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TWO-STAGE, LOW NOISE ADVANCED TECHNOLOGY FAN

V. ACOUSTIC FINAL REPORT

by

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16. Abstract
The NASA Q2S (quiet two-stage) fan is a 0.836m [32.9 in.] diameter model of the STF 433 engine fan, selected in a 1972 study for an Advanced Technology Transport (ATT) airplane. Noise-control features include: low tip speed, moderate stage pressure rise, large blade-vane spacings, no inlet guide vanes, and optimum blade and vane numbers. Tests were run on the baseline Q2S fan with standard inlet and discharge ducts. Further tests were made of a translating centerbody sonic inlet device and treated discharge ducts. Results were scaled to JT8D and JT3D engine fan sizes for comparison with current two-stage fans, and were also scaled to STF 433 fan size to compare calculated ATT flyover noise with FAR 36 limits.

Baseline Q2S results scaled to JT8D and JT3D engine fan sizes showed substantial noise reductions. Calculated unsuppressed baseline ATT flyovers averaged about 2.5 EPNdB below FAR 36 limits. Using measured sonic inlet results, scaled baseline Q2S fan results, and calculated attenuations for a 1975 technology duct liner, projected flyover noise calculations for the ATT averaged about FAR 36 limits minus 10 EPNdB. Advances in suppression technology required to meet the 1985 goal of FAR 36 limits minus 20 EPNdB are discussed.

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FOREWORD

The work described herein was conducted by the Pratt & Whitney Aircraft Division of United Technologies Corporation for the National Aeronautics and Space Administration, Lewis Research Center, under NASA Contract NAS3-16811. The program was completed under the management of NASA Project Managers Messrs.L. J. Herrig and W. L. Beede, Fluid System Components Division and Mr. W. A. Benser, Assistant Branch Chief. Acoustics technical management was supplied by Mr. M. F. Heidmann. The Pratt & Whitney Aircraft Program Manager was Mr. H. V. Marman and the Assistant Program Manager was Mr. P. A. Odegard. Acoustics Program direction was provided by Mr. T. G. Sofrin.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF TABLES

LIST OF TABLES (Cont'd)

SUMMARY

An experimental program has been conducted to determine the aerodynamic and acoustic characteristics of a 0.836 meter [32.9 inch] diameter two-stage fan. Designated as the NASA Quiet Two-Stage (Q2S) Fan, this design was an outgrowth of an earlier NASA-sponsored study to define an optimum powerplant for long range advanced technology transport (ATT) aircraft with a cruise Mach number between 0.85 and 0.9. The resulting engine, called STF 433, had a bypass ratio of 6.5 and employed a two-stage fan with an overall pressure ratio of about 1.9 and a design tip speed of 365.8 m/sec [1200 ft/sec]. In this study, it was predicted that the basic unsuppressed engine installation noise characteristics would meet FAR Part 36 limits. A noise level of 20 EPNdB below FAR 36 limits was predicted with advanced technology inlet and discharge duct acoustic suppression and use of special aircraft noise-abatement flight operations. A major objective of the program reported here was to verify predicted low noise levels for a two-stage fan design using acoustic design techniques developed for single stage fans.

The baseline 0.836 meter [32.9 inch] diameter Q2S fan tested under this program was geometrically similar to the STF 433 engine fan design. It incorporated a unique combination of several noise-control design features. These included: selection of a low tip speed and moderate stage pressure rise, large blade-vane axial spacings, and absence of inlet guide vanes. Numbers of blades and vanes were selected to provide cutoff of fundamental rotor blade frequencies. The baseline configuration incorporated acoustical treatment in the interstage cases. This treatment consisted of perforated facings and honeycomb backing spaces. For acoustic tests, the baseline configuration was equipped with a standard hardwall flight type inlet plus bellmouth, and hardwall fan discharge ducts.

A suppressed configuration was designed to minimize perceived noise of the Q2S test fan. Inlet-radiated noise suppression was provided by a translating centerbody sonic inlet device that contained some acoustic treatment. The suppression of aft-radiated noise was provided by means of an extensively treated fan discharge duct incorporating a treated circumferential splitter. This report concerns the acoustic program and also contains a brief survey of the aerodynamic performance characteristics for reference. A companion report deals with the aerodynamic program in detail.

Results of the Q2S fan acoustic tests were scaled to represent several full-scale engine fan sizes. This procedure makes it convenient to compare the acoustic characteristics of the Q2S fan design with FAR 36 limits for the ATT aircraft, and with current engine fans.

Calculations of flyover noise levels were made for an advanced technology transport (ATT) aircraft using three unsuppressed engines designated STF 433. These engines used Q2S fans scaled to a tip diameter of 1.82 meters [71.6 inches]. With hardwall baseline inlet and fan exit ducts, the calculated sideline noise for this aircraft was 5.5 EPNdB below FAR 36 limits; approach noise was 0.3 EPNdB above FAR 36 limits; cutback was 3.0 EPNdB below limits and takeoff was 1.7 EPNdB below limits. These results confirm the prediction that FAR 36 limits would be met with the baseline STF 433 fan.

Flyover noise was also calculated for the ATT aircraft using engines equipped with sonic inlets and fan exit duct treatment. Because the Q2S exit duct treatments were designed to minimize perceived noise in rig scale and also because the measured performance deviated significantly from current experience, predicted aft noise attenuations were used for these flyover studies. The results of these calculations showed the fully suppressed ATT aircraft sideline noise to be 12 EPNdB below FAR 36 limits. Approach, cutback, and takeoff were 8.2, 9.2, and 8.3 EPNdB below limits respectively.

