.32 (8.0)	20.32 (8.0)	20.32 (8.0)	15.24 & 5.08 (6.0) & (2.0)	20.32 (8.0)	60.96 (24.0)
HOLE DIAMETER, cm (in.)	1.52 (0.6)	1.52 (0.6)	1.52 (0.6)	1.52 (0.6)	1.52 (0.6)	1.52 (0.6)	0.1575 (0.062)

(c) CORE EXHAUST TREATMENT.

Figure 3. - Concluded.

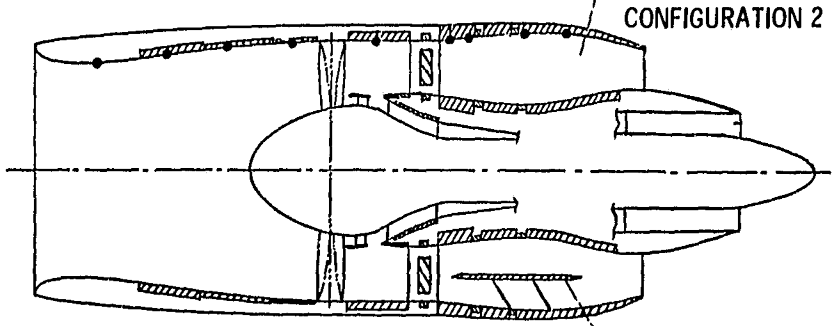


Figure 4. - Fully suppressed configuration, configuration 1. Without fan duct splitter, configuration 2.

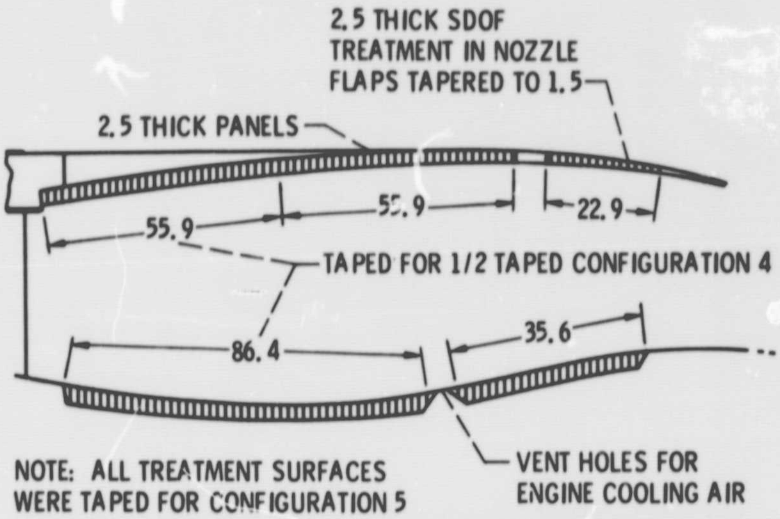


Figure 5. - Bulk absorber configuration 3 for UTW fan duct. Kevlar design density, 56 kg/m^3 (3.5 lb/ft^3). Facing sheet porosity, 30 percent open. Design tuning frequency, 1600 Hz. (All dimensions are in cm.)

