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NASA CR 135267
R76AEG195

# Quiet, Clean, Short-Haul, Experimental Engine (QCSEE)

# Under-the-Wing (UTW) Engine Acoustic Design

January, 1978

by


H.D. Sowers and W.E. Coward

GENERAL ELECTRIC COMPANY



(NASA-CR-135267) QUIET, CLEAN, SHORT-HAUL, EXPERIMENTAL ENGINE (QCSEE) UNDER-THE-WING (UTW) ENGINE ACOUSTIC DESIGN (General Electric Co.) 62 p HC A04/MF A01 CSCL 21E

N80-14117

Unclas

G3/07 33482


National Aeronautics and Space Administration

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# SECTION I

## SUMMARY

An acoustic design has been defined for the QCSEE under-the-wing configuration. The design intent is to enable a four-engine, STOL aircraft to meet a noise goal of 95 EPNdB on a 152.4 m (500 ft) sideline. The predicted acoustic performance will be evaluated by ground static demonstration tests of the fully suppressed engine. The design incorporates fan source noise reduction features such as low fan tip speed, low fan pressure ratio, high bypass ratio, large rotor to outlet guide vane (OGV) spacing, selected vane/blade ratio, and acoustic wall treatment between the rotor and OGV. Fan inlet noise suppression is obtained with a 0.79 throat Mach number inlet and with wall treatment. Fan exhaust noise suppression is provided by treated exhaust duct walls and a one-meter (40-inch), treated splitter. Core noise suppression is obtained by using a stacked treatment concept with thick, low-frequency combustion-noise treatment underneath and integral with the high-frequency turbine-noise treatment panels. The predicted noise levels and suppression estimates were obtained from various engine and scale-model tests, many of which were in support of the QCSEE program.

## SECTION II

## INTRODUCTION

The Quiet Clean Short-Haul Experimental Engine (QCSEE) program has as its overall objective the development of the propulsion technology required for future aircraft incorporating powered lift wing/flap systems. The program includes the development of two separate systems, one an over-the-wing (OTW) configuration, and the other an under-the-wing (UTW) configuration; this latter system is the subject of this report. The acoustic goal of the program is to insure that both systems will be very quiet in operation; the total system noise requirements for both configurations being 95 EPNdB during approach and takeoff and 100 PNdB max for reverse thrust, all on a 152.4 m (500 ft) sideline.

The base UTW engine has been designed with low noise features incorporating a low tip speed, low pressure ratio fan, having a large rotor-OGV spacing, and an acoustically optimized blade-vane ratio. All these features contribute to lowering the total system noise in a UTW powered lift, aircraft engine system.

The acoustic design of an engine system which will efficiently meet the noise requirements outlined for the QCSEE UTW engine requires, however, not only that the engine source noise levels must be as low as possible, but also that advanced technology acoustic-suppression concepts be applied. This requires that detailed predictions be made for all the possible engine noise sources, that accurate suppression estimates be made, and that careful attention be given to the methods used to obtain the in-flight, total system noise estimates from the static data predictions.

Existing component source predictions, based on data correlations from previous engine test experience, were used to arrive at the original unsuppressed engine noise estimates. Preliminary acoustic treatment designs, again based on past engine and laboratory duct tests, were defined for the purposes of total system noise-optimization studies.

A series of scale-model fan-noise test programs were concurrently run to study source noise and treatment effects, and laboratory duct tests of advanced treatment concepts were conducted. The results of these tests were employed to refine the system noise predictions and treatment designs, and to arrive at the final design for the UTW boilerplate test nacelle.

The acoustic design approach as originally planned was somewhat unique in that the boilerplate nacelle testing would be conducted prior to release of the composite nacelle treatment design. Thus, acoustic results obtained would then determine if further refinements to the treatment design were necessary to meet the noise goals. If such proved to be the case, the treatment panels would be made in interchangeable sections and could be replaced on a section-by-section basis with new panel designs constructed from stockpiled materials to evaluate the refinements.

The acoustic data obtained during the entire boilerplate nacelle test program would then be used to derive the final design for the UTW composite nacelle; it is on this nacelle that the total system noise design goals will be demonstrated.

Due to an engine malfunction during the mechanical checkout testing, the boilerplate acoustic testing was not conducted. Some contaminated, unsuppressed-noise data were obtained prior to the malfunction and these were used to support selection of the composite nacelle treatment design.

The procedures employed in making all the preliminary estimates, conducting development tests and full-scale engine tests, and integrating them into a final UTW engine acoustic design are the subject of this report. This report is meant to give an "overview" of the entire UTW engine acoustic design process. Detailed information regarding specific component test programs, treatment development programs, and engine tests is covered in specific individual reports which are referenced throughout.

## SECTION III

## DESIGN GOALS

### A. Noise Requirements

The noise requirements for the UTW engine are specified as a total system noise level (including jet/flap interaction noise) at the operating conditions associated with the takeoff and approach. A reverse thrust noise requirement is also specified for static aircraft conditions. These requirements are schematically outlined on Figure 1.

The takeoff-system noise requirement is 95 EPNdB on a 152.4 m (500 ft) sideline with the engines at 100.085 kN (22,500 lb) of thrust. The approach-system noise requirement is identical, with the exception that engine thrust is only 65% of takeoff. Table I is a summary of the other pertinent parameters defined for takeoff and approach. Included are such items as inlet angle of attack and upwash angles, which affect the fan inlet noise generation and high Mach inlet suppression, and blown flap angles, which affect the jet/flap noise generation. The takeoff flight path is defined as climbout at a constant angle of 0.218 rad (12.5°), with no power cutback; approach is at a constant angle of 0.105 rad (6°), again at a constant power setting. For preliminary design purposes, the aircraft altitude for which the sideline EPNL reaches the peak was assumed to be 61.0 m (200 ft). This assumption would be revised when engine data at all acoustic angles became available, thus allowing more sophisticated extrapolations to be employed.

The reverse thrust system sideline noise requirement is 100 PNdB at a reverse thrust equal to 35% of takeoff thrust with the aircraft static. For the UTW engine this can be accomplished by reversing the fan blade pitch, either through flat pitch or through stall.

### B. In-flight Extrapolation and Correction Procedures

The contract noise goals for takeoff and approach are defined in-flight for the total system, but the demonstrated engine-noise levels can only be measured during static testing, and the first series of tests will be made with the engine alone (no wing/flap system). Arriving at the final, demonstrated, in-flight, system-noise levels therefore requires a detailed extrapolation procedure. This procedure must be as accurate as possible. Accordingly, the procedure has been established as part of the contract and is defined in Appendix I to the Statement of Work. This procedure is also defined in Reference 1, Vol. II, Appendix A. Appendix I establishes the following:

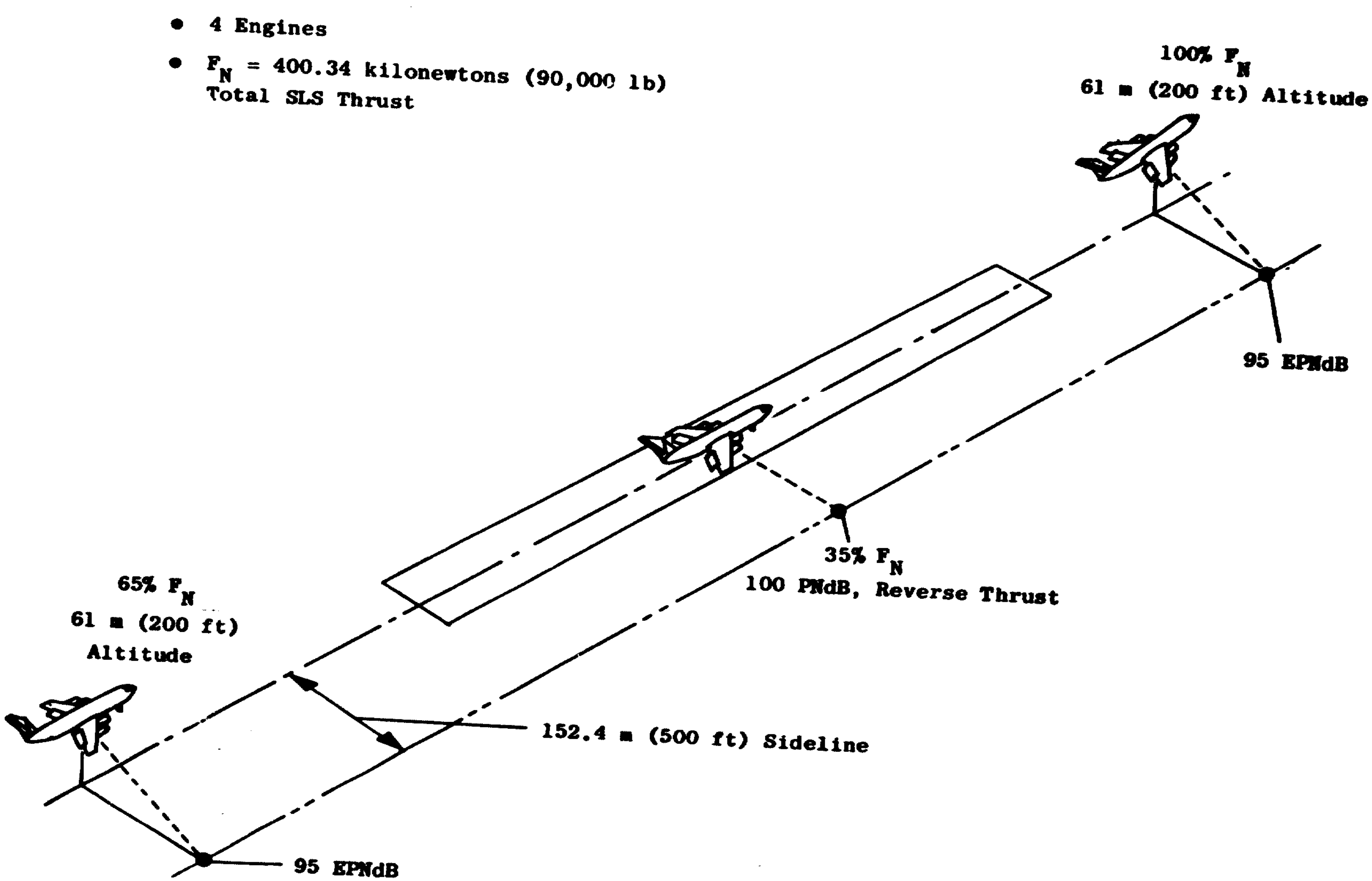



Figure 1. Acoustic Requirements.

Table I. Engine and Aircraft Characteristics for Acoustic Calculations.

| Flight Conditions | Takeoff | Landing |
|---|---|---|
| Aircraft Speed, m/sec (knots) | 41.15 (80) | 41.15 (80) |
| Flap Angle, radians (degrees) | 0.524 (30) | 1.047 (60) |
| Aircraft Climb or Glide Angle, radians (degrees) | 0.218 (12.5) | 0.105 (6) |
| Angle of Attack, radians (degrees) | 0.105 (6) | 0.035 (2) |
| Upwash Angle, radians (degrees) | 0.262 (15) | 0.192 (11) |
| Installed Net Thrust, percent | 100 | 65 |

1. Jet/Flap noise prediction procedures

2. Extrapolation procedures
   a) Inverse square law
   b) Atmospheric attenuation
   c) Extra ground attenuation

3. Static-to-flight corrections
   a) Doppler shift
   b) Dynamic effect
   c) In-flight cleanup and upwash angle correction
   d) Relative velocity effects on jet/flap noise
   e) Effect of soft ground

4. Acoustic shielding effects of aircraft structure

5. Calculation of system EPNL
   a) Correction for number of engines
   b) Correction for engine installed thrust
   c) Summation of component PNL's
   d) Calculation of EPNL from summed PNL's

These procedures have been employed for all noise estimates during the design of the UTW engine. Procedures for the calculation of in-flight system noise from measured static engine data are also specified in this document; these are similar to those already outlined and will be employed to evaluate the acoustic performance of the engine, as well as the effects of any changes in acoustic configuration.

## SECTION IV

## BASIC ENGINE DESIGN

### A. Low Source Noise Design Features

Many features of the QCSEE UTW engine design have been selected based on the low system noise requirements for a 100.085 kilonewton (22,500 lb) thrust engine installed in an under-the-wing configuration. Figure 2, taken from Appendix I of the contract, is a sketch of the baseline wing/engine installation (inboard location) with the blown flap system at take-off setting. The two major noise sources considered were the fan noise and the jet/flap noise.

Forward-radiated fan noise has been shown to be primarily a function of fan tip speed, and further, that tip speeds lower than 366 m/sec (1200 ft/sec) avoid the increased noise levels due to multiple pure tones associated with supersonic tip speed fans (Reference 1, Volume 1). The lowest tip speed, 289 m/sec (950 ft/sec), consistent with the other engine cycle requirements was therefore selected.

Aft radiated fan noise levels have been correlated primarily with fan pressure ratio (Reference 1, Volume 1). In addition to controling aft fan noise, the fan pressure ratio also determines the fan jet velocity. Since the predicted jet/flap noise is directly proportional to the exhaust velocity to the sixth power, low fan pressure ratios result in reduced aft-system noise levels. Since aft-generated fan noise can be suppressed with acoustic treatment, the fan pressure ratio was selected primarily in order to achieve low jet/flap noise levels.

The design of the fan physical configuration has also been acoustically optimized to provide source noise reduction features with minimum impact on weight and performance. A rotor-OGV spacing of 1.5 rotor chords was selected in order to lower the fan source noise and minimize the need for splitters in the fan inlet and exhaust. At spacings greater than 1.5 chords the additional noise reductions become very small: also, the additional weight penalties incurred would be greater than those associated with increasing the aft fan acoustic treatment, and this latter approach was followed.

Proper selection of the vane-blade ratio will provide additional source noise reductions in the fan pure tones. The fan fundamental blade passing tone is relatively low in frequency while the second harmonic tone lies in the high-noise-annoyance frequency bands and, hence, makes a large contribution to the system perceived noise levels. The vane-blade ratio was therefore selected at a value of 1.83 in order to minimize the generation of the second harmonic tone noise. This value of vane-blade ratio was selected from the analysis of Reference 2.

- Inboard Engine
- Wing Chord = 5.46 m (17.9 ft)
- Dimensions Based on 81.4 kilonewton (18,300 lb) Thrust Engine

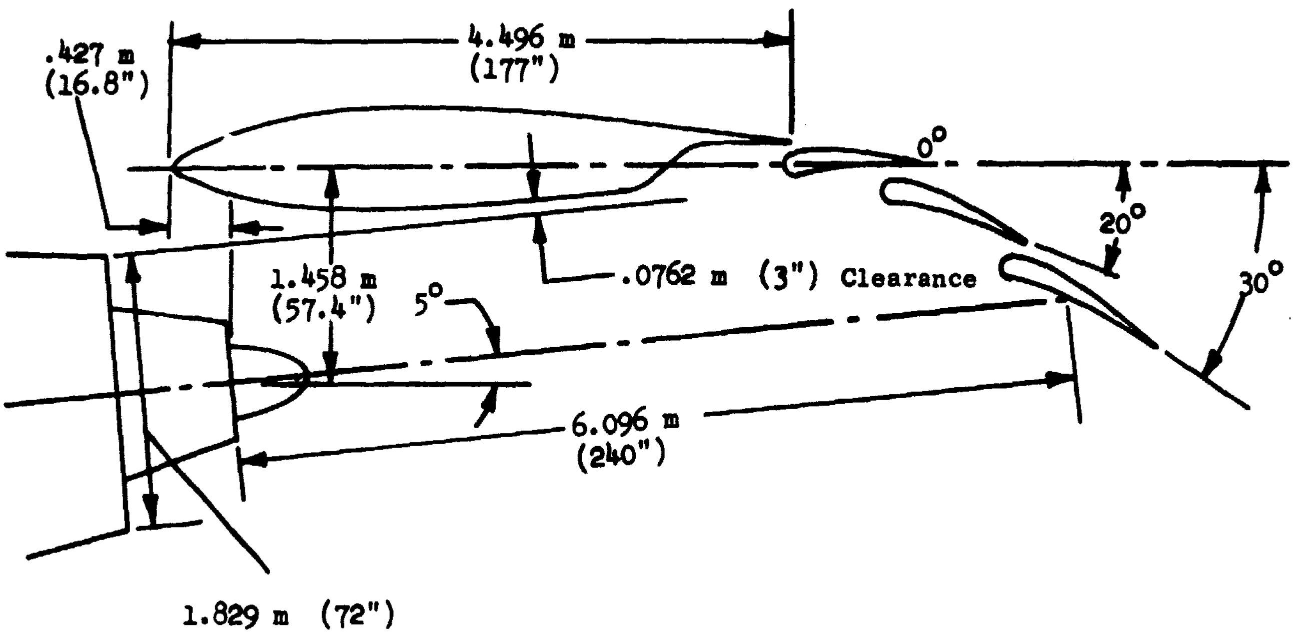



Figure 2. Reference Nozzle and Wing.