It was estimated that an additional 3.5 EPNdB reduction in noise could be achieved at approach thrust conditions if an improved sonic inlet could be designed to provide choking without separation at lower fan speeds. Achievement of 1985 goals of FAR 36 minus 20 EPNdB with advanced noise abatement flight operations will require improvement in exit duct noise suppression technology.

The sonic inlet tested on the Q2S fan effectively suppressed fan inlet noise when operating at choked flow with the centerbody in either the approach or takeoff positions. Adverse effects of the sonic inlet on fan efficiency and stall margin were small, and stable fan operation and speed control were achieved even at speeds 150 rpm above that required for full choking. At common fan speeds use of the sonic inlet had no measurable effect on aft radiated noise. However, in the approach position, higher than normal fan speed was required to choke the inlet, and this speed increase expectedly increased aft fan noise. A redesigned sonic inlet providing choking without separation at normal approach speed would presumably correct this characteristic.

Measured suppression characteristics of the aft duct lining designed to reduce perceived noise of the Q2S test fan did not meet requirements. Peak attenuations were less than calculated, the frequency where peak attenuation occurred was too high, and the bandwidth of absorption was narrower than expected. No explanation was found for these deviations from predicted performance, which was based on previous duct liner experience.

Static noise comparisons of the basic Q2S fan were made with the two-stage hardwall JT8D and JT3D fans. Acoustic data of the baseline Q2S fan (no inlet or discharge duct treatment) were scaled to a fan diameter the same as that for JT8D two-stage fan. Comparison of tone corrected noise levels at common fan thrust showed the Q2S fan to be 8.5 EPNdB quieter than the JT8D at approach conditions and 9.5 PNdB quieter at takeoff. A similar comparison for equivalent fan sizes showed the Q2S fan to be quieter than the JT3D two-stage fan by 9.5 PNdB at approach and 13.5 PNdB at common takeoff thrusts.

The results of this program confirmed the predicted potential of the basic Q2S fan design concept. Normal development efforts can reasonably be expected to produce further source noise reductions. Of the two suppression devices tested, the sonic inlet effectively blocked inlet noise and its effectiveness could be improved by design modifications to allow choking at lower fan speeds. Aft noise suppression, provided by sound absorbing discharge duct treatment, was not satisfactory for unresolved reasons. Furthermore, ATT flyover noise calculations using values of duct suppression consistent with current experience, indicate the need for significantly improving duct lining technology to meet FAR 36 minus 20 EPNdB noise goals.

INTRODUCTION

An earlier study conducted by Pratt & Whitney Aircraft in 1972 for the NASA-Lewis Research Center (ref. 1) had defined the optimum propulsion system characteristics for a long range, advanced technology transport (ATT) aircraft with a cruise Mach number between 0.85 and 0.9. The optimum basic engine (STF 433), projected for use in 1985, had a bypass ratio of 6.5 and employed a 1.82 meter [71.65 in.] diameter two-stage fan with an overall pressure ratio of about 1.9 and a design tip speed of 365.8 m/sec [1200 ft/sec].

This two-stage fan incorporated a novel combination of design features specifically for minimizing fan noise. These features included: moderate pressure rise per stage, moderate tip speed, large blade-vane axial spacing, selection of optimum numbers of blades and vanes, and the absence of inlet guide vanes. The STF 433 engine which incorporated this fan was predicted to meet FAR Part 36 noise regulations without the need for additional noise-reduction features. It was further predicted that by employing 1985 technology sound-absorbing liners in the ATT aircraft installation, noise levels of FAR 36 minus 15 EPNdB could be achieved and that these levels could be further reduced to FAR 36 minus 20 EPNdB by employing special noise-abatement flight maneuvers.

Under NASA-Lewis Contract NAS3-16811, P&WA designed, fabricated, and tested the 0.836 meter [32.9 inch] diameter, scale-model Q2S (quiet two-stage) fan. The general objective of the program was to develop and demonstrate the aerodynamic and acoustic performance characteristics required to meet these stringent goals.

The basic fan, in addition to incorporating all the noise reduction features specified above, was designed to permit the stator vane angles to be reset on the test stand. Provisions were also made to allow blade-vane spacing changes; however, this feature was not utilized. The interstage casing surfaces of the fan employed perforated facing (i.e., honeycomb backing sound-absorbing liners) for additional suppression. In addition to the baseline fan, inlet and aft noise reduction devices were designed and evaluated. For suppression of inlet-radiated noise, a translating centerbody sonic inlet device was provided. For suppression of fan discharge noise, a treated discharge duct, including a circumferential splitter, was fabricated. Details of the aerodynamic, acoustic, and structural design of this fan are given in reference 2.

Aerodynamic and acoustic tests were conducted on a special outdoor fan test rig. Four test configurations were evaluated during the acoustic portion of the program. This report presents the essential acoustic results of the baseline Q2S fan, and compares scaled versions of this design with two current two-stage engine fans and with the original predictions for the STF 433 engine fan. The inlet and discharge duct suppression devices are evaluated, and noise projections are made for a suppressed STF 433 fan installation incorporating these devices. For convenience, a summary of the aerodynamic results has also been included. A full account of the fan aerodynamic performance is available in the aerodynamic final report (ref. 3), and detailed acoustic data is presented in the acoustic data report (ref. 4).