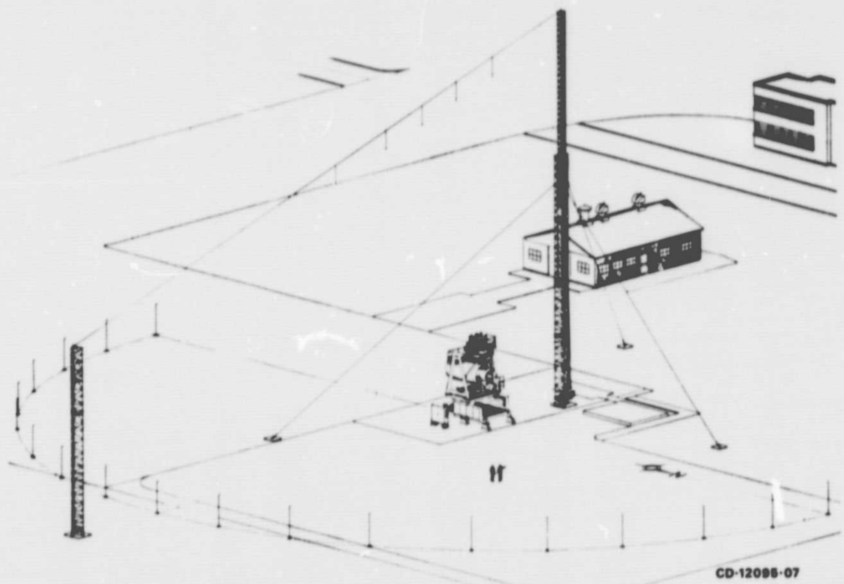
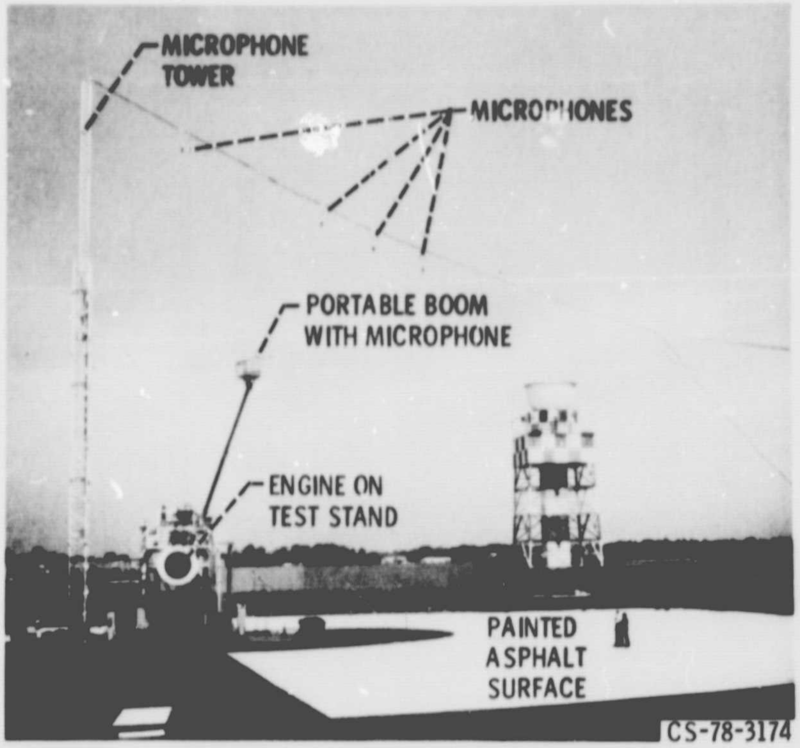
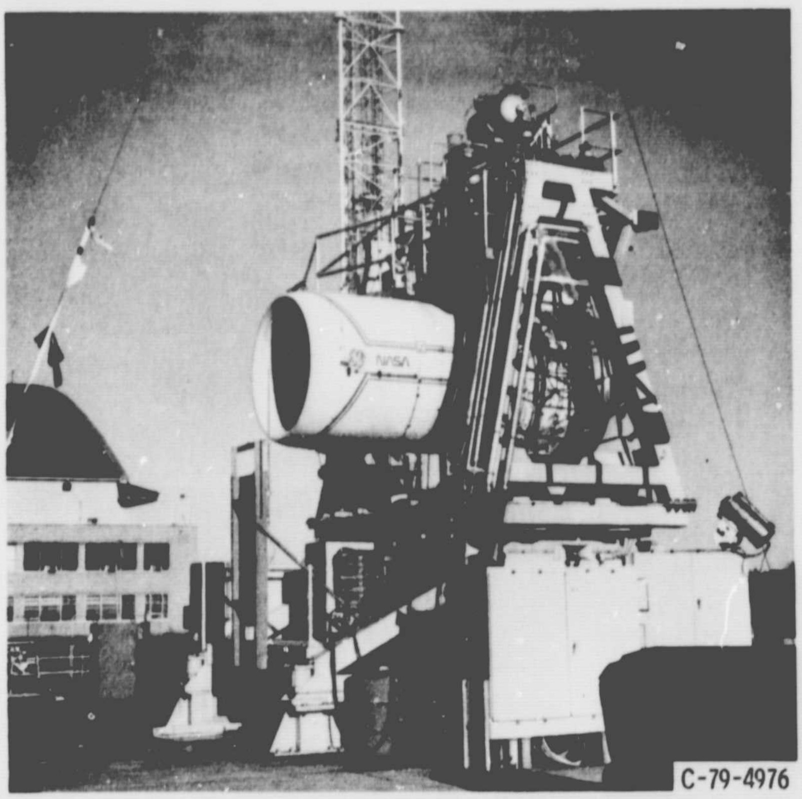


Figure 6. - Engine noise test facility sketch showing microphone towers.