The variable pitch fan blades and the variable fan exhaust nozzle area provide an additional degree of flexibility in optimizing the fan performance-versus-noise tradeoffs.

The use of a "high speed" core engine driving the fan through a reduction gear mechanism also provides certain acoustic benefits. The blade-passing tones of the compressor and low pressure turbine are thus in the very high frequency, low annoyance - weighted bands, even on approach. The core engine pressure ratio selection was also made with low jet velocities as a consideration, again to aid in minimizing jet/flap noise.

Table II shows the major engine design features which impact the predicted system noise levels in the UTW system. The considerations discussed above have produced an engine design which will assure low source noise levels while still meeting the performance and thrust-to-weight requirements.

B. Component and Model Source Noise Test Programs

Three separate acoustic test programs were carried-out to investigate noise from the various components of the QCSEE engine. Two of these were scale-model fan tests, both conducted in the anechoic chamber at the General Electric Corporate Research and Development Aero/Acoustic Facility in Schenectady, New York. The first series of tests employed a 50.8 cm (20 inch) diameter, low tip speed, low pressure ratio fan supplied by NASA in an investigation of aft radiated fan noise. The second series of tests employed a variable-pitch fan (of the same diameter), that was an exact scale model of the UTW rotor, in an investigation of inlet-radiated fan noise. The third test program was the measurement of combustor and turbine noise from the same core engine to be employed to drive the QCSEE fans. These test programs are summarized in detail in the component reports, but a brief outline of some of the results, in relation to the unsuppressed full-scale engine acoustic design is necessary:

Aft Fan Noise Test - This test, References 3 and 4, was conducted in two stages; the first was devoted to the study of fan source noise changes due to variations in exhaust duct configuration, and the second consisted of an extensive study of fan exhaust acoustic suppression. The source noise testing employed a series of variations in rotor-OGV spacing, vane-blade ratio, low flow Mach number vane passages, etc. The most important result from the source noise tests was the substantiation of the benefits obtainable with the selected spacing and vane-blade ratio.

Inlet Fan Noise Test - As in the case of the aft-noise tests, this program, Reference 5, was an investigation of both source noise generation and acoustic suppression effects. While the study of configurational effects on source noise was of course more limited (mainly blade pitch angle variations), this test was very important in that it provided the most accurate estimates of full-scale fan inlet source noise in takeoff, approach, and reverse thrust operation; the scaled-up results were employed accordingly as a part of the system noise predictions. Testing of the

Table II. 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 | 180.4 cm (71 in.) |
| Fan Pressure Ratio | 1.27 |
| Fan rpm | 3089 |
| Fan Tip Speed | 289.6 m/sec (950 ft/sec) |
| Number of OGV's | 33 (32 + pylon) |
| Fan Weight Flow (Corrected) | 405.5 kg/sec (894 lbm/sec) |
| Inlet Mach Number (Throat) | 0.79 |
| Rotor/OGV Spacing | 1.5 Rotor Tip Chords |
| Fan Exhaust Area | 1.615 $m^2$ (2504 $in.^2$) |
| Core Exhaust Area | 0.348 $m^2$ (540 $in.^2$) |
| Gross Thrust (SLS Uninstalled) | 81.39 kN (18,300 lbf) |
| Blade Passing Frequency | 920 Hz |
| Core Exhaust Flow | 31.3 kg/sec (69.1 lbm/sec) |
| Fan Exhaust Velocity | 197.8 m/sec (649 ft/sec) |
| Core Exhaust Velocity | 238.9 m/sec (784 ft/sec) |
| Bypass Ratio | 12.1 |
| Inlet Treatment Length/Fan Diameter | 0.74 |
| Vane/Blade Ratio | 1.83 |

inlet design which used wall treatment combined with high throat Mach number demonstrated the acceptability of this design for the engine.

The results from the acoustic suppression tests for both scale model fan programs were also used in the development of the acoustic treatment for the full-scale UTW boilerplate nacelle. These studies are outlined in Section V-A.

Core Engine Noise Tests - Noise measurements were taken on a turbofan engine, Reference 6, using the same core employed on the QCSEE propulsion systems. Both nearfield and farfield measurements were taken in order to determine the core internally generated noise levels. The resulting noise measurements were compared to predicted combustor and turbine noise levels to check the applicability of these prediction procedures to the QCSEE propulsion systems. The results were somewhat qualitative due to the difficulties inherent in attempting to extract the low core noise levels from a total noise signature that was dominated by other sources. In general, however, the results indicated that the combustor and turbine noise prediction procedures employed for the QCSEE system were acceptable for defining the levels of suppression required for the core.

## C. Unsuppressed System Noise Level Predictions

To obtain the predicted system noise levels, detailed predictions were made for each of several different noise sources:

Fan inlet - these predictions were made from the scaled model fan unsuppressed inlet noise data (Reference 5).

Fan exhaust - these predictions were made from correlations of measured acoustic data from full-scale fans, adjusting for weight flow, pressure ratio, and tip speed (Reference 1).

Low Pressure Turbine and Combustor - these predicted levels were obtained by the use of semiempirical prediction procedures developed by General Electric under separate contracts (Reference 7). As was indicated in Section IV-B, the applicability of these predictions was checked against measured data from a QCSEE-type core engine, Reference 6.

Jet/Flap - the jet/flap noise prediction procedure established in Appendix I to the Statement of Work, Reference 1, was developed by NASA through the use of semiempirical correlations with scale-model, blown-flap, test data (Reference 8).

Core Compressor and Reduction Gearing - these sources were estimated from empirical data correlations; they were estimated to be extremely low in level and, hence, were not contributing to the total system noise. Treatment was applied to the core inlet flowpath as a precautionary measure.

Possible "Floors" for Suppressed Noise - these items included noise generated by the flow over the internal surface, and around the struts and fan exhaust splitter. One of the design constraints applied to the engine was that the fan exhaust duct Mach number be kept at or below 0.47. These low Mach numbers result in very low flow noise levels with the exhaust splitter in place; thus, flow noise does not contribute to suppressed systems noise. The results of flow noise studies are reported in References 3 and 4.

System and Component Noise Spectra

The resulting predicted unsuppressed major component noise levels on a 61 m (200 ft) sideline, at the max forward and max aft angles, are given in Table III for takeoff, approach, and reverse thrust conditions. The 65% thrust at approach can be obtained by a variety of combinations of fan rotational speeds, blade pitch angles, and nozzle areas. For the design studies, the engine speed was assumed to be kept at the takeoff value (to satisfy engine response requirements) with the nozzle opened to the maximum allowable area to minimize jet/flap noise, and a closed fan blade angle of +5° to reduce thrust. In a similar manner, the 35% reverse thrust can be obtained by reversing the fan blade pitch either through stall or through flat pitch. The scale model fan-inlet tests indicated that the stall blade angles were quieter and provided the necessary reverse thrust. A blade angle of -100°, at 86% of design speed, was therefore selected to satisfy the thrust and engine operating requirements.

Figures 3 through 7 are presentations of these same predicted unsuppressed component noise sources on a spectral basis. In these cases, the spectra are presented at the appropriate noise measurement points defined in Section III. The corrections have been made for Doppler shift and dynamic effect (where applicable), but the other in-flight corrections defined in Appendix I to the Statement of Work have not been applied. In this extrapolation procedure, all corrections from this point on (excepting acoustic suppression) are made on the basis of ΔPNdB, not on a modification of spectral shape. It is readily apparent that fan noise is the dominant high frequency source, while jet/flap noise controls in the lower frequencies. It is also apparent from reference to Table III that fan inlet noise is by far the dominant source in reverse thrust.

Table III. Unsuppressed Engine Component Noise Levels.

- 61 m (200 ft) Sideline
- Single Engine, Static
- Peak Noise Angle for Total System

| | Max. Forward Angle* PndB | | | |
|---|---|---|---|---|
| | Fan | Turbine | Combustor | Jet/Flap |
| Takeoff Power | 106.6 | 95.6 | 90.0 | 100.1 |
| Approach Power | 110.3 | 87.5 | 85.5 | 95.3 |
| Reverse Thrust | 117.5 | 94.0 | 93.5 | 86.6 |

| | Max. Aft Angle* PNdB | | | |
|---|---|---|---|---|
| | Fan | Turbine | Combustor | Jet/Flap |
| Takeoff Power | 112.3 | 99.1 | 97.8 | 97.8 |
| Approach Power | 106.1 | 96.0 | 96.0 | 90.7 |
| Reverse Thrust | 107.3 | 100.0 | 99.5 | 85.5 |

* Note: Max Forward Angle (for Total System Noise) is 80° from Inlet on Takeoff, and 60° on Approach and Reverse Thrust. Max Aft Angle is 120°.

- 80° Acoustic Angle
- 152.4 m (500ft) Sideline at
  61 m (200ft) Altitude
- Single Engine (Thru Step 4.4, Appendix I)

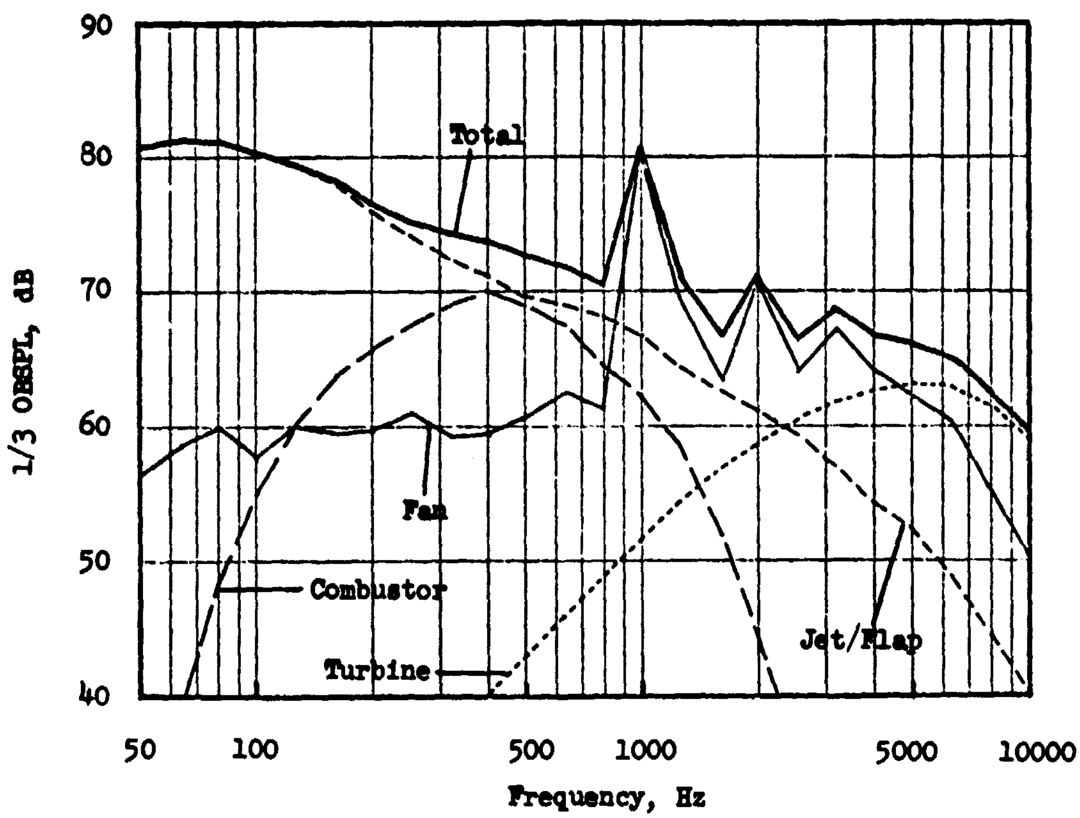



Figure 3. Takeoff Unsuppressed Spectra, 80°.

- 120° Acoustic Angle
- 152.4 m (500 ft) Sideline at 61 m (200 ft) Altitude
- Single Engine (Thru Step 4.4, Appendix I)

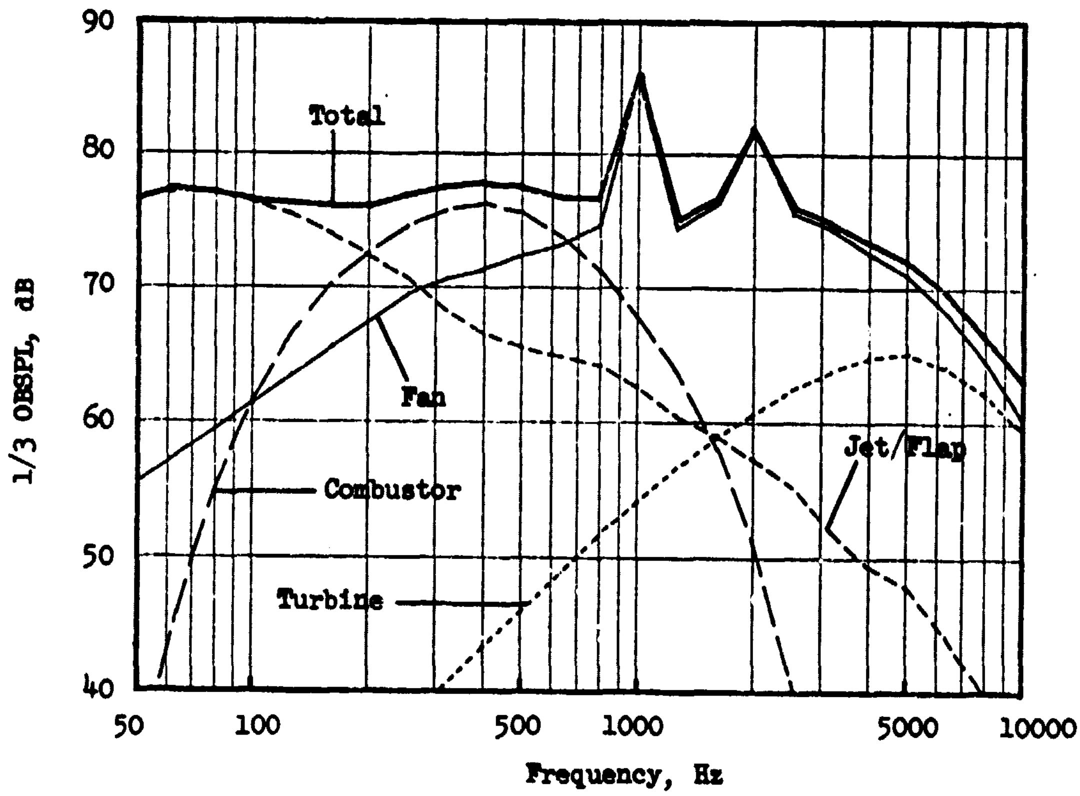



Figure 4. Takeoff Unsuppressed Spectra, 120°.

- 60° Acoustic Angle
- 152.4 m (500 ft) Sideline at 61 m (200 ft) Altitude
- Single Engine (Thru Step 4.4, Appendix I)

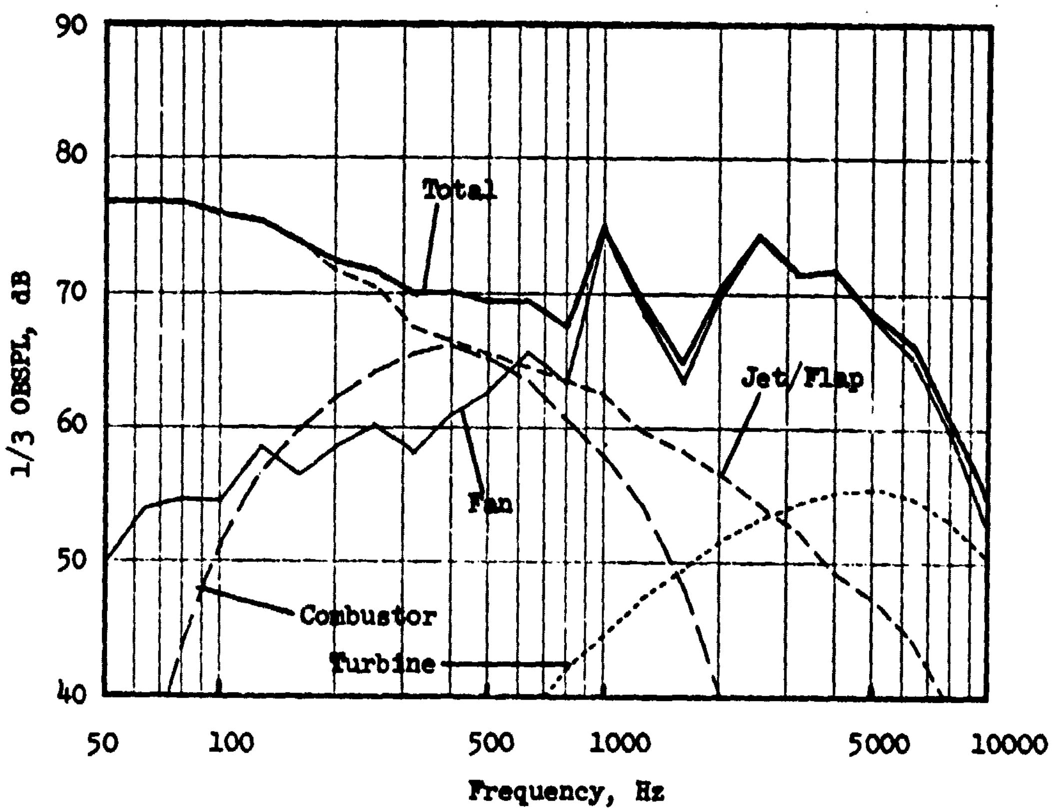



Figure 5. Approach Unsuppressed Spectra, 60°.