APPARATUS AND PROCEDURE

FAN AERODYNAMIC DESIGN

The design of the Q2S fan (Figure 1) was influenced by both acoustic and aerodynamic considerations. Features to reduce noise included low tip speeds, moderate blade loadings, proper relationships between numbers of blades and vanes, and axial spacings of two aerodynamic chord lengths between blade rows. Because of the low tip speeds and moderate loadings, two stages were required to provide the desired pressure ratio. A summary of the general design parameters is provided in Table I.

TABLE I – GENERAL DESIGN PARAMETERS

Corrected Speed $N/\sqrt{\theta}$	= 8367 rpm
Corrected Flow $W\sqrt{\theta}/\delta$	= 96.39 kg/sec [212.5 lbm/sec]
Specific Flow $W\sqrt{\theta}/\delta/A$	= 209.2 kg/sec m^2 [42.85 lbm/sec ft^2]
Tip Diameter	= 0.836 meters [32.90 inches]
Hub-Tip Ratio	= 0.4
Tip Speed	= 365.8 m/sec [1200 ft/sec]

	Pressure Ratio		Adiabatic Efficiency (%)	
	Local	Cumulative	Local	Cumulative
Rotor 1	1.485	1.485	89.5	89.5
Stator 1	0.984	1.461	–	85.6
Rotor 2	1.317	1.924	90.9	87.3
Stator 2	0.987	1.898		85.3

The fan was designed with a constant tip diameter to allow the entire flowpath convergence to be taken on the hub, thus preventing excessive hub loadings and reducing the large past-axial turnings inherent in a low speed, low hub-tip ratio rotor. The 1st stage rotor was designed to turn the flow approximately 30 degrees past-axial at the hub, and the 2nd stage rotor was designed for no past-axial turning. The fan exit flow (2nd stage stator exit) was axial and had an exit design Mach number of about 0.45. Design velocity vectors, overall performance parameters, and additional details are provided in the design report (ref. 2).

A summary of rotor and stator blading parameters is given in Table II. Because of the larger number of vanes relative to blades, the aspect ratios and solidities of the stators are higher than those for the rotors. Hub chord lengths were determined primarily by mechanical considerations, and tip chords were determined by the desired solidity levels. Airfoil series were selected for low loss at design Mach numbers.

TABLE II – BLADE AND VANE GEOMETRY PARAMETERS

	Rotor 1	Stator 1	Rotor 2	Stator 2
Number of Airfoils	28	62	35	76
Airfoil Series	MCA	MCA	MCA	65/CA
Aspect Ratio[1]	2.75	5.03	2.54	3.89
Aspect Ratio[2]	2.19	3.81	2.21	3.73
Taper Ratio[3]	1.232	1.099	1.028	0.9709
Hub Chord - meter[inch]	0.087 [3.530]	0.0513 [2.020]	0.859 [3.3820]	0.0489 [1.930]
Tip Chord-meter [inch]	0.1105 [4.350]	0.0564 [2.220]	0.883 [3.476]	0.0475 [1.870]
Tip Solidity	1.18	1.33	1.18	1.38
Hub Solidity	2.28	2.50	2.14	2.46

1) Average length/axially projected hub chord
2) Average length/chord at tip
3) Tip chord/hub chord

ACOUSTIC DESIGN

The basic design of the Q2S fan included a unique combination of proven noise-control features. A two-stage fan was selected to permit use of a moderate tip speed and a moderate rise in stage pressure. The fan was designed without inlet guide vanes to eliminate the interaction of rotor blades with inlet-guide-vane wakes, a noise source. The numbers of rotor blades and stator vanes in each stage were selected to provide "cut-off" of rotor-stator interaction noise at the fundamental blade-passage frequencies. To further minimize noise, axial spacings of two aerodynamic chords were used between rotor and stator stages.

Acoustic theory specifies that for subsonic rotor tip speeds if the number of stator vanes, s, is greater than twice the number of rotor blades, r, interaction noise at blade-passing frequency will decay within the fan cases and inlet and exit ducts. The number of airfoils in each rotor and stator are given in Table II. The numbers listed satisfy the relation s = 2r + 6 for adjacent blade row combinations except for the 1st-stage-stator/2nd-stage-rotor which, because of mechanical and aerodynamic constraints limiting the number of 1st-stage stator vanes, satisfies the relation s = 2R - 8. As a further refinement, the ratio of blades in the two rotor stages was selected so that harmonics of blade-passage frequencies would not produce dissonant chord combinations.

Even with incorporation of these noise-control features, additional inlet and fan discharge duct suppression was required to approach the stringent FAR 36 - 20 EPNdB noise goal. A description of the design features of these suppression devices follows.

FAN INLET DESIGN

Two inlet configurations were designed for this program: a standard inlet (the baseline configuration) and a sonic inlet with an axial translating centerbody for acoustic suppression. Details of both inlets are given in the design report (ref. 2).

Standard Inlet

The standard inlet was designed to provide a one-dimensional throat Mach number of 0.68 at the cruise operating condition. The inlet length to fan tip diameter ratio was 1.03, and the overall contraction ratio ($A_{highlight}/A_{throat}$) was 1.65. The highlight is defined as the most forward point on the inlet cowling, and is shown in Figure 2.