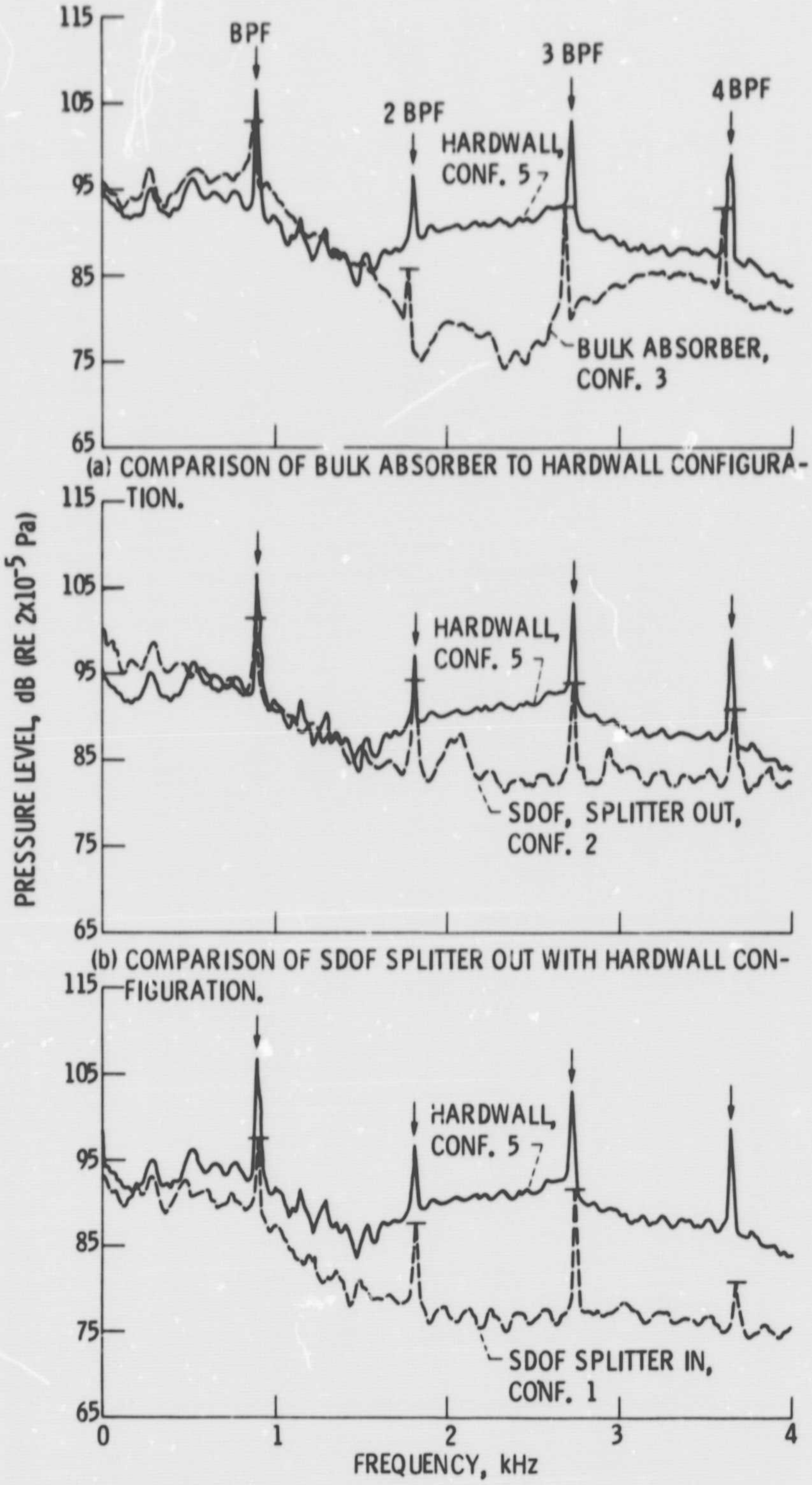


(a) VIEW SHOWING ACOUSTIC ARENA.



(b) CLOSE-UP.

Figure 7. - Photograph of QCSEE UTW engine on test stand.



(c) COMPARISON OF SDOF SPLITTER IN CONFIGURATION WITH HARDWALL.

Figure 8. - Takeoff power narrowband spectra at aft angle of 110°; 45.7 m. Filter bandwidth 30 Hz.