- 120° Acoustic Angle
- 152.4 m (500 ft) Sideline at 61 m (200 ft) Altitude
- Single Engine (Thru Step 4.4, Appendix I)

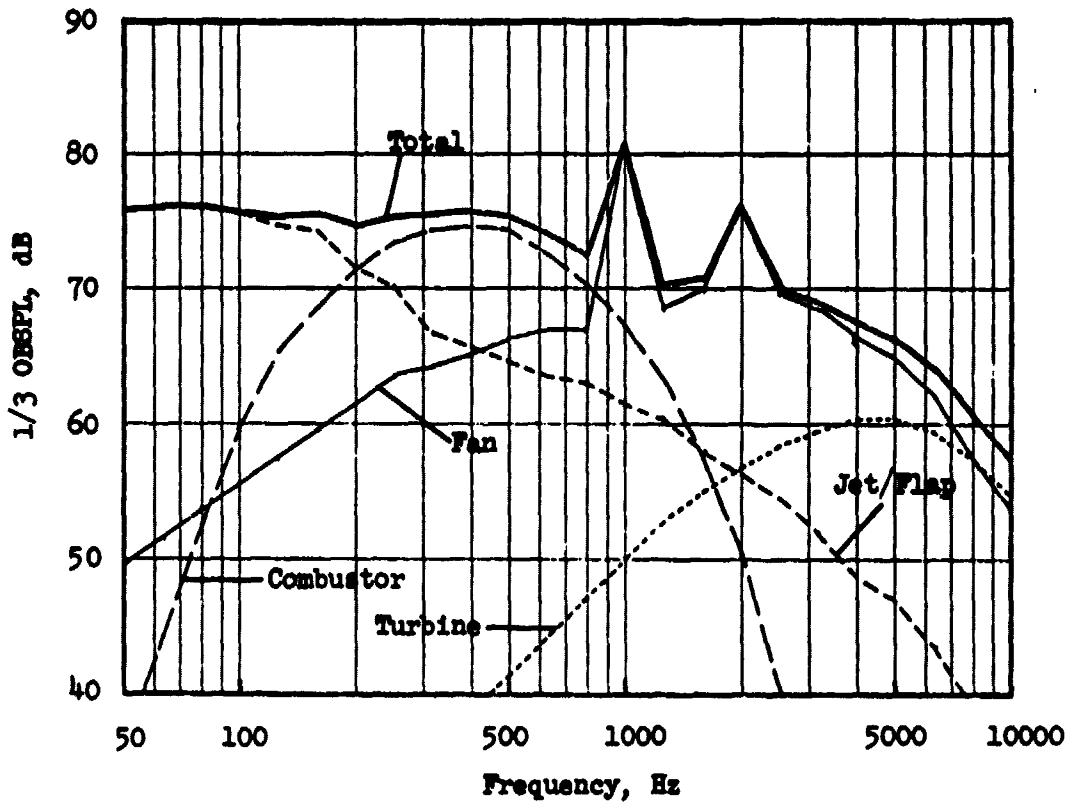



Figure 6. Approach Unsuppressed Spectra, 120°.

- $60^{\circ}$ Acoustic Angle
- 152.4 m (500 ft) Sideline
- Single Engine (Thru Step 6.4, Appendix I)

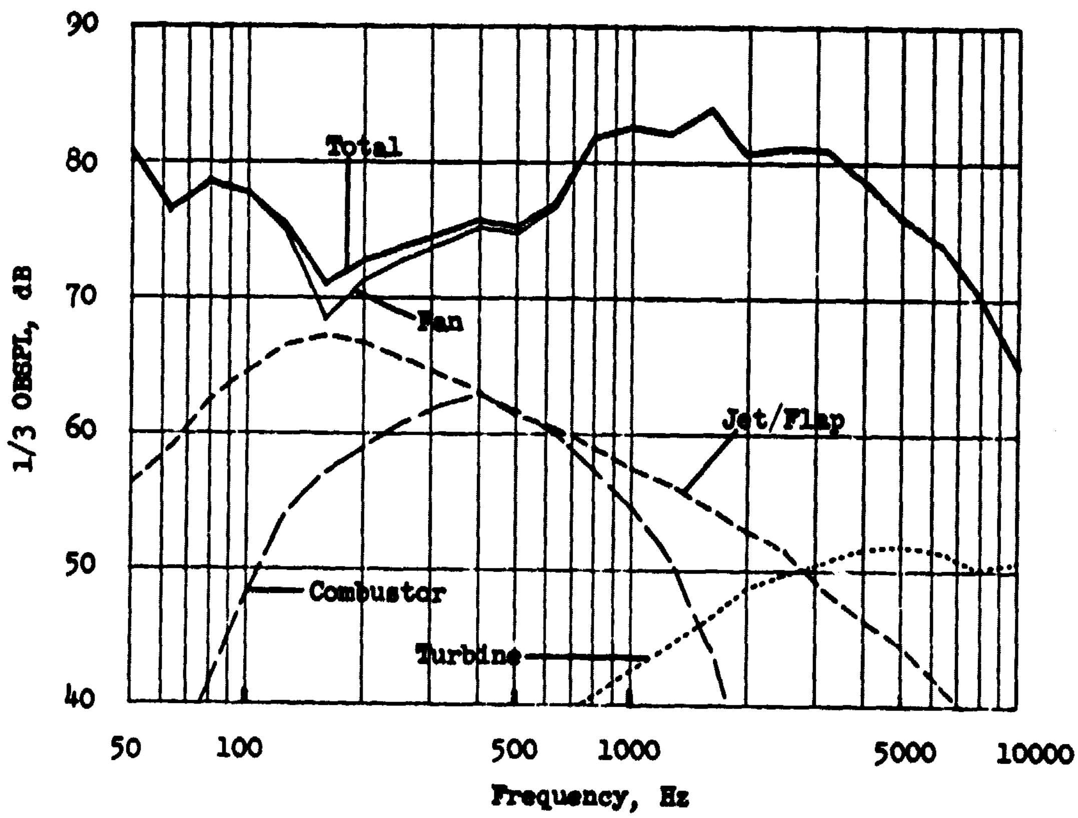



Figure 7. Reverse Thrust Unsuppressed Spectra, 60°.

## SECTION V

## BOILERPLATE NACELLE ACOUSTIC TREATMENT DESIGN

### A. Treatment Design and Development Summary

Given the unsuppressed component noise levels, and the suppressed system design goals, the required component acoustic suppression levels were developed. The acoustic treatment for the UTW boilerplate and nacelle was designed to fit these requirements. Treatment was based on testing conducted during the previously referenced inlet and fan exhaust scale model noise test, as well as on laboratory duct tests and information from the existing General Electric treatment development data bank. The details of this treatment design procedure are given in Reference 9; it is, however, worthwhile to summarize the entire procedure as follows:

Fan Exhaust Duct - The acoustic treatment design for the UTW boilerplate fan exhaust was developed based on the results of the scale model aft fan noise test program (Rotor 55, References 3 & 4), plus previous GE experience in laboratory duct testing, scale model fan tests, and full-scale engine tests. The results from the Rotor 55 scale model acoustic suppression tests yielded the following conclusions:

- Variable depth treatment gives a wider suppression bandwidth, with less peak suppression, relative to constant depth treatment. The suppression level at high frequencies is greater than would be expected for variable depth treatment with each section functioning independently.

- A faceplate porosity of 12% gave more suppression than 27% porosity, for both constant and variable depth configurations of the QCSEE models tested.

- Varying faceplate porosity with variable depth treatment gave improved suppression, relative to variable depth with constant porosity.

- The losses in suppression due to blockages of the treated surface were much lower than the predicted loss based on linear extrapolation. The actual loss is only 25% to 50% of that predicted.

- The suppression levels achieved are independent of treatment orientation (i.e., treatment depth can either increase or decrease in the direction of flow).

- Treatment in the fan frame, between the rotor and OGV's, gives added suppression (both tone and broadband) either with or without additional treatment in the fan exhaust.

These conclusions were used to develop a design procedure for the UTW fan exhaust treatment, as follows:

- Compare the measured Rotor 55 suppression results to the predicted suppressions made using the existing procedures (based on engine data).

- From the above comparisons, determine the adjustments to the existing engine data correlation (these adjustments included increases to the predicted high frequency suppression and reductions in the penalty imposed for treatment-area blockage).

- Using the adjusted design procedure from above, design a treated duct that is optimized to give the most effective suppression in regard to the unsuppressed fan exhaust noise spectrum.

- Optimize the faceplate porosity for each treated panel of the above design, using a correlation of optimum porosity with the ratio of duct height to design frequency wave length ($H/\lambda$) developed from laboratory duct test data.

Figures 8 and 9 are typical examples showing, respectively, how the previous suppression prediction procedure fitted the measured Rotor 55 data, and the closer fit achieved with the adjusted procedure. Figure 10 is a presentation of the predicted unsuppressed UTW fan exhaust noise spectrum, shown both with and without "annoyance" weighting. The Noy-weighted spectrum shows the frequency bands that most affect the calculation of perceived noise level, and it was used to determine the necessary treatment tuning requirements. Figure 11 shows the duct data used to determine the optimum faceplate porosity for the fan exhaust duct panels. Finally, Figure 12 is a typical example of the additional suppression due to rotor-OGV treatment that was measured on Rotor 55. These data were used to estimate the benefits of rotor-OGV treatment in the QCSEE fan frame. The resulting fan exhaust treatment design is presented in the following section.

Fan Inlet Duct - In order to provide the required suppression with a conventional treated inlet, the preliminary design studies indicated that the use of prohibitive inlet lengths (or treated inlet splitters) was necessary. It was determined that with wall treatment only, the treated-length-to-fan diameter ratio ($L_T/D_F$) would have to be much greater than 1.0. Previous tests had shown that large inlet suppressions were available from high throat Mach number effects; it was therefore decided that the best design approach would be to use an inlet with a throat Mach number of 0.79 with treated walls. This "hybrid" inlet design approach allowed the use of a much shorter inlet ($L_T/D_F$ = 0.74) without the need for splitters. The item of fundamental importance in the scale model inlet test program (UTW simulator, Reference 5) was thus to prove that such an inlet would provide the needed suppression. The design of the full-scale inlet was based on the results of those tests. The procedure here was somewhat more direct than in the case of the fan exhaust duct, since the UTW simulator was an exact scale model of the full-sized UTW fan and inlet, and the results could be scaled directly to the engine. However, during the simulator testing it became apparent that certain design improvements could be made to the model inlet treatments to optimize the treatment where it was most needed. The inlet acoustic treatment is most

- Rotor 55 Data
- 100% Corrected Fan Speed
- Max Aft Angle

- Variable Depth, Mixed Porosity

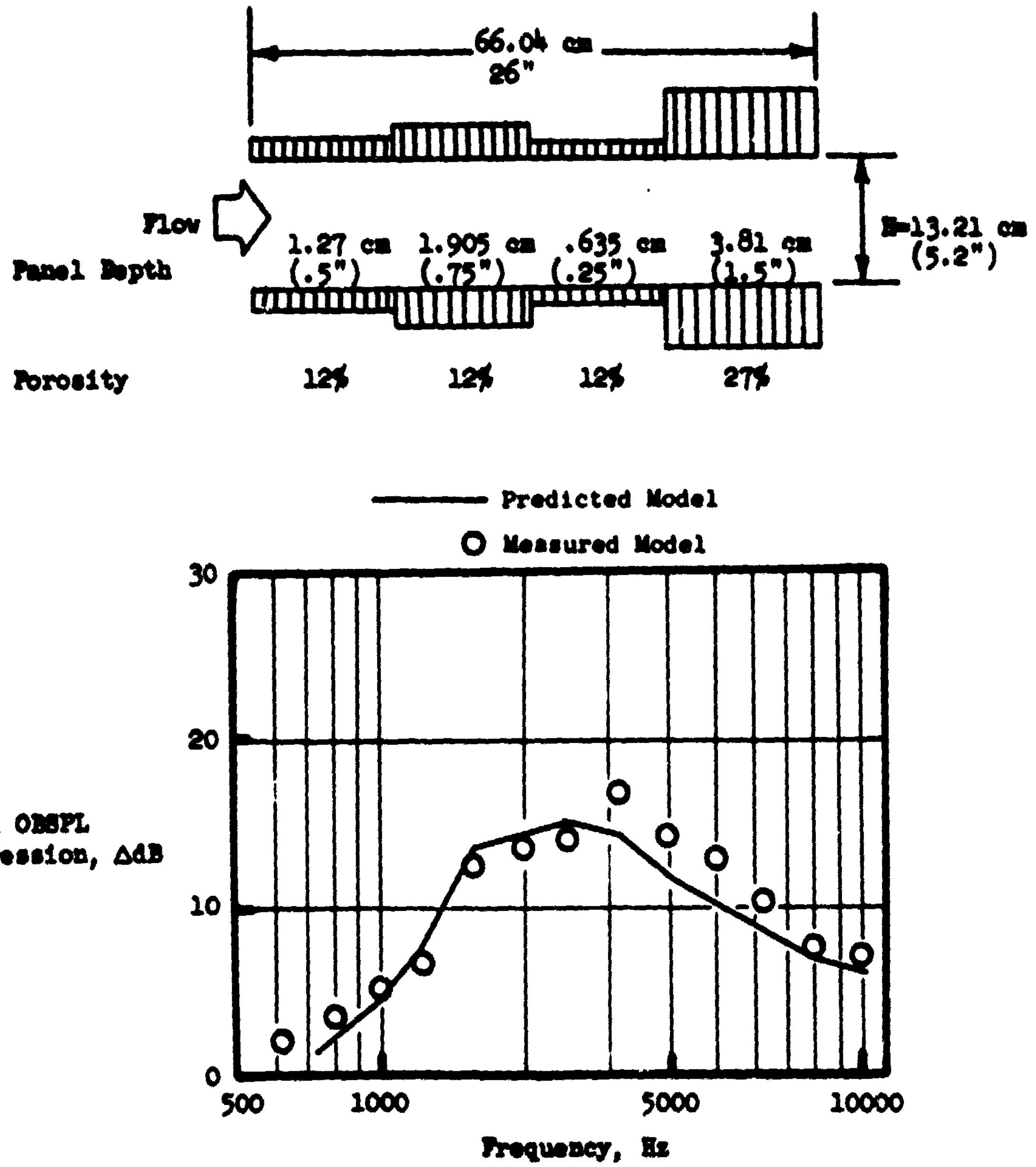



Figure 8. Model Fan Exhaust Duct Suppression.

- Rotor 55 Data
- 100% Corrected Fan Speed
- Max Aft Angle

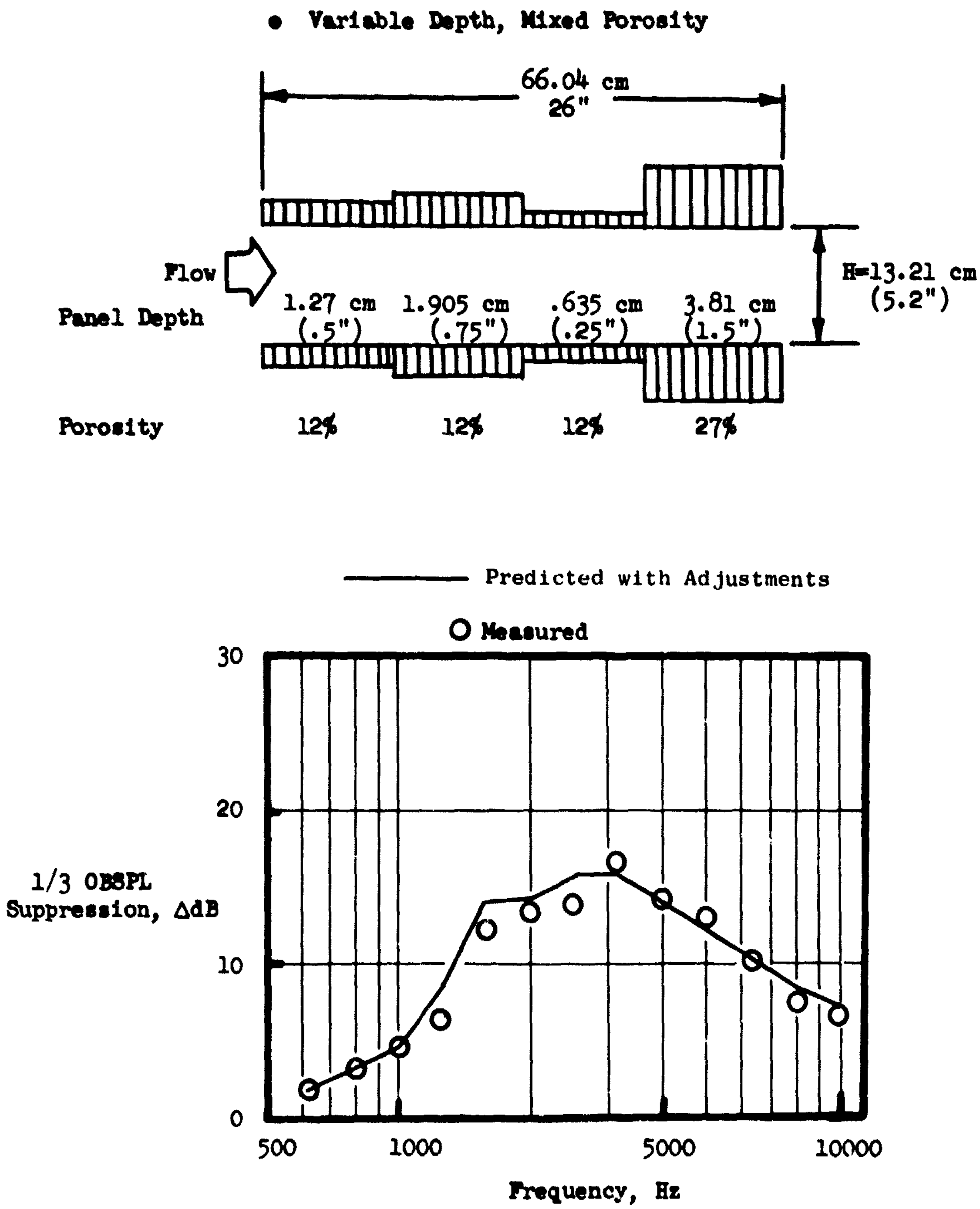



Figure 9. Model Fan Exhaust Duct Adjusted Suppression.