Sonic Inlet

The sonic inlet provided a means of controlling area to achieve throat Mach numbers that would provide significant noise suppression over a range of fan operating conditions. Selection and design of the sonic inlet was based on considerations of aerodynamic, structural, and fan performance compatibility. The only acoustic design requirement was that flow distrurbances produced by the sonic inlet construction be minimized so that aft-radiated noise resulting from fan-inflow disturbance interactions would be as low as possible. A translating centerbody was selected as the most practical compromise among acoustic, aerodynamic, and mechanical design criteria. The centerbody could be located in three axial positions representing the ATT engine (STF 433 engine, ref. 1) conditions of cruise (design), takeoff, and approach with the latter two positions having capability of providing sonic inlet Mach numbers.

The sonic inlet was designed to avoid excessive boundary layer growth and flow separation. Since the fan aerodynamic design was essentially complete when the sonic inlet aerodynamic design was initiated, the inlet design had to be compromised to retain the fan root flow angle associated with the conventional spinner. This resulted in an overall inlet length of about 1.2 meters [47.5 in.] for an inlet length to fan tip diameter ratio (L/D) of approximately 1.45. This is somewhat larger than 1.0 which is the maximum ratio judged practical for flight application. An L/D ratio of 1.0 would have been possible had it not been necessary to diffuse the inlet flow to a rather high area to retain the fan root platform contour. To minimize the sonic inlet L/D for this design, the inlet nozzle was designed to choke at 80 percent of design corrected flow. This corresponded to an approach corrected fan speed of 75 percent of design. Attainment of approach thrust at this high flow required a variable duct nozzle. Approach thrust with a fixed nozzle would have been obtained at 63 percent of corrected fan design speed. For evaluation of acoustic performance of the subject fan, 63 percent corrected fan speed was defined as standard approach fan speed. Since the sonic inlet was to be tested at static conditions only, an attempt was made to reproduce the accelerations on the inlet surface which would be encountered at aircraft approach flight conditions. This was done by generating a 2.5:1 elliptical shape from the throat to approximately the inlet highlight station and blending this contour to a circular arc by making them tangent, and continuing the circular arc to complete the inlet contour. The overall contraction ratio ($A_{highlight}/A_{throat}$) of this configuration was equal to 1.45. The sonic inlet in the approach, takeoff, and cruise configurations is shown in Figure 2. Positioning of the centerbody was accomplished by means of axial spacers.

An inlet operating with a completely choked throat does not transmit sound upstream. In a rig or engine, the sound attenuation increases as throat Mach number increases toward 1.0. At full choke the amount of attenuation that can be measured is not a function of design, but depends on flanking paths and background noise levels. Because inlet pressure loss and fan performance degradation increase as the inlet approaches a fully choked condition, it may be desirable to operate the inlet at a throat Mach number less than 1.0. Therefore, a limited amount of acoustic treatment was incorporated in the sonic inlet design for the purpose of providing additional suppression at part-choke operating conditions.

ACOUSTIC TREATMENT DESIGN

Sound-absorbing treatment devices were incorporated in the sonic inlet, the fan interstage cases, and in the suppressed version of the fan discharge ducts. Treatments were designed to provide maximum annoyance (PNLT) suppression in the 0.836 meter [32.9 in.] diameter fan rig rather than to be a model of a full size engine fan treatment. Details of the acoustic treatment designs are given in reference 2.

Treatment selection procedures required estimates of the source noise spectra. For this purpose one-third octave band spectra for an existing two-stage fan engine, the JT3D, were used as a starting point. At a fan rig tip speed corresponding to a desired operating condition (e.g., approach), JT3D data were selected and scaled up in frequency by the ratio of engine-to-rig diameters. The resulting spectra were corrected in level for changes in size, blade-vane spacing, and pressure ratio, as described in detail in reference 2. The dominant annoyance frequency range was next determined by transforming the estimated source noise spectra into subjective "Noy" values. By truncating these spectra to various Noy levels and integrating, target attenuation spectra were obtained corresponding to levels of PNdB suppression. Finally from extensive design information available, treatment parameters were selected to provide the required suppression.

Sonic Inlet Acoustic Treatment

A limited amount of treatment was applied to the walls of the sonic inlet to provide improved attenuation of forward-radiated noise during operation with the sonic inlet not at full choke. The inlet treatment was designed to be mainly effective in absorbing the upstream traveling waves (i.e., treatment was tuned to attenuate waves propagating forward from within the fan). Treatment was restricted to axial locations where the calculated wall Mach numbers did not exceed 0.7 at any of the operating points. Flow separation from the wall could have occurred because of surface roughness in a region of flow diffusion if the treatment had been extended to regions of higher Mach number. With the translating centerbody in the forward (i.e., approach) position, the lengths of treatment exposed were approximately 0.482 meters [19 in.] on the inner wall and 0.599 meters [22 in.] on the outer wall to provide a treatment length to passage height ratio of about 1.6. Retraction of the centerbody covered the treatment on the inner wall and reduced the ratio by about one-half. Backing depth was 0.00635 meters [0.25 in.] and design facing sheet percent open area was six percent both for the inner and outer wall treatments. These values were chosen to tune the inlet treatment to the center of the inlet attenuation target spectrum.