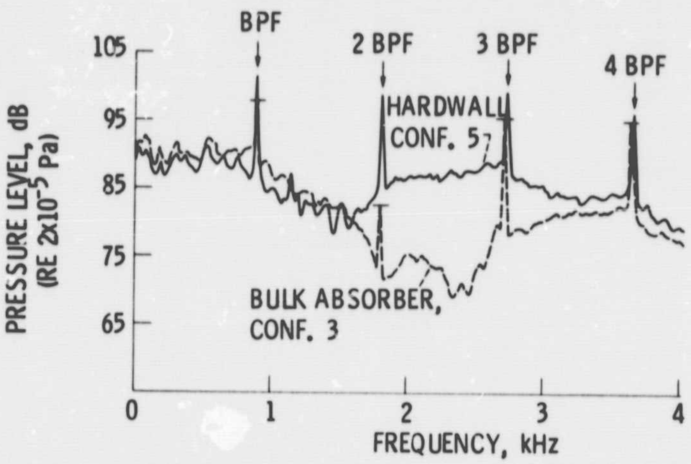


Figure 9. - Approach power narrowband spectra at aft angle of 110°; 45.7 m filter bandwidth 30 Hz. Comparison of bulk absorber and hardwall configuration.

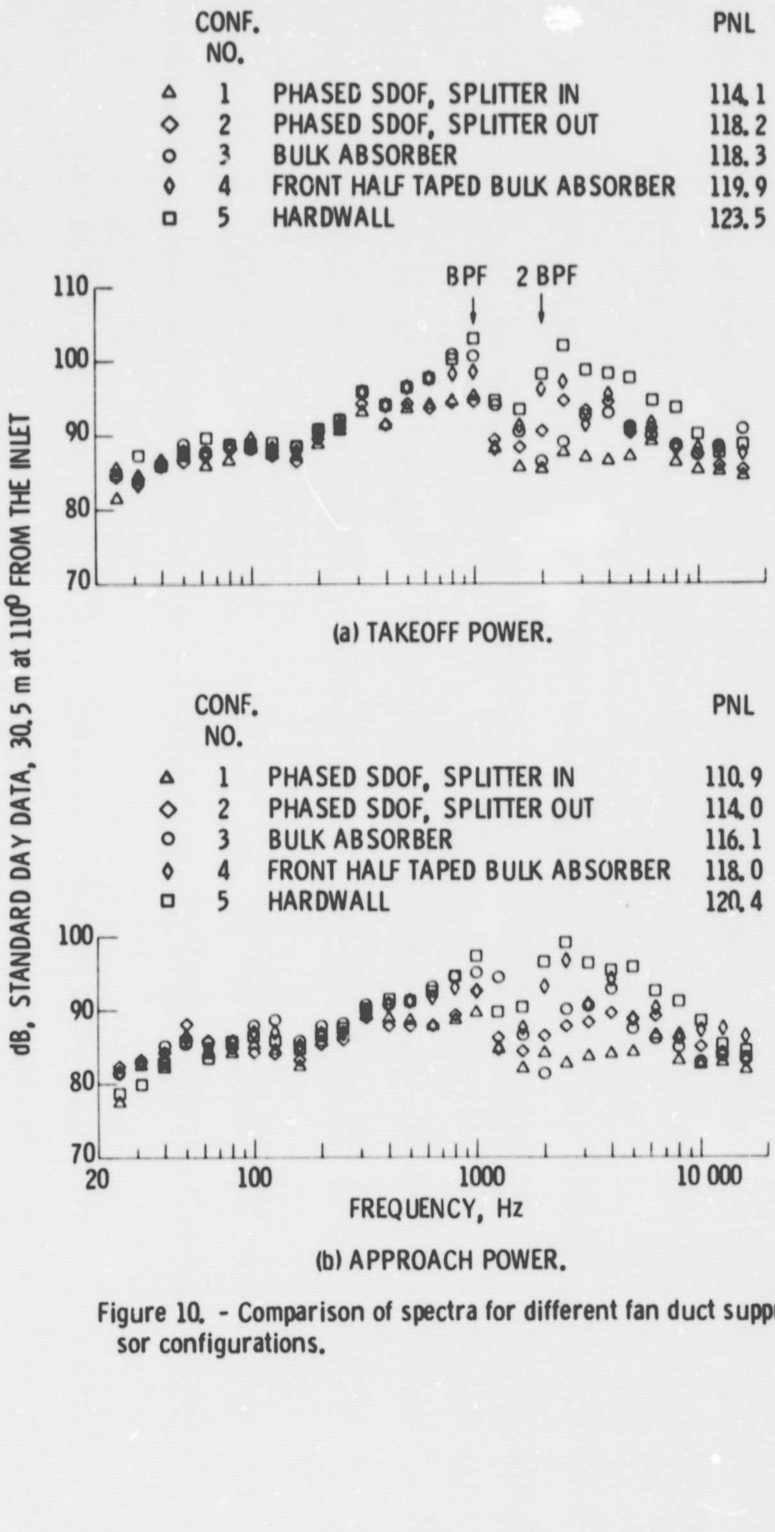