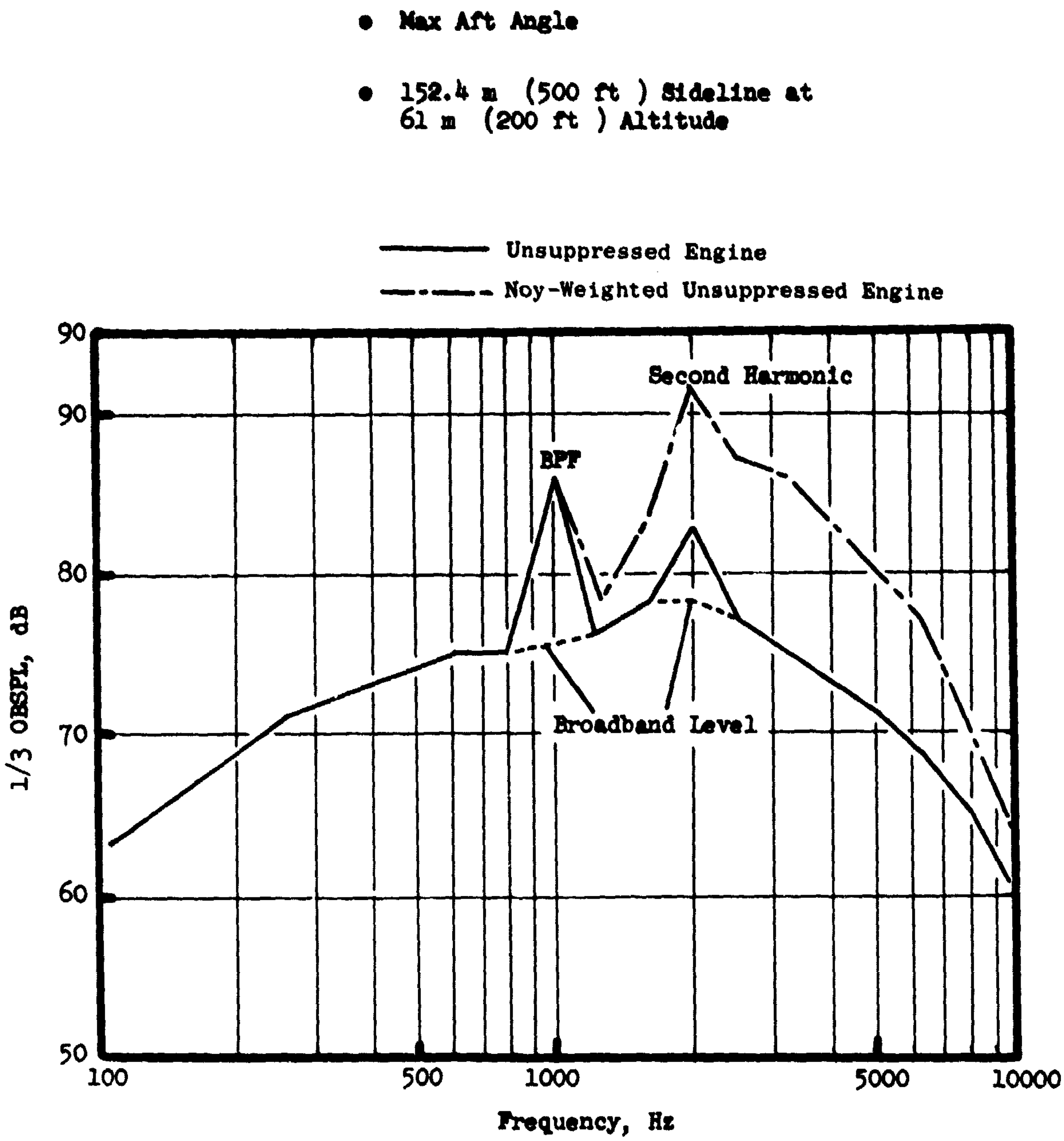



Figure 10. Unsuppressed Fan Exhaust Spectra.

• Based on Acoustic Duct Data

• Duct Mach No. = .4

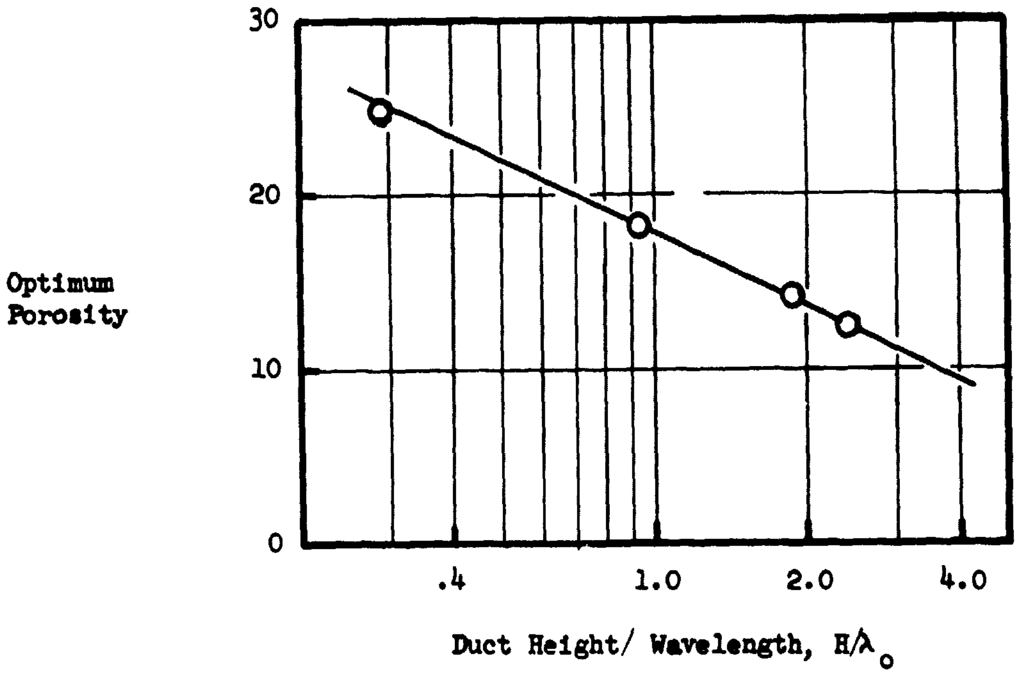



Figure 11. Optimum Porosity.

- Rotor 55 Data
- 100% Corrected Fan Speed
- Max Aft Angle

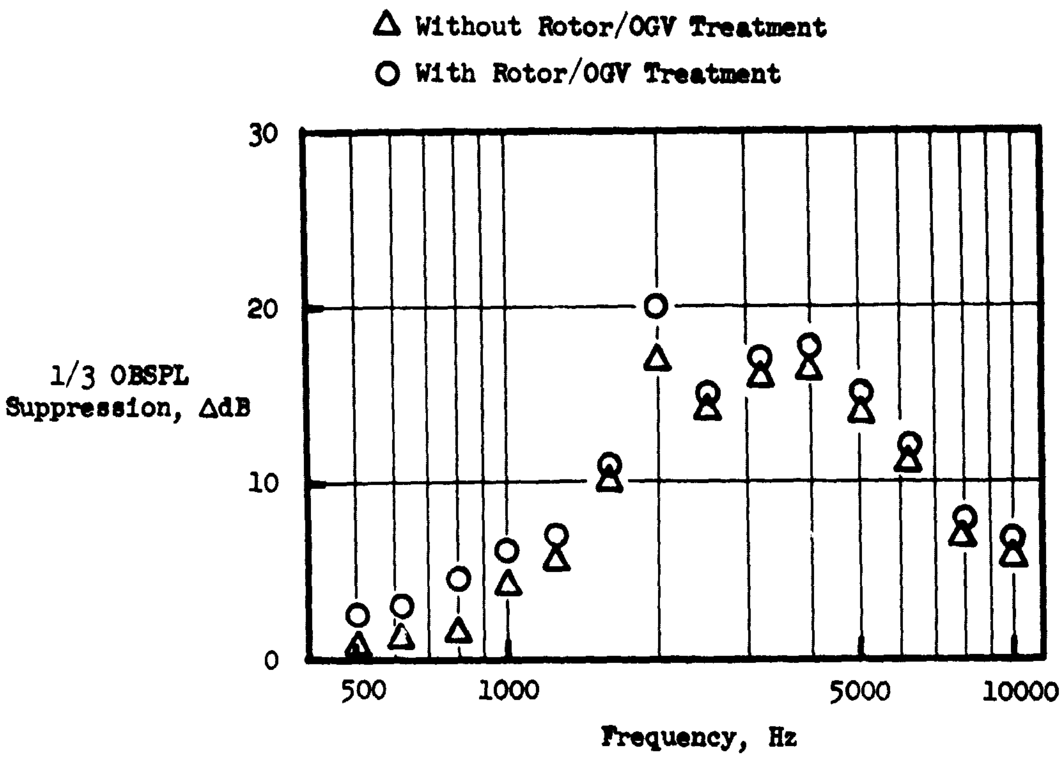



Figure 12. Scale Model Fan Rotor/OGV Treatment Suppression.

directly beneficial in the cases of approach and reverse thrust; at takeoff, the high inlet throat Mach number provides most of the needed suppression. The unsuppressed data from the simulator indicated that the reverse thrust case was the most critical in terms of its impact on the total systems noise goals; hence the basic UTW inlet boilerplate treatment was designed for this case. This design was of course less than optimum for the approach and takeoff cases, but it was shown to be adequate to still allow the total system noise goals to be met for these cases. There were several inlet treatment designs that were tested on the UTW simulator. One design which gave a balanced performance between takeoff, approach, and reverse thrust was selected. This inlet consisted of three varying-depth panels, each with a 9.2% porosity faceplate, and tuned to frequencies of 3150 Hz, 2000 Hz, and 1000 Hz during reverse thrust operation. The measured unsuppressed reverse thrust spectrum was, however, found to have a greater high-frequency noise content than previously predicted. Figure 13 is a comparison of the measured and predicted reverse thrust noise spectrum (scaled to full size). The measured Noy-weighted reverse thrust spectrum is shown in Figure 14; it is this spectrum that was used as a basis for the boilerplate treatment design. The measured performance for the selected inlet during reverse thrust is shown on Figure 15. In order to adjust the suppression to a more optimum value for the measured reverse thrust noise, it was decided to retune the treatment to higher frequencies, namely 3150 Hz, 2500 Hz, and 1600 Hz (in reverse thrust). The predicted suppression spectrum thus obtained is also shown on Figure 15. The predicted retuned suppression was obtained by estimating the effect for each section separately, then adjusting and re-adding to get the new total. Once the design had been so established, the suppression obtainable during approach operation could be estimated by a similar procedure; these estimates are shown on Figure 16. The baseline unsuppressed spectra for takeoff and approach are shown on Figures 17 and 18, respectively. It should be noted that the unsuppressed takeoff spectra on Figure 18 already includes the effect of suppression due to inlet throat Mach number. Figure 19 is a comparison of the suppression obtained due to throat Mach number alone, and due to a combination of treatment and throat Mach number. It can be seen that at 0.79 throat Mach number, approximately 3 PNdB of the total 13 PNdB suppression comes from the treatment.

As has been indicated, the design modifications give an increased suppression during reverse thrust operation, while still giving adequate suppression on takeoff and approach to allow the system noise design goals to be met. The resulting boilerplate inlet design is shown in the next section.

Core Exhaust Duct - The QCSEE core exhaust provides a rather severe problem in acoustic suppression design. The unsuppressed source noise spectrum is composed of two parts: high frequency broadband noise from the low pressure turbine, and low frequency broadband noise from the combustor. Figure 20 shows these individual unsuppressed component spectra, along with the Noy-weighted total. It is apparent that, to obtain any meaningful noise reduction, the suppressor must attenuate both the high and low frequency noise simultaneiously. Due to the relatively short length of the core duct, sufficient amounts of thick (low frequency) and thin (high frequency)

- Max Forward Angle
- 152.4 m (500 ft ) Sideline
- 35% of Takeoff Forward Thrust

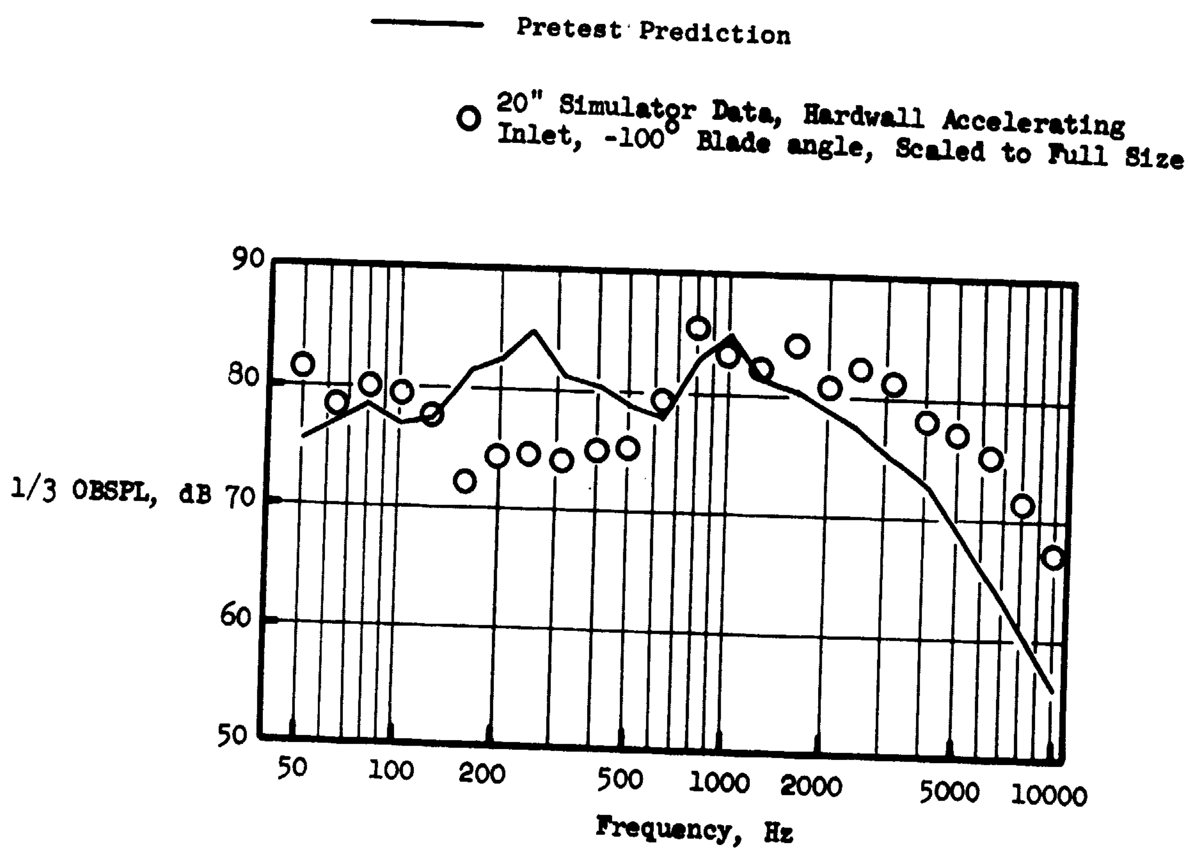



Figure 13. Scale Model Fan Reverse Thrust Spectra.