Interstage and Exit Duct Acoustic Treatment

The interstage region treatment was selected to attenuate the lowest blade-passing-frequency (28E) at approach. The exit duct treatments, including treatment on the inner and outer walls and on both sides of the single splitter, were tuned for the center of the target, about 3200 Hz. On the basis of empirical data, including curves of tuning versus backing depth and PNL reduction versus treatment-length-to-duct-height ratio, this single-splitter design was found to be superior to no splitter and two-splitter designs. By selecting deeper backing depths for the duct wall treatment and shallower depths for the splitter, a relatively thin 0.016 meters [0.62 in.] splitter was possible and a minimum blockage achievable. At the same time, the attenuation spectrum, compared to a spectrum for the splitter and wall treatment tuned to the same frequency, could be broadened to cover the attenuation target. The facing sheet values were chosen for an optimum combination of bandwidth and peak attenuation rather than for peak attenuation alone.

Preliminary estimates of required treatment area were made by reference to guideline curves of PNdB reduction as a function of treatment-length-to-passage-height ratio (L/H). For the exit duct, the axial length of about 1.016 meters [40 in.] available for treatment and a passage height of 0.178 meters [7 in.] would result in an L/H ratio of about 12 with one splitter. The cross-sectional blockage of the splitter reduced the passage height and this was taken into account. Tuning curves that relate treatment backing depth to frequency of peak attenuation were used for initial selection of backing depths. A succession of iterations was then performed in which attenuation spectra were calculated by means of an analytical solution of the wave equation for the principal mode in the duct for incremented values of backing depths and facing sheet resistances until an optimum coverage of the attenuation target was found. A summary of the acoustic treatment design parameters is given in Figure 3.

TEST FACILITY

The Q2S fan was tested on a special outdoor noise facility, X-308 stand. The aerodynamic and acoustic tests were performed separately. For the aerodynamic tests an inlet plenum chamber was employed. The acoustic testing was conducted without the inlet plenum and with all aerodynamic probes removed or retracted.

The Q2S fan was driven by a free-turbine through a 3 to 5 step-up gear. Hot gas for the drive turbine was supplied by a JT3C6 gas generator. Since the gas generator supplied more hot gas than the free-turbine could accept, the excess was dumped overboard through a silencer. The gas generator was housed in an acoustically treated enclosure with an inlet silencer; acoustically treated walls were provided between the drive system ducts and the fan noise measurement microphone array to minimize drive system noise contamination of the fan noise data.

The X-308 test stand is located in a remote, wooded site at Bradley International Airport. This site was chosen for its low ambient noise level and to avoid community noise problems. Figure 4 shows aerial views of the site from four points of the compass.

The noise field between the fan noise rig and the farfield acoustic measuring stations was covered with carefully graded crushed stone. The crushed stone surface provided a surface with low, repeatable reflectivity. It also provides good drainage to keep puddles from rain or melted snow from changing the reflectivity of the surface.

The gas generator and rig controls were all automatic. The rig speed, once set by the rig operator, was maintained within ±10 rpm by the electronic control on the gas generator with feedback from the free-turbine speed pickup. All critical gas generator and rig functions were monitored automatically. If critical limits were exceeded, the rig was shut down.

A pressure differential type surge detection system was provided for the rig. This system was coupled to the rig variable-area nozzle and opened the nozzle in the advent of a rig stall.

The rig nozzle was controlled by the rig operator. This allowed complete mapping of the fan speed lines and taking data along fixed nozzle area operating lines.

The facility incorporated several systems of ducts and faired wall sections to provide smooth fan discharge stream flow on the side of the rig facing the microphone array. Another essential function of these wall sections was to shield the microphones from drive system aerodynamic and internal noise.

The test facility is diagrammed in detail in Figure 5a which shows some of the above-mentioned wall configurations. For tests to evaluate the potential of the Q2S fan sonic inlet suppression device, the facility was equipped with a special aft acoustic wall which shielded the forward farfield microphones from fan discharge noise. This removable facility acoustic shield is shown in Figure 5b.

Three views of the normal Q2S fan installation in X-308 stand are presented in Figure 6. Figure 7 shows the facility converted for the special sonic inlet tests by the addition of the aft acoustic shield. This shield was mounted on a wheeled structure to expedite emplacement and removal. The structure also mounted an overhang to deflect facility noise behind the normal wall system. Additional sealing barriers were installed, as shown, to secure the best possible shielding of the forward microphones from all noise sources except the test fan inlet. Aft noise measurements had no significance in this special test arrangement.

ACOUSTIC INSTRUMENTATION

Farfield Microphones

Fan farfield noise measurements were made using B&K model 4134, 0.013 meter [0.5 in.] diameter microphones mounted on Altec Model 165A cathode follower bases. Power was supplied to each unit from a P&WA microphone power supply that provided polarizing voltage and heater current. These microphones were mounted on poles on a 45.7 meter [150 ft.] radius as shown on Figure 8. The array of microphones covered a 170 degree arc starting at the forward rig centerline, as shown in Figure 9. The microphones were mounted at a height of 7 meters [23 ft.]. This microphone height in conjunction with the rig centerline height of 3 meters [10 ft.] gave a "ground dip" frequency of approximately 200 Hz which was below the range of interest. The microphones were oriented on the ends of the poles so as to receive radiated noise at approximately grazing incidence and to minimize ground reflections at frequencies above 400 Hz. The microphone system provided relatively flat frequency response characteristics from 20 Hz to 20 kHz with a dynamic range in excess of 100 dB based on the upper useful limit of the microphones of 160 dB.

Nearfield Microphone

For tests with the sonic inlet, a microphone was positioned at rig centerline height at a distance of approximately 4.5 meters [15 ft.] from the inlet and at an angle of 45 degrees from the inlet centerline, as shown in Figure 9. This microphone was used to indicate when full choke of the inlet had been reached and to provide additional data on performance of the sonic inlet.