Figure 10. - Comparison of spectra for different fan duct suppressor configurations.

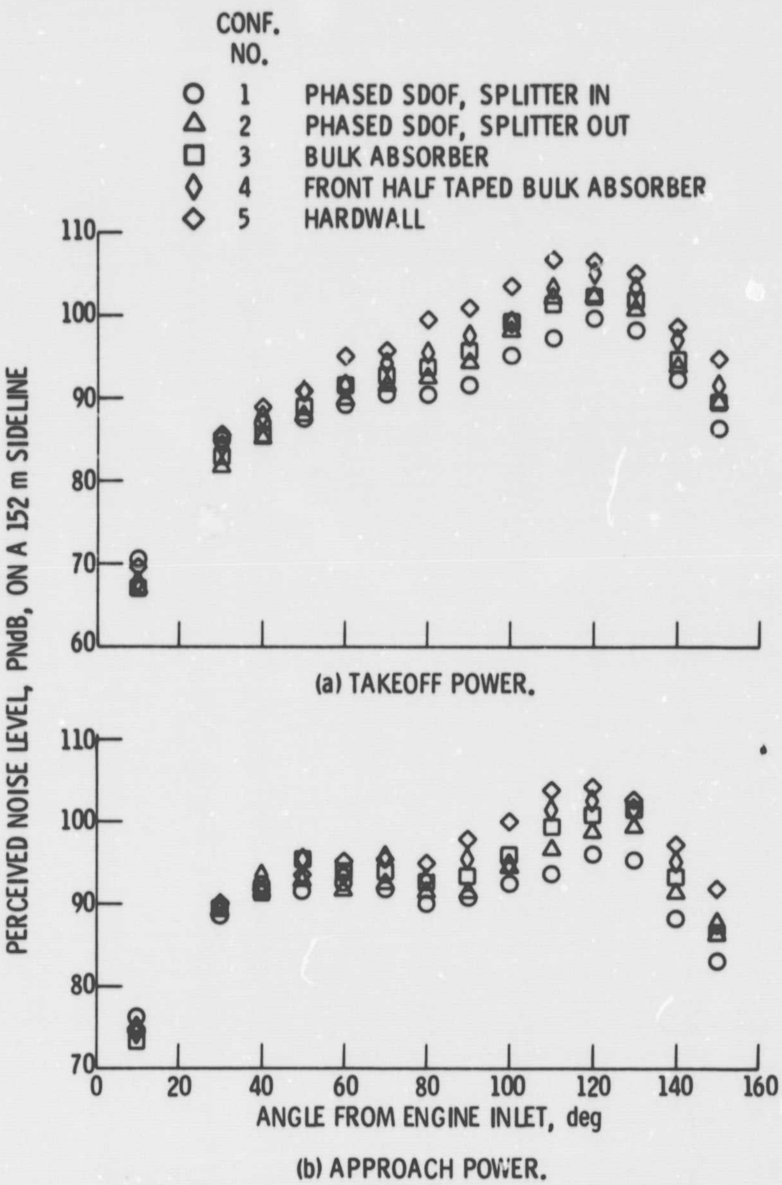


Figure 11. - The effect of suppressor configuration on the variation of perceived noise level with angle from inlet. 152 m sideline data.