- Max Forward Angle
- 152.4 m (500 ft ) Sideline
- 35% of Takeoff Forward Thrust
- $-100^{\circ}$ Blade angle
- 20" Simulator Data Scaled to Full Size
- 86% Corrected Fan Speed

——— Unsuppressed

- - - - - - - Noy Weighted Unsuppressed

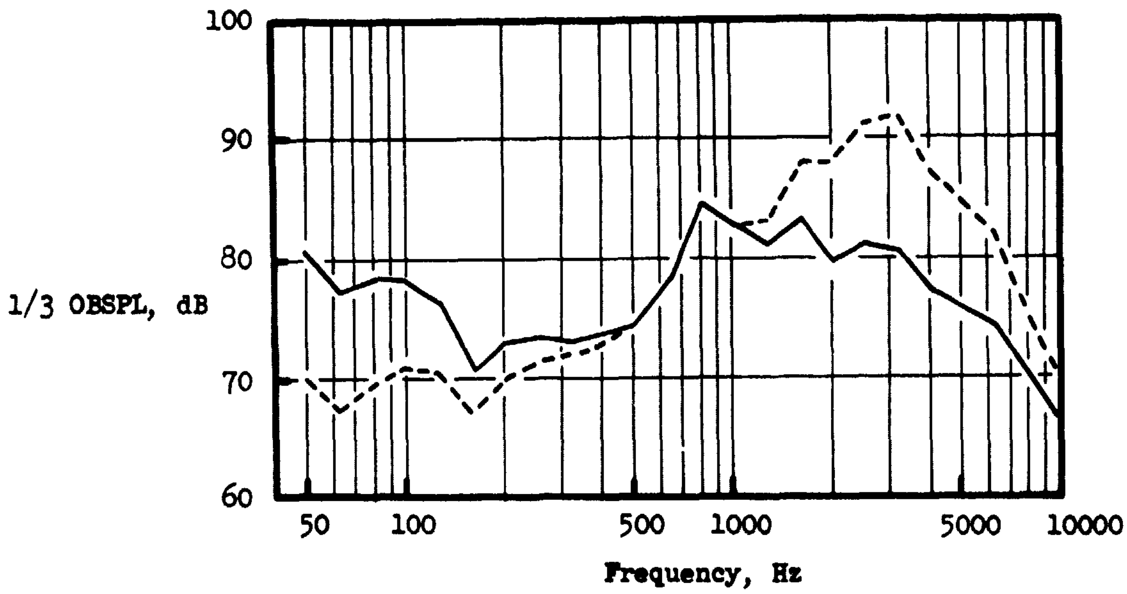
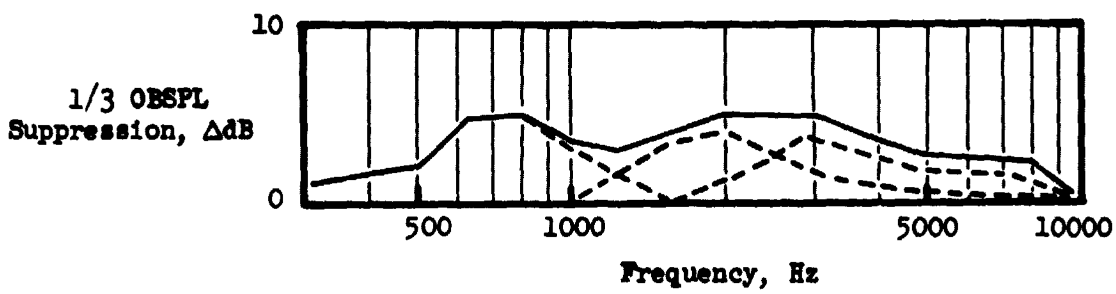



Figure 14. Unsuppressed Reverse Thrust Spectra.

- $60^\circ$ Acoustic Angle
- 61 m (200 ft ) Sideline
- 35% of Takeoff Forward Thrust
- $-100^\circ$ Blade Angle
- 86% Corrected Fan Speed

Measured Model Data

- Treatment B, 10% Porosity




Total Suppression

Estimated Suppression per Section of Treatment

Engine Prediction

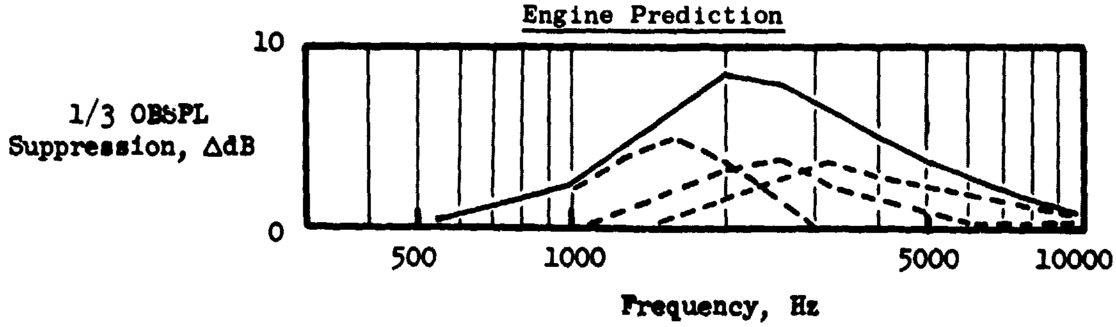



Figure 15. Reverse Thrust Suppression Spectra.

- $60^{\circ}$ Acoustic Angle
- 61 m (200 ft) Sideline
- 65% Forward Thrust
- $+5^{\circ}$ Blade Angle
- 95% Corrected Fan Speed

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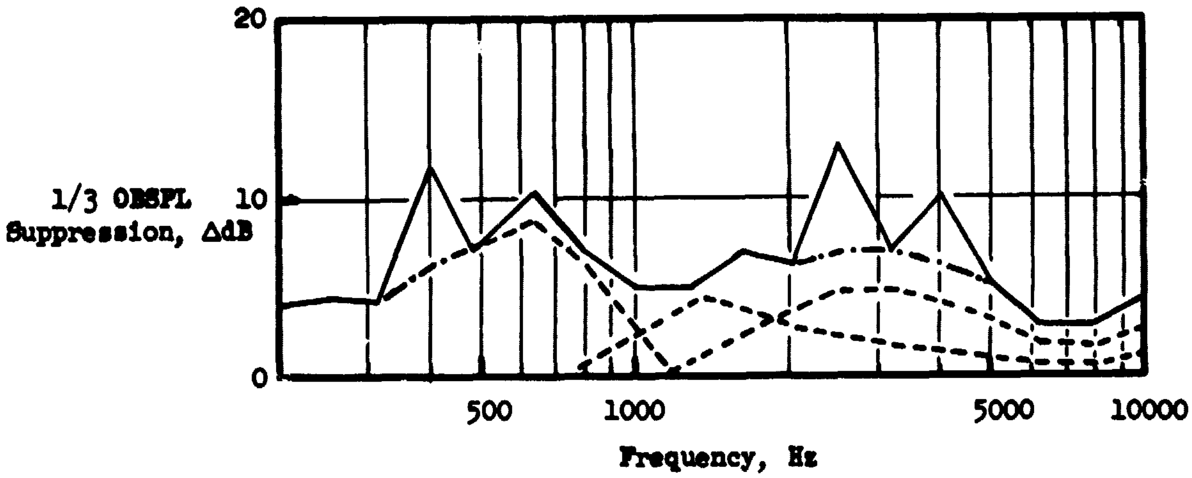
<u>Measured Model Data</u>

- Treatment B, 10% Porosity




——— Total Suppression

- - - - - Estimated Suppression per Section of Treatment

<u>Engine Prediction</u>

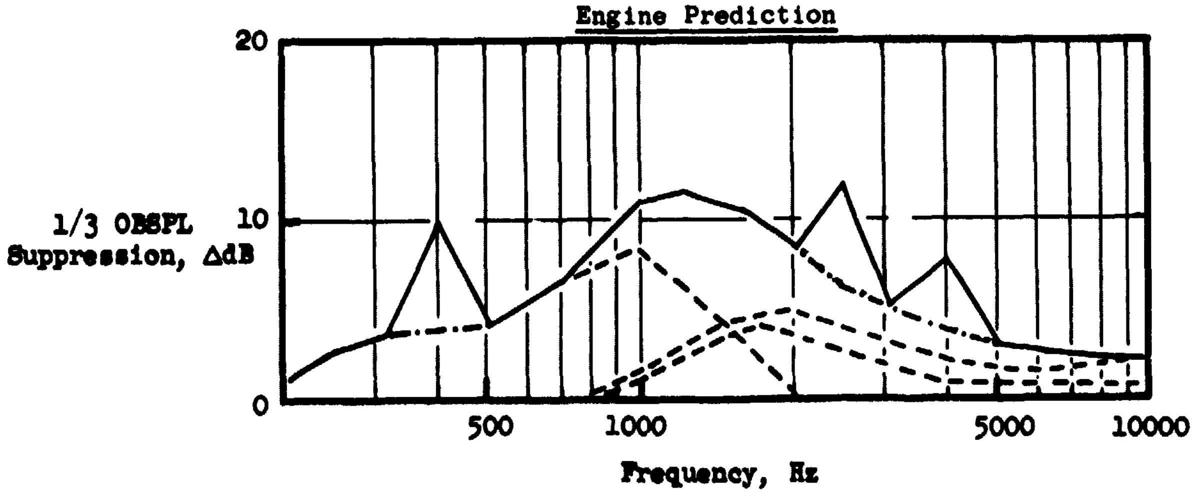



Figure 16. Approach Suppression Spectra.

- $60^\circ$ Acoustic Angle
- 152.4 m (500 ft) Sideline at 61 m (200 ft) Altitude
- .79 Throat Mach Number

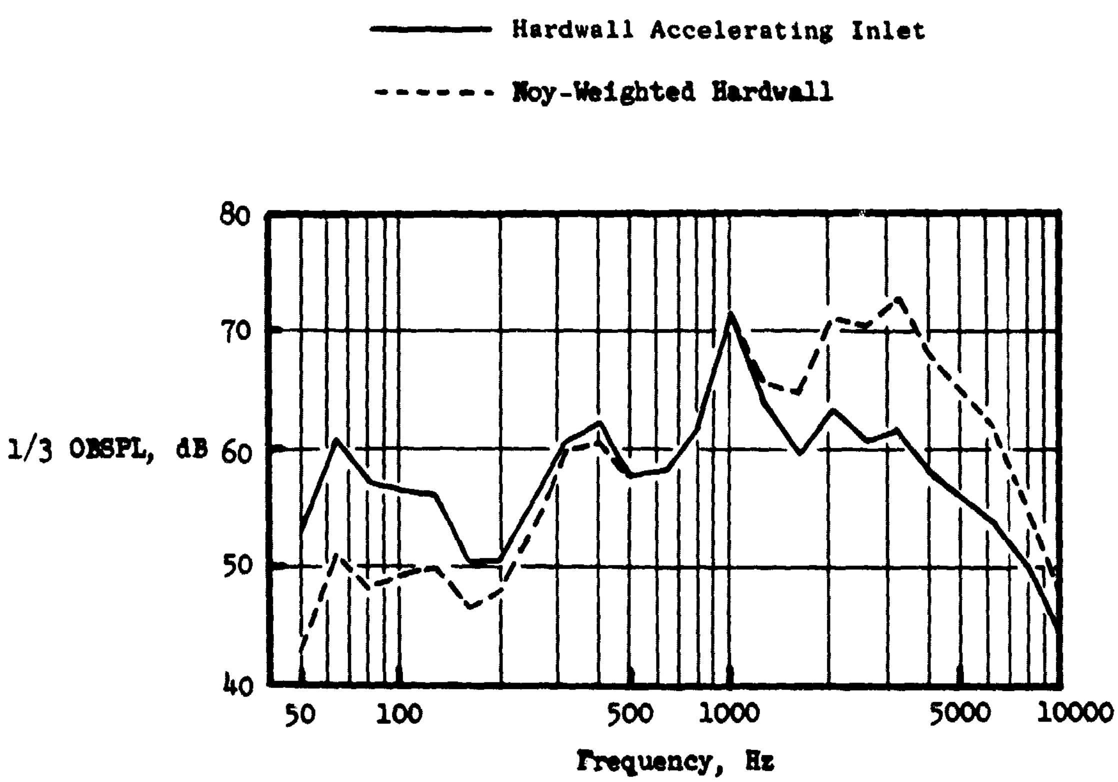



Figure 17. Takeoff Fan Inlet Spectra.

- $60^\circ$ Acoustic Angle
- 152.4 m (500 ft) Sideline at 61 m (200 ft) Altitude
- $+5^\circ$ Blade Angle
- 65% Forward Thrust
- 95% Corrected Fan Speed

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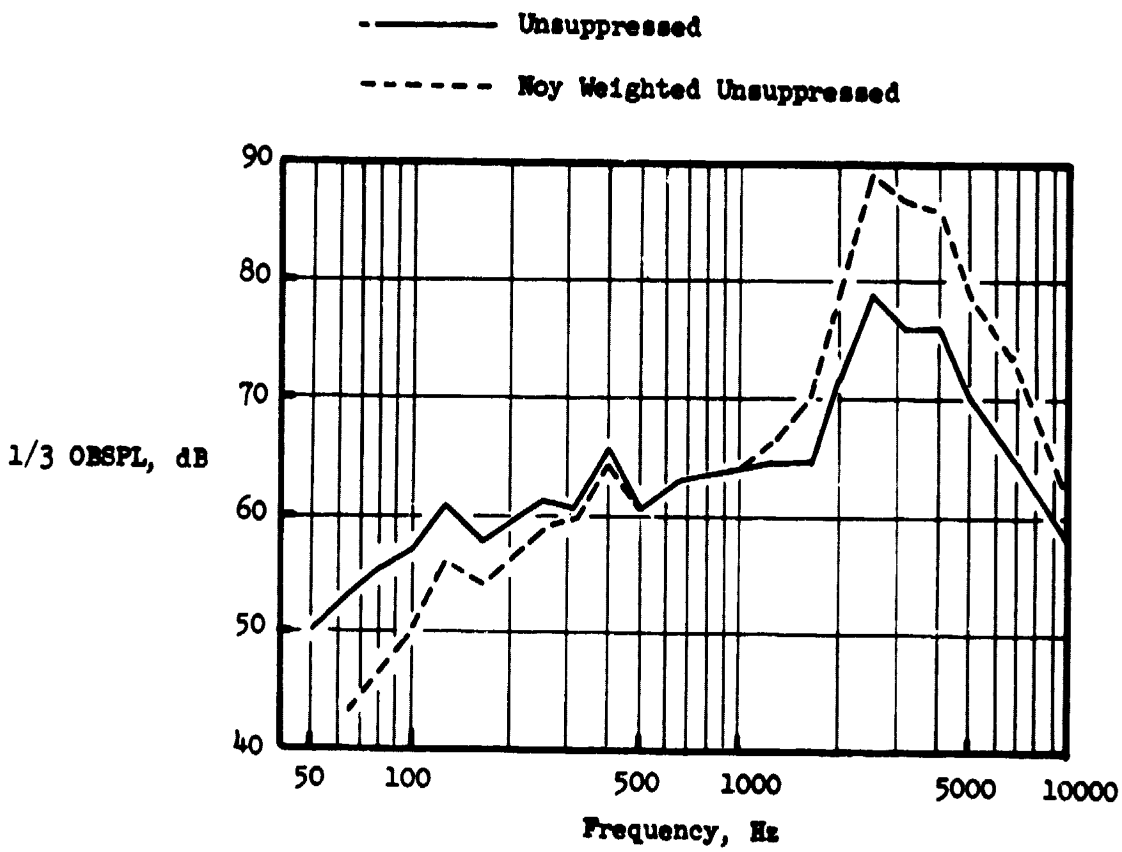



Figure 18. Approach Unsuppressed Fan Inlet Spectra.