Inlet and Fan Duct Flush-Mounted Microphones

In addition to the far field noise measurements, rig internal noise measurements were obtained in the inlet and fan discharge ducts. These measurements were made with flush-mounted, Kulite model XCQL-25S, high-response pressure transducers which were excited by P&WA signal amplifiers. Each transducer provided a useable sound pressure level range of from 110 dB to 199 dB with a resonance frequency in excess of 125 kHz, which was greater than five times the highest frequency of interest.

Sound Recording System

The sound recording system was composed of: 1) microphones and high response transducers and their complements, 2) underground cables connecting the microphones to the recording console, and 3) the recording console which was located in the control room and contained power supplies, signal conditioners, calibration equipment, a narrow-band plotter, a 14-channel analog magnetic tape recorder, switching facilities, and on-line data reduction equipment, Figures 10 and 11 show the functional layout. System response calibration signals were provided by means of a local oscillator and random noise generator. Gain settings were established on each channel at the preamplifier and were used to obtain optimum signal-to-noise recordings. The gain settings were noted on the recorder log sheets and announced on the tape voice channel. Microphones from the farfield array were recorded simultaneously in groups of ten.

Instrumentation Calibration

The microphones were calibrated in the laboratory on the system shown in Figure 12. A variable frequency, electrostatic actuator was used to obtain the microphone open-circuit sensitivity and frequency response. The calibration data were processed by a computer program which provided a printout of one-third octave band corrections.

For field calibrations of the microphones, a B&K Type 4220 Pistonphone was used. Immediately prior to and after each series of fan test recordings, an acoustic calibration was performed by applying the B&K Pistonphone to each microphone, providing a known sinusoidal sound-pressure-level to the diaphragm for establishing an acoustic reference level. This Pistonphone had been calibrated in the laboratory by applying its output to a WE640AA reference microphone which bore a current calibration certificate from the National Bureau of Standards.

In addition, broadband random electronic signals were inserted into each channel of each magnetic tape used during testing at the point of microphone extension cable output to determine system frequency response for each data channel. The frequency response of the installed cathode followers and microphone extension cables from the farfield array to the recording console was obtained prior to the start of the program by a point to point sine wave insertion covering the range of measurement (45 Hz to 22 kHz.)

Results of the above calibrations were incorporated into the data reduction sequence to provide correction factors which were applied to the data such that the results represent the sound pressure level existing at the point before the introduction of the microphone. By virtue of these calibrations, the accuracy of the resultant data was determined to be within the ±1.0 dB tolerance specified in International Electrochemical Commission (IEC) Publication 179.

TEST PROCEDURE

After completion of shakedown and aerodynamic performance runs all instrumentation probes were removed or retracted from the flow passages to eliminate these possible sources of irrelevant noise. Farfield and flush-mounted internal microphone data were recorded in separate runs because of recording channel capacity limitations. Atmospheric conditions were monitored continuously during the acoustic tests. No tests were made if wind velocity was over 14.5 kilometers per hour [9 miles per hour], if there was ice or snow on the ground around the test site, or if it was raining or snowing.

The fan discharge duct terminated in a remotely controllable, variable area nozzle (shown in Figure 1). By setting the area to control room gage indication, speed runs were made corresponding to wide-open nozzle area, a low operating line setting, and a nominal higher pressure operating line nozzle setting. A range from 40 percent to 100 percent of design speed was covered on the wide-open line; ranges from approach to cruise speed were run on the other operating lines. Selected fan operating nozzle points were set by adjusting fan duct exit nozzle area and fan rotative speeds.

After setting a new point, acoustic data were taken only when rig performance had stabilized. Recordings were made for a period of one minute. Online monitoring of waveform and spectral analysis was performed for selected microphones to obtain immediate sample acoustic characteristics. Experienced personnel listened to farfield noise at essentially every data point to form psychoacoustic impressions of the Q2S fan noise characteristics.

DATA REDUCTION

Sound Data Reduction System

A schematic of the one-third octave band analysis system is shown in Figure 10. The recorded noise was spectrally analyzed using a set of 27 one-third octave band filters having geometric mean frequencies extending from 50 Hz to 20 kHz. These filters complied with the filter characteristics recommended in IEC Publication 225. The system was set up to provide a readout of one-third octave levels for each microphone, time averaged over a minimum time period of 42 seconds for each operating condition. Following this analysis, the data were stored on a digital magnetic tape for input to the computer.

Narrowband (32 Hz bandwidth) analyses were performed on a Federal Scientific High Speed System. This system provided for wide-range, high-speed digitization of the narrowband analysis of analog data. Resultant spectra were stored and averaged in a local memory before being plotted as narrowband spectrum plots. A seven second real-time average was provided by the local memory.

Sound Data Reduction Procedure

Measured 45.7 meter [150 ft.] radius, one-third octave band levels were processed by computer and presented in either tabular form or as plotted curves. After the necessary instrumentation corrections (system frequency response, microphone and cable response, and gain adjustments) were applied, one-third octave sound-pressure-levels "as measured" at the 45.7 meter [150 ft.] radius were obtained. The computer program then applied corrections to normalize the data to 15°C [59°F] and 70 percent relative humidity using the corrections defined in FAR 36 and corrected results were printed out as illustrated in Figure 13. Extrapolation of 45.7 meter [150 ft.] radius corrected data to 61, 112.8 and 243.8 meter [200, 370, and 1000 ft.] sideline distances was then achieved by applying inverse square attenuation and 15°C [59°F], 70 percent relative humidity atmospheric attenuation. For all cases the printout sheets showed the overall sound pressure level, perceived noise level, and tone corrected perceived noise levels for each microphone. Also shown were maximum (dB at peak angle) SPL, PNL, and PNLT. Figure 14 shows a typical printout sheet of extrapolated sideline data.