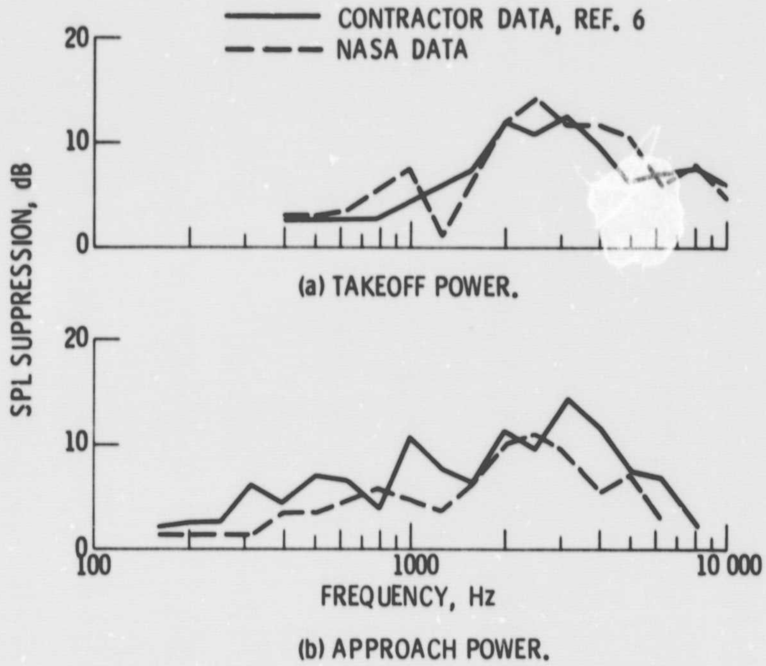


Figure 12. - Comparison of measured 1/3 octave SPL suppression at 110° from the inlet for the phased SDOF, splitter in, configuration 1.

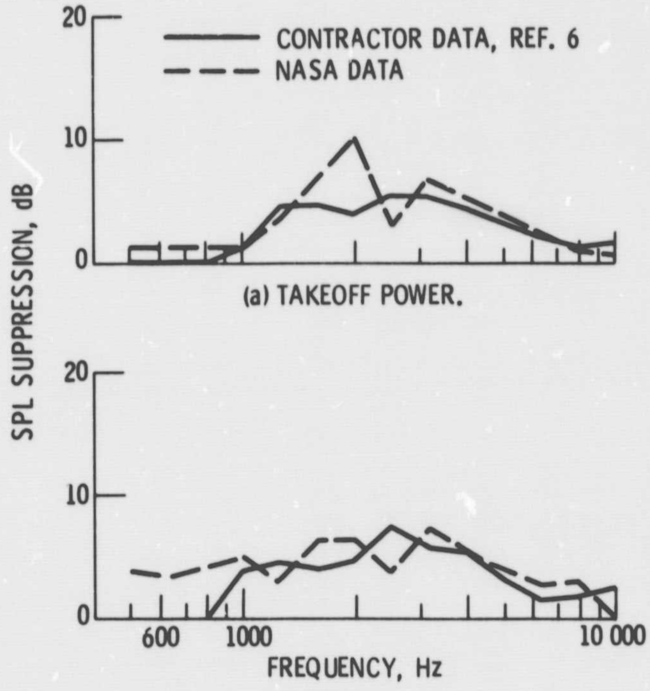


Figure 13. - Comparison of measured 1/3 octave SPL suppression at 120° from the inlet for the phased SDOF, splitter out, configuration 2.

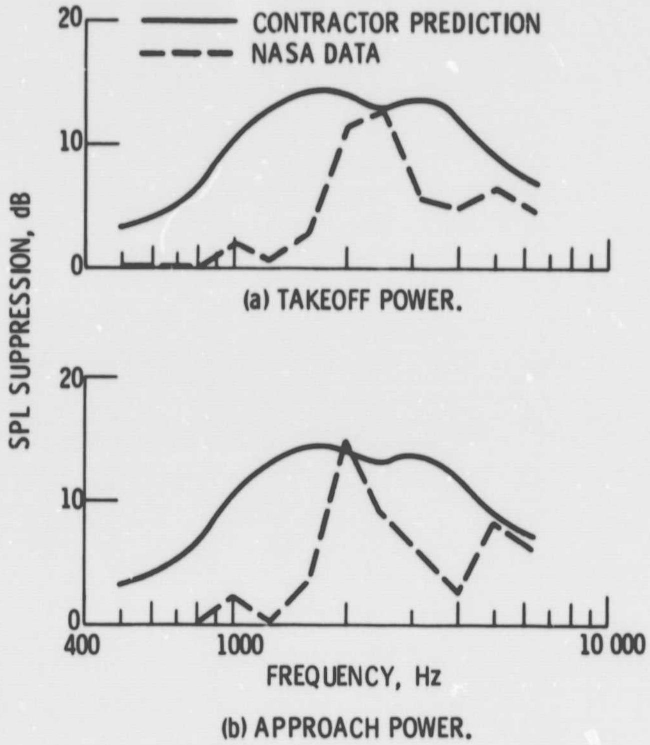


Figure 14. - Comparison of measured and predicted 1/3 octave SPL suppression at 110° from the inlet for the bulk suppressor, configuration 3.