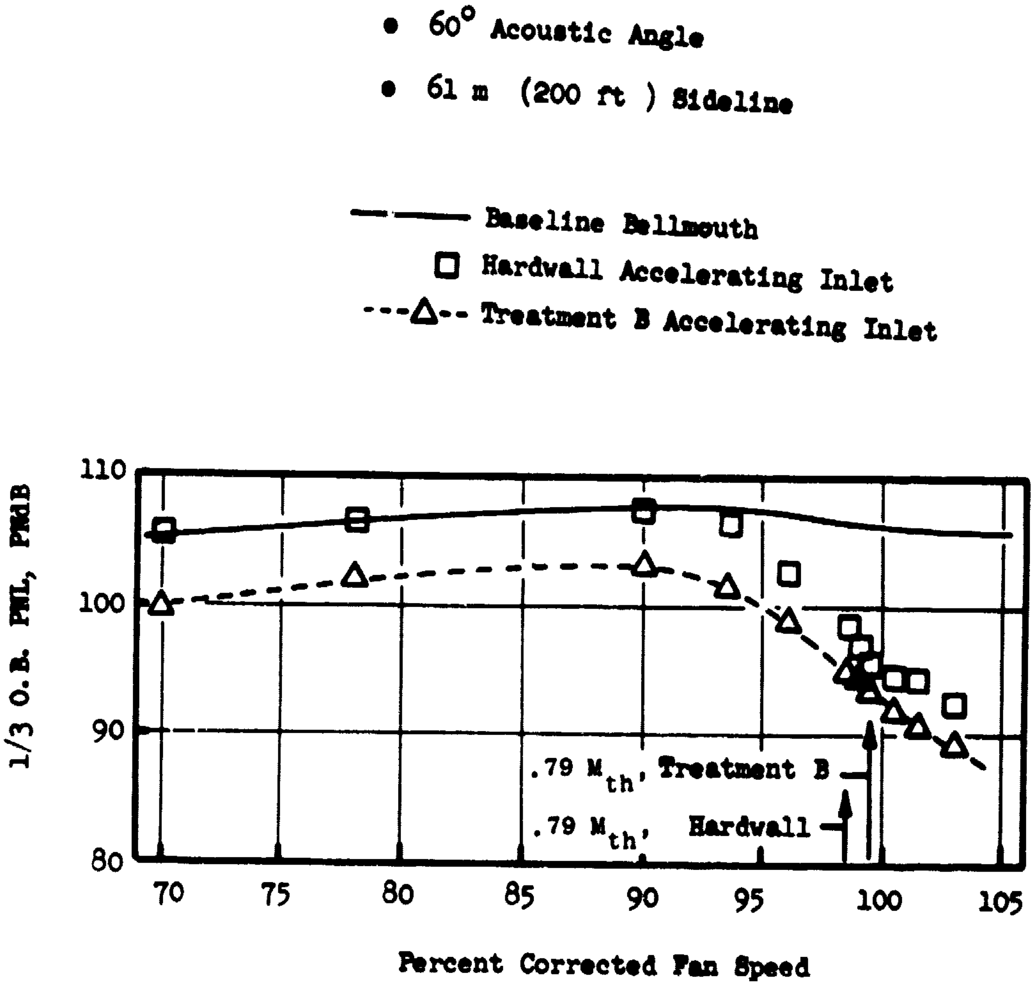



Figure 19. Comparison of Accelerating Inlet Noise with and Without Treatment.

- 120° Acoustic Angle



- 152.4 m (500 ft ) Sideline at
  61 m (200 ft ) Altitude

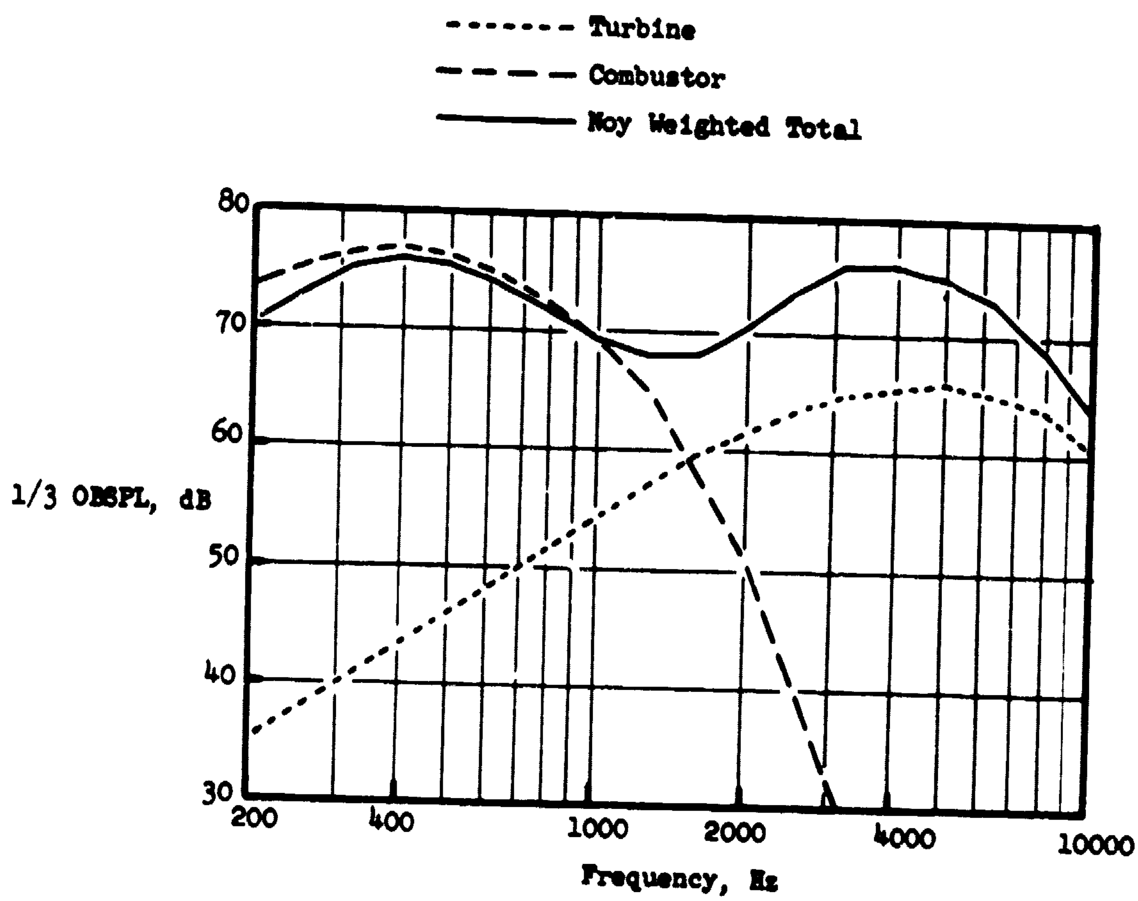



Figure 20. Takeoff Unsuppressed Core Noise Spectra.

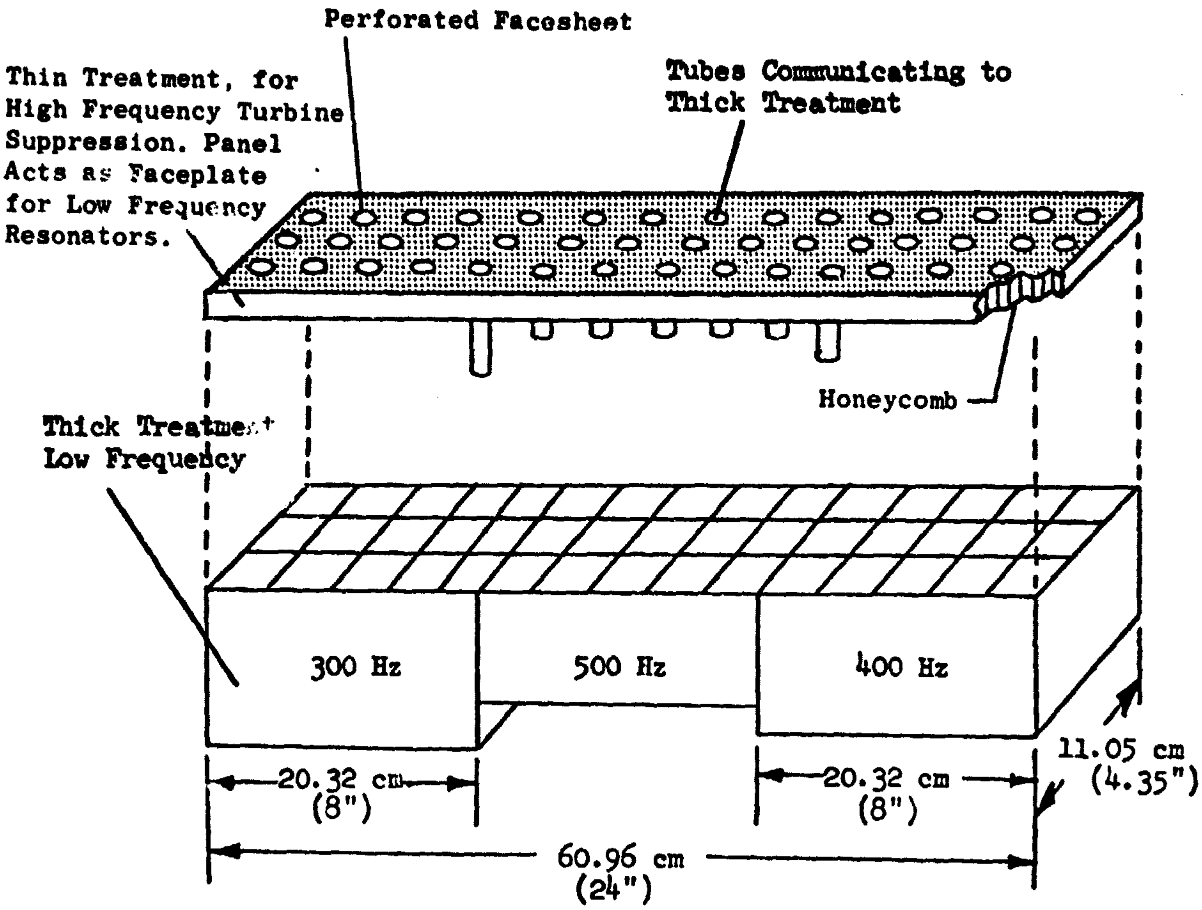
treatment cannot be placed in tandem to give adequate suppression. It was decided, therefore, to adapt a new concept and employ a "stacked" treatment design. In this concept, the thin turbine treatment is placed along the duct walls; the thick combustor treatment is then placed behind this turbine treatment, communicating to the duct by means of tubes passing through the turbine treatment. The resulting resonator treatment design for the combustor thus has an effectively large faceplate thickness, which in turn makes it possible to get much lower frequency tuning from the available depths. Without such an approach, there is insufficient depth to obtain the required low frequency tuning.

In order to determine the effectiveness of such a treatment design, a sample was built and tested in a laboratory high temperature acoustic duct. Figure 21 shows a sketch of the test hardware. It was found that the stacked treatment design will provide the required levels of suppression for both the high and low frequency regions. The design of the boilerplate nacelle core suppressor was developed from this test configuration and is detailed in the following section.

## B. Suppressed Boilerplate Nacelle Configuration

Figure 22 summarizes the main acoustic features of the UTW boilerplate nacelle. A high throat Mach number inlet (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 fan exhaust suppression utilizes inner and outer wall treatment with varying thickness to obtain increased suppression bandwidth. A 101.6 cm (40 inch) splitter is necessary to obtain the required suppression level. Acoustic treatment is also used in the fan frame passage between the rotor and outlet guide vanes, and on the pressure surfaces of the outlet guide vanes. A major concern in the aft duct is noise generated by flow over the treated surfaces, struts, and splitter. To keep these sources below the suppressed fan noise, the duct Mach number is limited to 0.47. The core exhaust suppression utilizes a low frequency design for combustor reduction combined 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 to reduce forward radiated compressor noise. The resulting final detailed acoustic treatment designs for the UTW boilerplate nacelle are shown on the following figures and tables. In all cases, the designs have been adopted (where necessary) to fit within available space limitations and, also, to take advantage of "off-the-shelf" materials for construction.

Figure 23 and Table IV provide the details of the fan exhaust duct treatment design; the predicted fan exhaust suppression spectrum for this design is shown in Figure 24. The resulting Noy-weighted suppressed fan exhaust noise spectrum (on takeoff) is shown on Figure 25. It can be seen that the design yields a very balanced suppression and that, in order to obtain substantial further decreases in the perceived noise level, it would be necessary to suppress over a very wide bandwidth.




| | Turbine Treatment | Combustor Treatment | | |
|---|---|---|---|---|
| Tuning Freq., Hz | 4000 | 300 | 400 | 500 |
| Porosity = | 22.5% | 10% | 10% | 10% |
| Faceplate Thickness = or Neck Length | 0.0813 cm (0.032 in.) | 6.35 cm (2.5 in.) | 5.08 cm (2.0 in.) | 4.45 cm (1.75 in.) |
| Cavity Depth = | 2.54 cm (1.0 in.) | 1.52 cm (0.6 in.) | 1.52 cm (0.6 in.) | 1.52 cm (0.6 in.) |
| Hole Diameter = | 0.1575 cm (0.062 in.) | 10.16 cm (4.0 in.) | 9.53 cm (3.75 in.) | 7.62 cm (3.0 in.) |

Figure 21. Stacked Treatment Test Configuration.

- Fan Pressure Ratio = 1.26
- Fan Tip Speed = 289.6 m/sec (950 ft/sec)
- Number of Fan Blades = 18

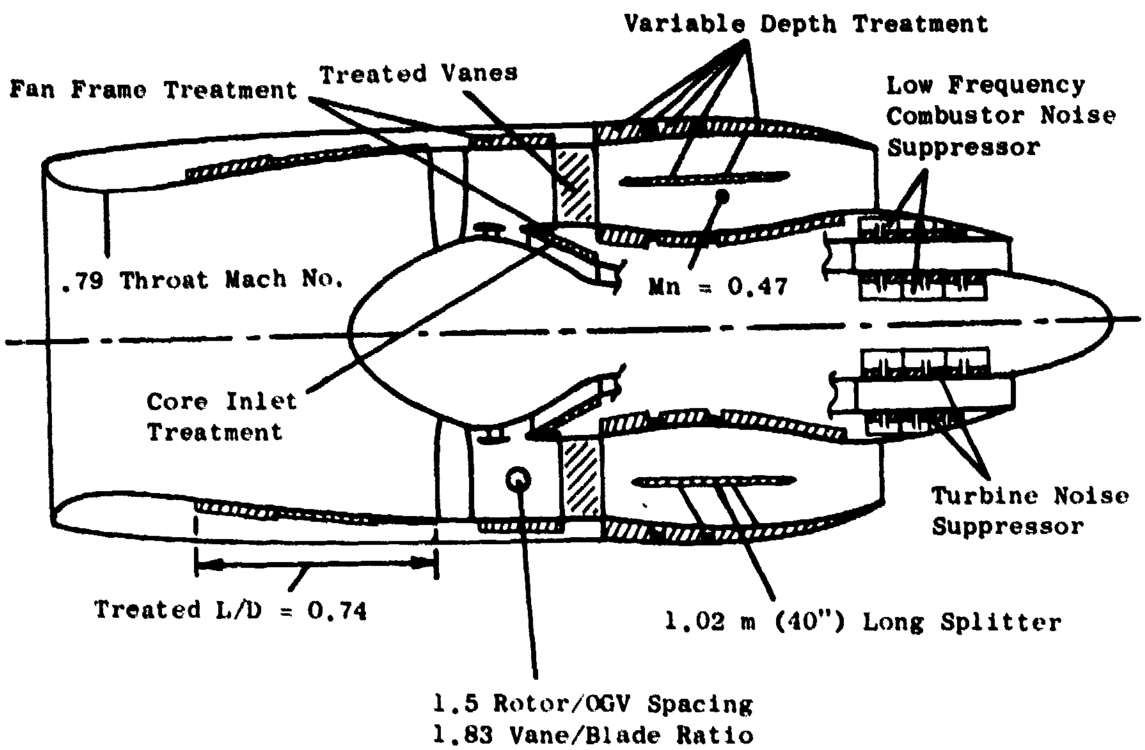
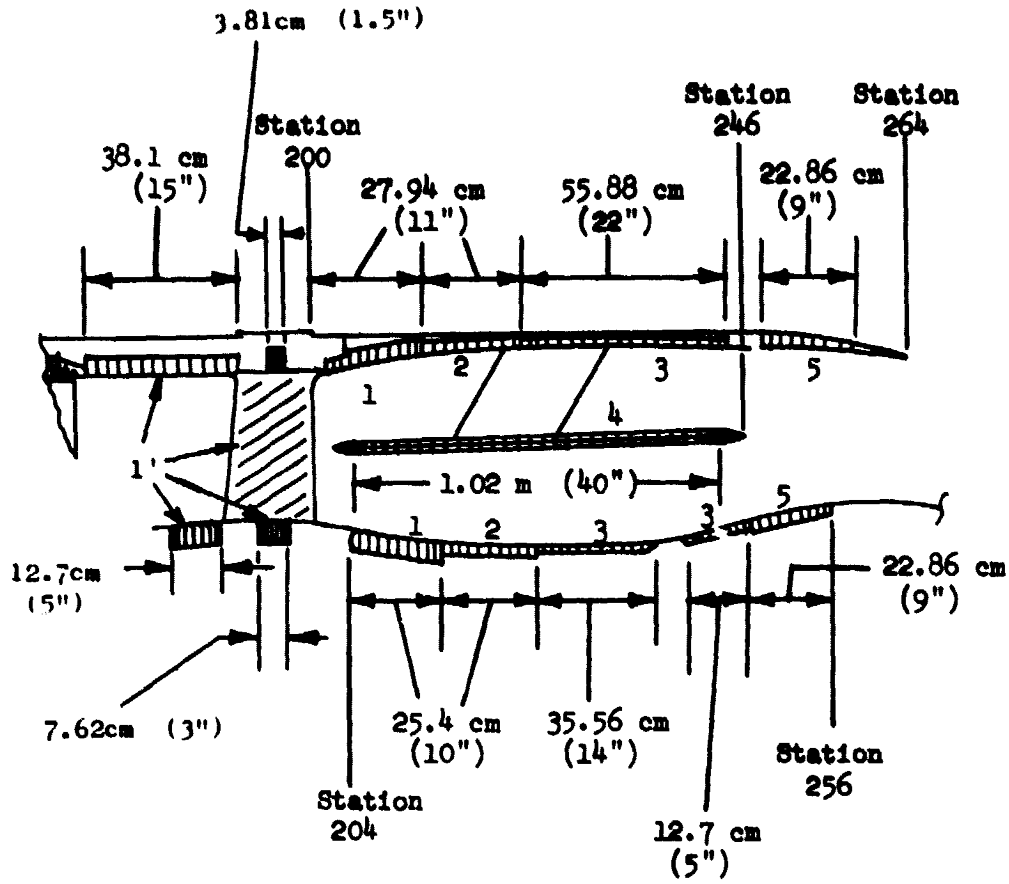



Figure 22. Schematic of Suppressed Boilerplate Nacelle.




| | Depth | | Porosity | Tuning Frequency |
|---|---|---|---|---|
| Fan Frame Treatment, 1' | 5.08 cm | (2") | 10% | 1000 Hz |
| Treated Vanes | .762 cm | (.3") | 10% | 4000 Hz |
| Fan Exhaust Treatment | | | | |
| Section 1 | 5.08 cm | (2") | 22% | 1250 Hz |
| " 2 | 2.54 cm | (1") | 15% | 2000 Hz |
| " 3 | 1.90 cm | (.75") | 15% | 2500 Hz |
| " 4 | 1.27 cm | (.5") | 11.5% | 2500 Hz |
| " 5 | 2.54 cm | (1") | 15.5% | 1600 Hz |

Figure 23. Boilerplate Nacelle Exhaust Duct Treatment.