Special Data Reduction Procedures

Two special procedures were applied to the reduced data: one to remove externally generated low frequency broadband noise, and the other to remove occasional spurious discrete frequency tones originating in the facility drive system components.

The removal of extraneous low-frequency noise was based on extensive full-scale engine data, comparison of previous fan data from X-308 stand, and published fan spectra for fan rigs in which the fan discharge air had a cleaner flow environment. The vertical fan discharge flow splitter in X-308 stand was used to shield the microphones from aerodynamic noises produced behind the splitter by the passage of fan and drive turbine discharge streams over necessary structural support elements. Fan jet mixing and scrubbing noise from this splitter radiated to the microphones, and noises generated behind the splitter were only partially prevented from affecting the microphone array.

Based on examination of a variety of relevant fan noise data, the low-frequency adjustment procedure (in use by P&WA for some time) was as follows: The one-third octave band containing the lowest blade-passage frequency tone (28E) was identified. For the band located two one-third octaves below this blade frequency band, the SPL was noted. Then a linear function with a slope of one dB per third octave band was passed through the noted SPL point. The resulting spectrum was consequently linear up to and including the band that was two third octave bands below blade-passage frequency, after which it followed the data. This adjustment procedure was performed automatically by computer processing for all the Q2S fan farfield data.

The second procedure used in arriving at "adjusted" spectra involved removal of occasional discrete tones not originating in the Q2S fan. "Buzz-saw" noise was not a problem because it was not present due to low fan tip speeds and because attention was restricted primarily to low percent speed points. Great care was exercised to avoid removal of certain tones that were not harmonics of either rotor blade frequency but were known to exist in multistage machines. It can be shown (ref. 5) that tones that are a linear integer combination of the harmonics of each rotor blade frequency are generated in a two-stage fan. Not all such tones are capable of propagation, and the levels of the propagating ones depend on complicated factors. To insure against the inadvertent removal of such tones, selected narrowband spectra were obtained from the recorded data at conditions and angles of primary interest. Every tone present in the spectra was then examined to determine if it could be assigned to this linear combination tone class. The criterion turned out to be simply that such tones must be integer multiples of the difference frequency of the rotor blading (multiples of 35-28=7 times shaft rotation frequency).

When an extraneous tone of significant level was found which did not satisfy the above criterion, it was noted. Then a hand calculation was made to determine the one-third octave band level correction needed to remove the energy associated with the presence of the tone in that one-third octave band. Special input correction data cards were supplied to computer runs, where needed, to arrive at adjusted spectra prior to the scaling and perceived noise computer programs.

All farfield data presented in this report have been adjusted for low frequency corrections, but removal of extraneous tones was restricted to low speed operation and configurations and microphone locations where such tones might affect peak PNLT values. These data are called "adjusted" data; however, because these data represent the Q2S fan characteristics better than "raw" data, the qualifying term "adjusted" is usually omitted. It will be seen in the section on results that the differences in tone-corrected perceived noise levels (PNLT) between adjusted and unadjusted data were generally less than one PNdB.

Power Level Calculations

Further calculations were made to determine the acoustic power radiation characteristics of the Q2S fan. For this purpose, the special reduction procedures for low-frequency and discrete tone corrections described above were not involved. Furthermore, the 45.7 meter [150 ft.] microphone data were corrected to "theoretical day" conditions, which involved using zero air attenuation instead of "standard day" air attenuation values. After the corresponding 45.7 meter [150 ft.] theoretical day levels were obtained, the computer program performed a spatial integration resulting in printout of the acoustic power levels for each frequency band and overall acoustic power levels for the forward (0 to 90 deg.), aft (90 to 180 deg.) and total spatial radial (0 to 180 deg.). Power level data are presented in the acoustic data report (ref. 4) and are not presented herein.

Data Scaling Procedure

A follow-on computer program was used to scale adjusted Q2S fan data to JT8D, JT3D, and STF 433 fan sizes and provide extrapolated PNL, PNLT, OASPL, and dB(A) data at 45.7, 61, 112.8, and 304.8 meters [150, 200, 370, and 1000 ft.] sideline distances with a printout format, as illustrated in Figure 15.

AERODYNAMIC PERFORMANCE

In addition to determining the acoustic characteristics of the Q2S fan, a major objective of the program was to evaluate fan aerodynamic performance. For this purpose special tests were run using an inlet plenum chamber equipped with a calibrated nozzle for determining airflow. Special instrumentation rakes, removed or retracted for the acoustic program, were used to measure details of internal performance. Radial-distortion tolerance tests were conducted using axisymmetric screens upstream of the fan. Performance tests were conducted on both baseline and suppressed configurations. Results of the performance program are briefly summarized here, – for a detailed report, see reference 3.