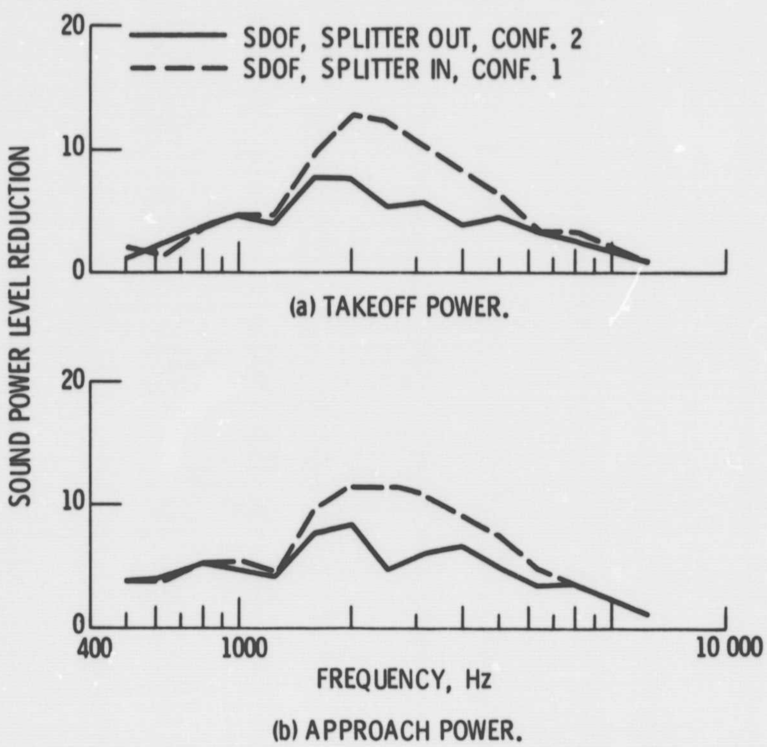


Figure 15. - Effect of splitter on measured 1/3 octave sound power level reduction.

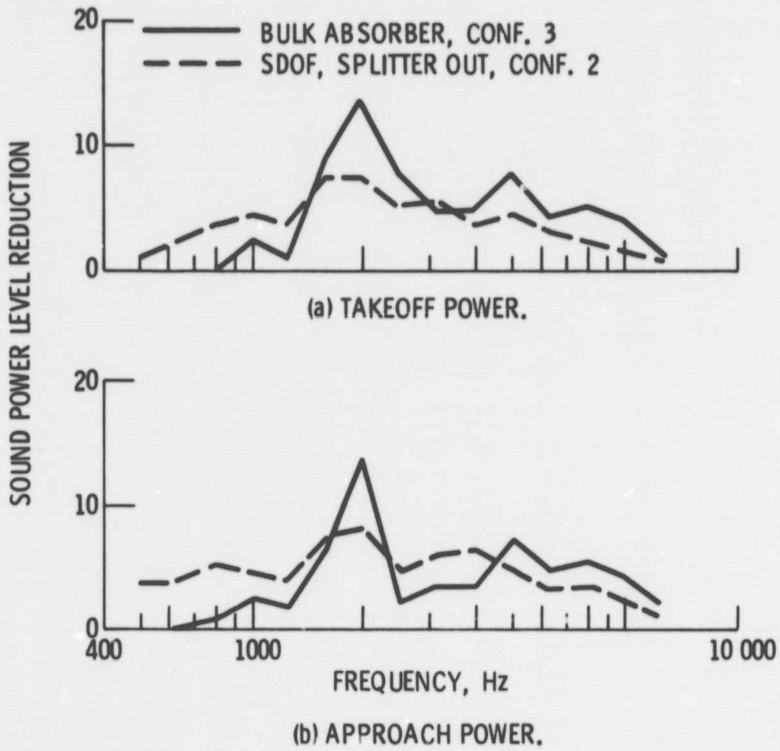


Figure 16. - Comparison of measured 1/3 octave sound power level reduction.