Table IV. Boilerplate Nacelle Fan Exhaust Treatment Design.

| Fan Frame Treatment | Treated Vanes |
|---|---|
| Cavity Depth - 5.08 cm (2.0 in.) | Cavity Depth - 0.762 cm (0.3 in.) |
| Porosity - 10% | Porosity - 10% |
| Hole Size - 0.1589 cm (0.0625 in.) | Hole Size - 0.1589 cm (0.0625 in.) |
| Face Sheet Thickness - 0.0889 cm (0.035 in.) | Face Sheet Thickness - 0.127 cm (0.05 in.) |
| | Treatment on Pressure Side of Blade |

Fan Exhaust - Walls and Splitter

| Section* | Depth | Porosity | Hole Size | Face Sheet Thickness |
|---|---|---|---|---|
| 1 | 5.06 cm (2.00 in.) | 22% | 0.1589 cm (0.0625 in.) | 0.1016 cm (0.040 in.) |
| 2 | 2.54 cm (1.00 in.) | 15% | 0.1589 cm (0.0625 in.) | 0.1016 cm (0.040 in.) |
| 3 | 1.91 cm (0.75 in.) | 15% | 0.1589 cm (0.0625 in.) | 0.1016 cm (0.040 in.) |
| 4 | 1.27 cm (0.50 in.) | 11.5% | 0.198 cm (0.078 in.) | 0.2032 cm (0.080 in.) |
| 5 | 2.54 cm (1.00 in.) | 15.5% | 0.1589 cm (0.0625 in.) | 0.1016 cm (0.040 in.) |

* Reference Figure 23

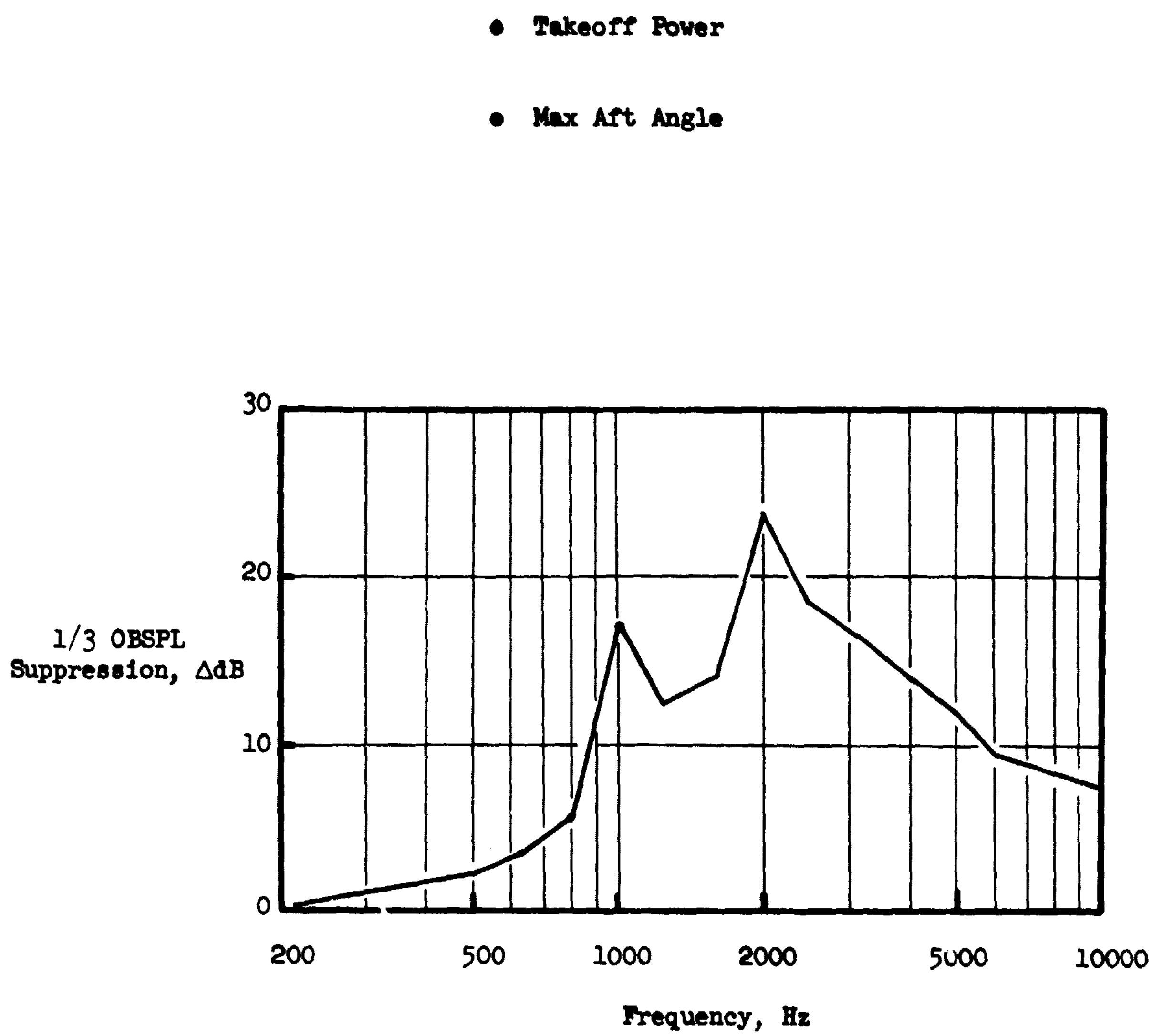



Figure 24. Boilerplate Nacelle Fan Exhaust Predicted Suppression.

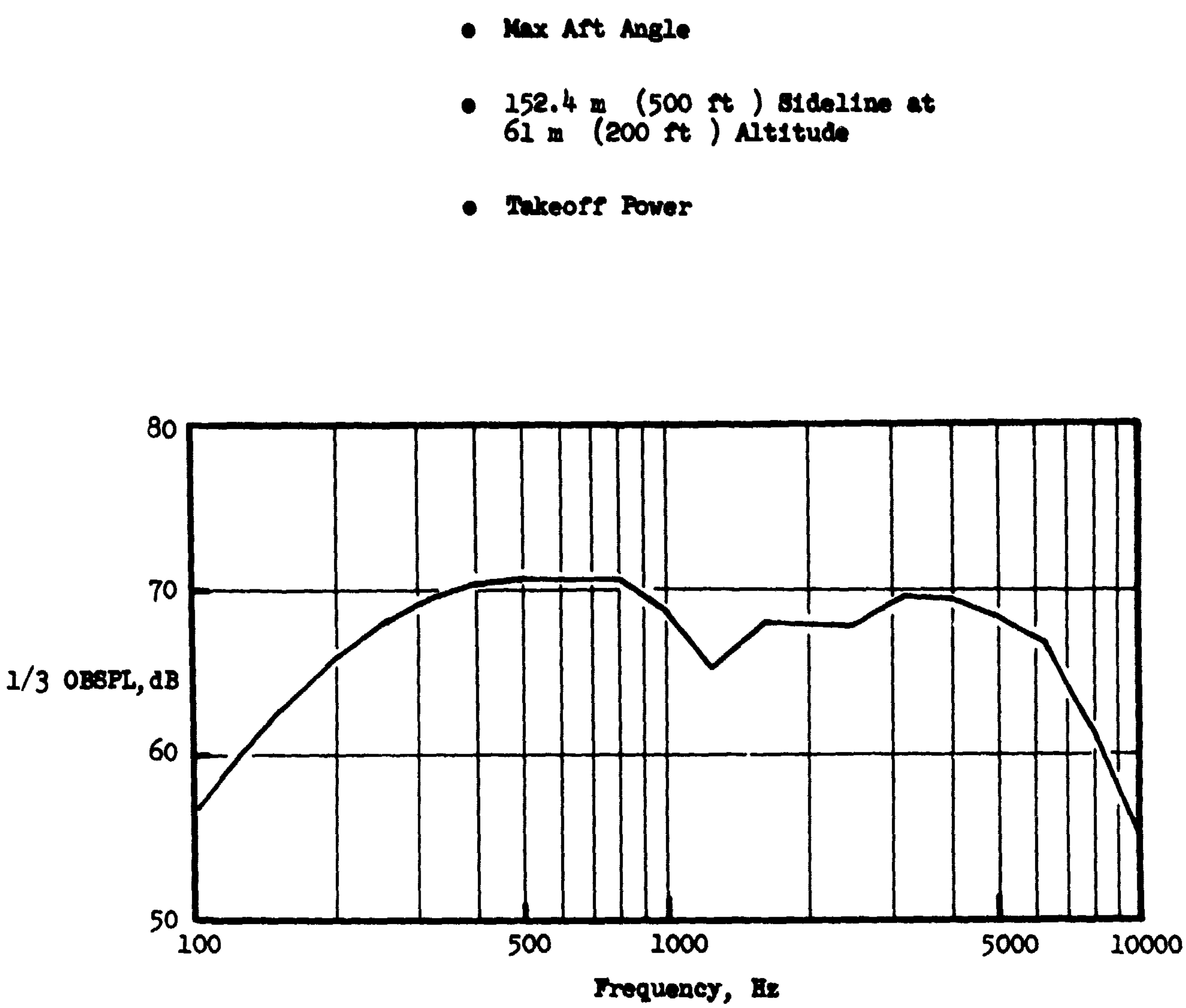



Figure 25. Boilerplate Nacelle Suppressed Fan Exhaust Spectrum.

In a similar manner, Figure 26 and Table V show the inlet treatment design; the predicted suppression spectra were shown on Figures 15 and 16 for reverse thrust and approach, respectively. It should be noted that the tuning changes with the flow direction and Mach number; hence, the suppression peak shifts from the forward to reverse thrust cases.

The details for the core exhaust stacked-treatment design are provided in Figure 27, and the predicted suppression spectrum is given in Figure 28. The core compressor inlet treatment is shown in Figure 29.

The suppression spectra predicted for each treatment element were applied to the appropriate unsuppressed source noise spectra (similar to those shown in Figures 3 through 7, with the exception that dynamic effects were not included) and the component PNL suppressions were calculated. These ΔPNL's are summarized on Table VI. These suppression values were then input in the system noise calculation procedures outlined in Section III, and the total in-flight system noise EPNL's were determined. These calculations are summarized in Tables VII through IX for, respectively, takeoff, approach, and reverse thrust.

It is apparent that the system EPNL goals are met on takeoff and approach with a margin of approximately 1.5 EPNdB. However, the peak PNL in reverse thrust is predicted to be 3.9 PNdB higher than the goal. This is due to the greater than expected unsuppressed fan inlet source, based on the scaled-up 20-inch simulator results. Although the inlet suppression on reverse thrust has already been increased by retuning, it would be difficult to obtain further increases without degrading the suppression on takeoff or approach and eroding the margin present at those conditions. It was thought that the treated nacelle design outlined herein provided the most balanced approach to meeting the noise goals.

• Treated $L_T/D_F = 0.74$

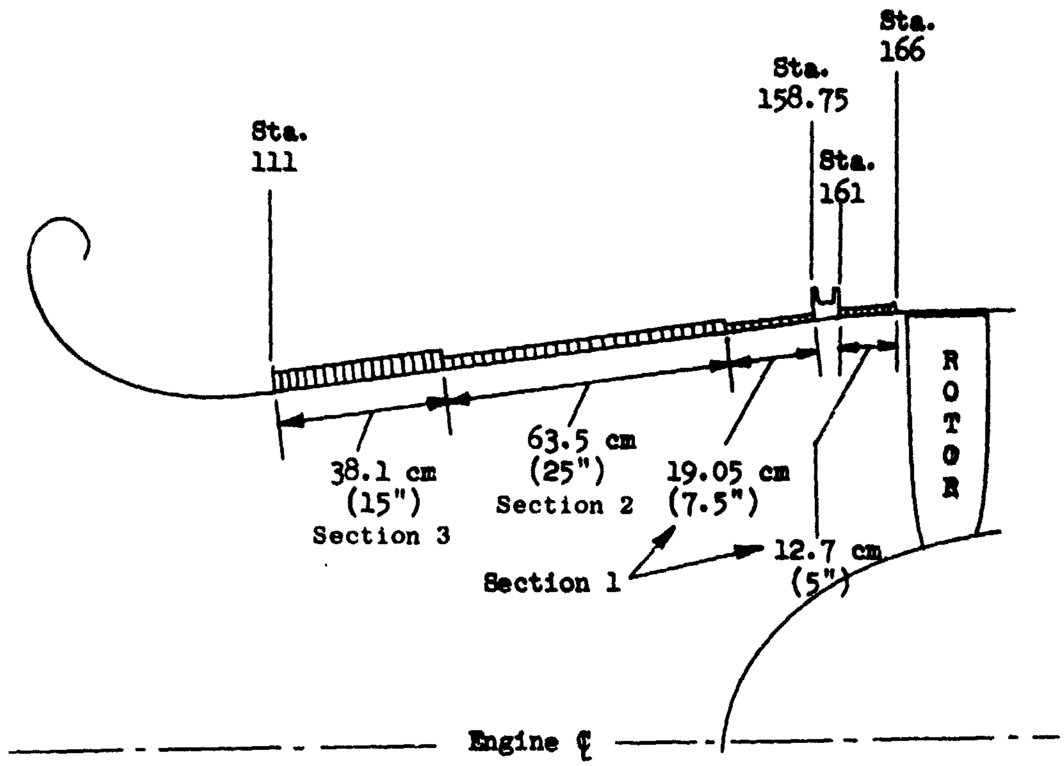



Figure 26. Boilerplate Nacelle Fan Inlet Treatment.

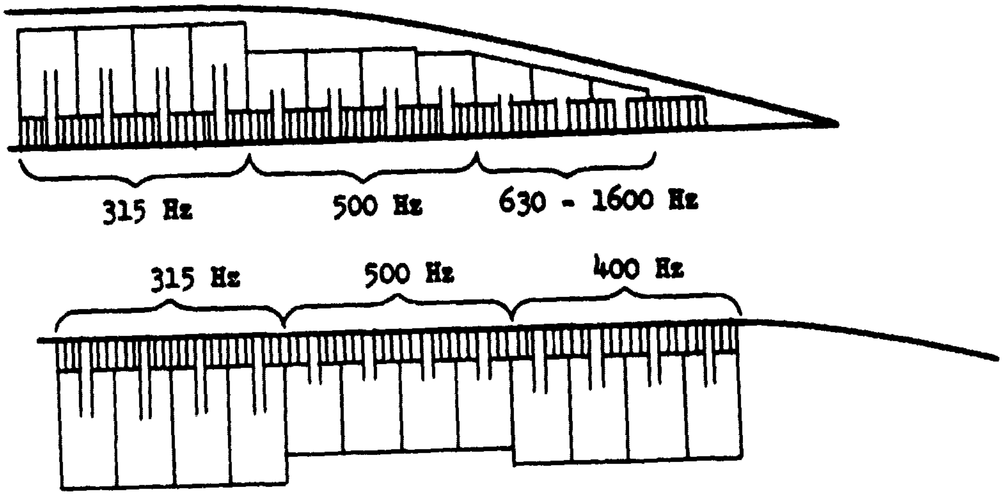
Table V. Boilerplate Nacelle Fan Inlet Treatment Design Details.

| Section* | Hole Size | Porosity | Cavity Depth | Faceplate Thickness |
|---|---|---|---|---|
| 1 | 0.1589 cm (0.0625 in.) | 9.89% | 1.27 cm (0.50 in.) | 0.0813 cm (0.032 in.) |
| 2 | 0.1589 cm (0.0625 in.) | 9.89% | 1.91 cm (0.75 in.) | 0.0813 cm (0.032 in.) |
| 3 | 0.1589 cm (0.0625 in.) | 9.89% | 3.82 cm (1.50 in.) | 0.0813 cm (0.032 in.) |

Design Frequencies

| Section* | Reverser Thrust | Forward Thrust |
|---|---|---|
| 1 | 3150 Hz | 2000 Hz |
| 2 | 2500 Hz | 1600 Hz |
| 3 | 1600 Hz | 1000 Hz |

* Reference Figure 26




| | Combustor Inner Wall | | | Combustor Outer Wall | | | Turbine Both Walls |
|---|---|---|---|---|---|---|---|
| Tuning Frequency, Hz | 315 | 400 | 500 | 315 | 500 | 630 - 1600 | 3150 |
| Neck Length, cm (Faceplate Thick.)(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) | .08128 (.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 - .51 (1.6)-(.2) | 1.905 (.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 (.6) | 1.52 (.6) | 1.52 (.6) | 1.52 ((.6) | 1.52 (.6) | 1.52 (.6) | .1575 (.062) |

Figure 27. Boilerplate Nacelle Core Exhaust Treatment.

• Based on Laboratory Duct Test Results

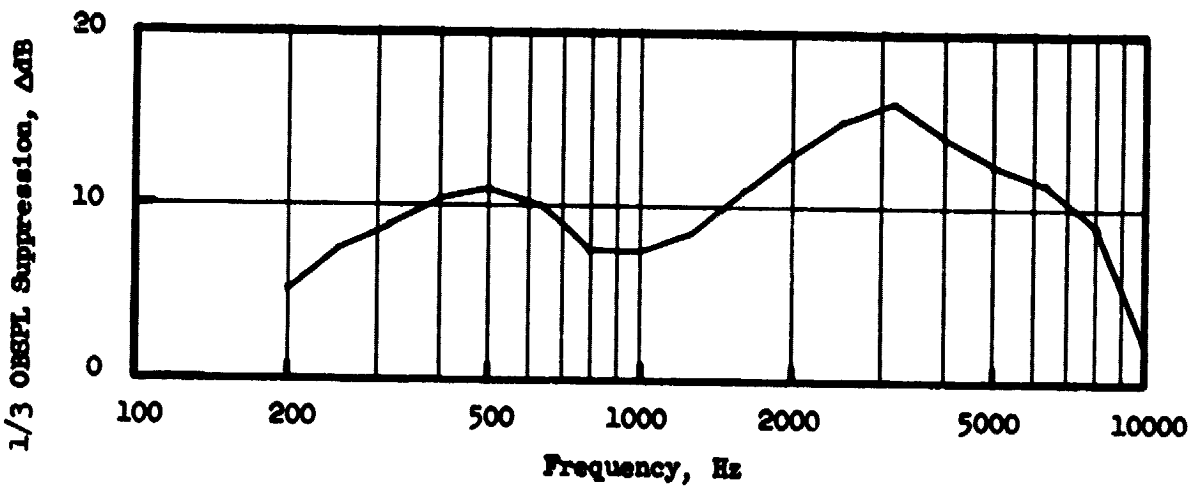



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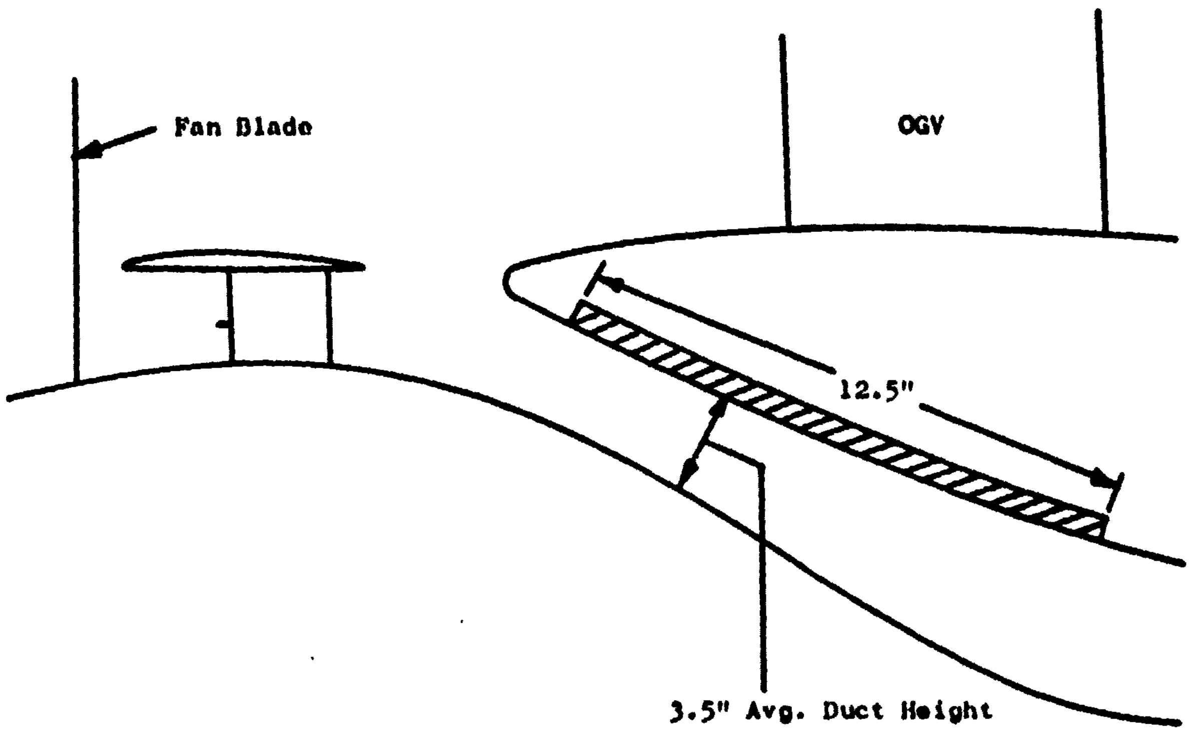
Figure 28. Boilerplate Nacelle Core Exhaust Predicted Suppression.




SDOF Honeycomb, .500 cm. (.197") Thick

8000 Hz Tuning Frequency

.119 cm.(.047") Faceplate Thickness

10% Porosity

.159 cm.(.0625") Hole Size

Figure 29. Boilerplate Nacelle Core Compressor Treatment.

Table VI. Boilerplate Nacelle Predicted Component Suppression.

- 152.4 m (500 ft) Sideline

| Power Setting | Suppression, ΔPNL | | | |
|---|---|---|---|---|
| | Inlet* | Fan Exhaust | Core Exhaust | |
| | | | Combustor | Turbine |
| Takeoff | 12.3 | 13.4 | 5.1 | 9.8 |
| Approach | 6.3 | 13.4 | 5.1 | 9.8 |
| Reverse Thrust | 4.3 | 9.3 | 5.1 | 9.8 |

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* Inlet Suppression Includes Throat Mach Number Effects

Table VII. Boilerplate Nacelle Predicted Takeoff Noise.

| | Max. Forward Angle ($80^{o}$) PNdB | | | | Max. Aft Angle ($120^{o}$) PNdB | | | |
|---|---|---|---|---|---|---|---|---|
| | Fan | Turbine | Combustor | Jet/Flap | Fan | Turbine | Combustor | Jet/Flap |
| Single Engine - Unsuppressed 61 m (200 ft) Sideline | 106.6 | 95.6 | 90.0 | 100.1 | 112.3 | 99.1 | 97.8 | 97.8 |
| Total Corrections - Appendix I Procedure | -9.6 | -7.4 | -3.9 | -5.5 | -7.6 | -9.3 | -5.2 | -7.8 |
| Corrected Level - 152.4 m (500 ft) Sideline at 61 m (200 ft) Altitude | 97.0 | 88.2 | 86.1 | 94.6 | 104.7 | 89.8 | 92.6 | 90.0 |
| Suppression | 12.8 | 9.8 | 5.1 | - | 13.4 | 9.8 | 5.1 | - |
| Suppressed System | 84.2 | 78.4 | 81.0 | 94.6 | 91.3 | 80.0 | 87.5 | 90.0 |
| Sum Constituents | | 95.6 | | | | | 95.3 | |
| PNdB to EPNdB | | | | 93.6 EPNdB | | | | |

• Takeoff Power 100.08 kilonewtons (22,500 lb) Installed Thrust

Table VIII. Boilerplate Nacelle Predicted Approach Noise.

| | Max. Forward Angle ($60^\circ$) PNdB | | | | Max. Aft Angle ($120^\circ$) PNdB | | | |
|---|---|---|---|---|---|---|---|---|
| | Fan | Turbine | Combustor | Jet/Flap | Fan | Turbine | Combustor | Jet/Flap |
| Single Engine - Unsuppressed 61 m (200 ft.) Sideline | 110.3 | 87.5 | 85.5 | 95.3 | 106.1 | 96.0 | 96.0 | 90.7 |
| Total Corrections - Appendix I Procedure | -10.1 | -7.1 | -3.3 | -5.5 | -7.6 | -9.2 | -5.4 | -8.0 |
| Corrected Level - 152.4 m (500 ft.) Sideline at 61 m (200 ft.) Altitude | 100.2 | 80.4 | 82.2 | 89.8 | 98.5 | 86.8 | 90.6 | 82.7 |
| Suppression | 6.3 | 9.8 | 5.1 | - | 13.4 | 9.8 | 5.1 | - |
| Suppressed System | 93.9 | 70.6 | 77.1 | 89.8 | 85.1 | 77.0 | 85.5 | 82.7 |
| Sum Constituents | 96.0 | | | | 90.3 | | | |
| PNdB to EPNdB | 93.3 EPNdB | | | | | | | |

- Approach Power (65% Fwd. Thrust at A/C Speed)
- Takeoff Fan Speed
- $+5^\circ$ Blade Angle, A18 = 2.129 $m^2$ (3300 $in^2$)

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Table IX. Boilerplate Nacelle Predicted Reverse Thrust Noise.

| | Max. Forward Angle ($60^\circ$) PNdB | | | | Max Aft Angle ($120^\circ$) PNdB | | | |
|---|---|---|---|---|---|---|---|---|
| | Fan | Turbine | Combustor | Jet/Flap | Fan | Turbine | Combustor | Jet/Flap |
| Single Engine - Unsuppressed 61 m. (200 ft.) Sideline | 117.5 | 94.0 | 93.5 | 86.6 | 107.3 | 100.0 | 99.5 | 85.5 |
| Total Corrections - Appendix I Procedure | -9.1 | -10.5 | -7.3 | -7.1 | -8.7 | -10.7 | -7.3 | -7.1 |
| Corrected Level - (152.4 m. (500 ft.) Sideline Static) | 108.4 | 83.5 | 86.2 | 79.5 | 98.6 | 89.3 | 92.2 | 78.4 |
| Suppression | 4.5 | 9.8 | 5.1 | - | 9.3 | 9.8 | 5.1 | - |
| Suppressed System | 103.9 | 73.7 | 81.1 | 79.5 | 89.3 | 79.5 | 87.1 | 78.4 |
| Sum Constituents | | 103.9 | | | | 92.5 | | |

- Reverse Thrust
- 86% Corrected Fan Speed
- $-100^\circ$ Blade Angle

## SECTION VI

## COMPOSITE NACELLE DESIGN

Original planning called for the evaluation of UTW boilerplate nacelle acoustic test results prior to releasing the acoustic design for the composite nacelle. This procedure would have allowed the treatment to be tuned to the real or as measured unsuppressed spectra. However, an engine failure resulting from ingestion of a nozzle flap during reverse thrust testing negated this plan. Some limited acoustic data had been taken during the mechanical checkout testing prior to the failure. These data were obtained at uncontrolled ambient conditions (winds, humidity) and, more importantly, with aerodynamic instrumentation rakes and a large instrumentation strut located in the engine flowpath. The data were reviewed and compared to predicted levels to determine if there were any indications that the treatment design selected for the UTW boilerplate nacelle would not be adequate. This analysis did not reveal any basis for changing the design: thus, it was decided to use the boilerplate nacelle treatment design with the composite nacelle. The composite nacelle test program was also modified to provide testing that would allow an evaluation to be made of the individual treatment designs, fan inlet, fan exhaust, and core.

## SECTION VII

## CONCLUDING REMARKS

In the foregoing sections an acoustic design has been defined for the QCSEE UTW engine. The design is intended to enable a four-engine STOL aircraft to meet a takeoff and approach noise goal of 95 EPNdB and a reverse thrust goal of 100 PNdB maximum, all measured on a 152.4 m (500 ft) sideline.

The QCSEE UTW acoustic design incorporates fan source noise reduction features such as low fan tip speed, low fan pressure ratio, high bypass ratio, large rotor to outlet guide vane (OGV) spacing, a selected vane/blade ratio, acoustic wall treatment between the rotor and OGV's, and acoustically treated stator vanes.

Fan inlet noise suppression is provided by a near-sonic (0.79 throat Mach number) inlet with multiple-thickness acoustically treated walls. Fan exhaust suppression is obtained by multiple-thickness treated exhaust walls and a one-meter (40 inch) acoustically treated splitter. Core noise suppression is provided by using a "stacked treatment" concept in which thick, low-frequency combustor noise treatment is located under and integral with thin high-frequency turbine noise treatment panels.

The UTW acoustic design and the predicted noise levels and suppression estimates were based on various engine and scale-model tests, and a number of laboratory flow duct tests, many of which were performed as part of the QCSEE program.

The original treatment development plan provided for UTW engine acoustic tests of an initial boilerplate (BP) nacelle treatment design and a retuning of selected treatment elements to compensate for differences between actual engine noise and predicted engine noise characteristics and to better match treatment design to engine suppression requirements. After application of the same procedure to the modified BP nacelle treatment, a final acoustic design would be determined for a composite flight type nacelle for final evaluation of engine acoustic performance. However, the failure of the UTW engine exhaust nozzle flap prior to acoustic testing with consequent schedule and funding difficulties forced abolition of the plan. Hence, the BP nacelle and the composite nacelle acoustic treatment designs are the original design without benefit of the treatment development engine tests.

The predicted takeoff and approach noise levels of 93.6 and 93.3 EPNdB, respectively, are well below the 95 EPNdB noise goal, The 103.9 PNdB predicted maximum noise level at reverse thrust exceeds the 100 PNdB noise goal, however, only a reduction of the reversed fan discharge velocity by reducing the fan pressure ratio is likely to effect a sizable reduction in reverse thrust noise, if engine tests corroborate the predicted noise level. The actual engine acoustic performance will be determined by ground static demonstration tests of the fully suppressed engine.

## SECTION VIII

## REFERENCES


1. Anon, "Quiet Clean Short-Haul Experimental Engine (QCSEE) - Preliminary Analyses and Design Report," Vols. I and II, NASA CR's 134838 and 134839, December 1974.

2. Mani, R., "Discrete Frequency Noise Generation from an Axial Flow Fan Blade Row," ASME Paper 69-GE-12, presented at Applied Mechanics and Fluids Engrg. Conference, June 16-18, 1969.

3. Stimpert, D.L., and McFalls, R.A., "Demonstration of Short-Haul Aircraft Aft Noise Reduction Techniques on a Twenty Inch (50.8 cm) Diameter Fan," 3 Vols., NASA CR's 134849, 134850, and 134851, April 1975.

4. Stimpert, D.L., and Clemons, A., "Acoustic Analysis of Aft Noise Reduction Techniques Measured on a Subsonic Tip Speed 50.8 cm (Twenty Inch) Diameter Fan," NASA CR-134891, January 1977.

5. Bilwakesh, K.R., Clemons, A., and Stimpert, D.L., "Acoustic Tests on a Twenty Inch (50.8 cm) Diameter Scale Model (1:3.5) Fan and Inlet for the Under-the-Wing Engine, Volume I," NASA CR-135117, Febuary 1978.

6. Sowers, H.D., and Coward, W.E., Quiet Clean Short Haul Experimental Engine (QCSEE) Core Engine Noise Measurements," NASA CR-135160, December 1977.

7. Kazin, S.B., Matta, R.K., et.al., "Core Engine Noise Control Program - Volume III Prediction Methods," U.S. DOT, FAA-RD-74-125, August 1974.

8. Clark, B.J., and Dorsch, R.G., "Flap Noise Prediction Method for a Power Lift System," AIAA Paper 73-1028, October 14, 1973.

9. Clemons, A., "Quiet Clean Short-Haul Experimental Engine (QCSEE) Acoustic Treatment Development and Design," NASA CR-135266, March 1978.