The baseline fan with the standard inlet cowling attained an efficiency of 86.4% at design speed, but surged before reaching the design pressure ratio. This premature surge was due to excessive aerodynamic loading on the hub wall between the 1st-stage rotor and stator, poor flow in the 1st-stage rotor hub region, or a combination of these factors. Above 90 percent of design speed the stall line fell below the design operating line. A 20 percent stall margin was measured at 63 percent design speed. Attempts to improve the stall margin by restaggering the 1st-stage stator open five degrees were only marginally successful. Fan pressure ratio at design speed increased from 1.87 to 1.90, but fan efficiency decreased 1.5 percentage points. Maximum corrected flow at design speed exceeded design flow. The pressure ratio-flow characteristic would have passed very near the design point if it were not for the premature stall. At design speed a 0.155 tip-radial distortion ($\Delta P/P_{max}$) resulted in a stall margin of four percent over the stall limit with uniform inlet flow, and reduced peak efficiency one percent point. At 63 percent of design speed, tip-radial distortion reduced the stall margin appreciably. The tip-radial distortion was completely attenuated by the fan, principally by the first stage.

A 0.17 hub-radial distortion ($\Delta P/P_{max}$) resulted in a negative stall margin at all speeds when compared to the stall limit for uniform inlet flow. Fan peak efficiency at design speed was reduced eight percentage points. The hub distortion was partially attenuated, principally by the second stage.

At design speed, the sonic inlet device in the cruise position penalized system efficiency from 1.5 percentage points near stall to 4.5 percentage points at open throttle. The pressure recovery of the sonic inlet device in the cruise position was 0.9819 near stall and 0.9796 at open throttle. The effects of the sonic inlet on the stall margin of the fan were small and would have been acceptable if the fan had achieved design stall margin.

Recovery of the acoustically treated exit duct with the acoustic splitter and wall treatment was 0.9655. This was approximately 1.3 percent below the recovery for the untreated duct.

ACOUSTIC RESULTS AND DISCUSSION

Acoustic measurements were obtained for the following Q25 fan configurations (see Figure 16):

Configuration A. Baseline untreated engine inlet cowling, treated interstage, and untreated exit ducts (aft splitter removed) without a facility acoustic shield.

Configuration B. Fully treated sonic inlet, treated interstage, and treated exit duct including aft splitter without a facility acoustic shield.

Configuration C. Fully treated sonic inlet, treated interstage, and treated exit duct including aft splitter with a facility acoustic shield.

Configuration D. Baseline untreated engine inlet cowling, treated interstage, and treated exit duct including aft splitter, without a facility acoustic shield. (Inlet as in A, exit ducts as in B.)

Only limited data for comparative purposes was taken for Configuration D.

Noise levels were measured for all configurations with microphones located along a 45.7 meter [150 ft] radius arc from the rig and covering the angular range from 0 to 170 degrees measured from the rig forward centerline. For tests with the sonic inlet, measurements were also taken on a near field microphone. All performance instrumentation probes were removed or retracted from the airstream during the noise tests. To facilitate accurate scaling of spectral data from the rig to predict noise for a full-scale fan configuration having a diameter of about twice rig size, acoustic data were recorded up to frequencies of 20 kHz which is twice the range required for calculation of psycho-acoustic noise characteristics in units of PNdB or EPNdB. In addition to farfield acoustic data, internal wall microphone data were obtained from selected locations in the inlet and fan discharge ducts.

The results for the baseline (A) configuration are presented in the following subsections to document its acoustic characteristics. These results are followed by the results for the sonic inlet and treated exit duct configurations to provide an evaluation of the effectiveness of the suppression devices.

In addition to the test results, comparisons are made of the Q2S fan noise levels, scaled in size, with the noise levels of current JT3D and JT8D engine fans, and the noise levels predicted for the STF 433 engine. Comparisons with FAR 36 limits are also presented.

The experimental methodology used is illustrated in Table III. In the Table III array, diagonal items refer to acoustic documentation of the four configuration and off-diagonal entries indicate where comparisons were made between applicable configurations to evaluate specific acoustic features.

TABLE III — QUIET TWO-STAGE FAN TEST PROGRAM OBJECTIVES

	CONFIGURATIONS			
	A	B	C	D
A.	Document baseline Q2S fan acoustic characteristics			
B.	Evaluate aft duct treatment with sonic inlet installed *(see below)	Determine fully-suppressed Q2S fan characteristics		
C.		Determine forward-diffracted noise from fan discharge duct	Determine acoustic potential and operating characteristics of sonic inlet	
D.	Evaluate suppression of aft duct treatment *(see above)	Check possible aft noise increase due to use of sonic inlet		Test Q2S fan with aft duct treatment only and standard inlet

QUIET TWO-STAGE FAN BASELINE RESULTS

Fundamental noise characteristics of the Q2S fan were obtained from tests on the baseline configuration, designated as configuration A (Figure 16). Points at which acoustic data were taken are shown on the performance map, Figure 17. The nominal operating line shown on Figure 17 is lower than that shown in reference 6 because of the lack of high-speed stall margin.

Selected data from this program are presented in this subsection to illustrate the acoustic characteristics of this fan. More extensive results are tabulated in the Acoustic Data Report (ref. 4).

The variations of peak inlet and aft quadrant noise with fan corrected speed are shown in Figures 18a and 18b respectively.

All peak values of tone-corrected perceived noise (PNLT) shown in Figure 18 were adjusted to correct for low frequency scrubbing noise. At low speeds where applicable, data were also corrected for spurious tone noise. These corrections were applied as discussed in the section entitled Data Reduction. As shown in Figure 18a, peak inlet quadrant noise increased almost linearly with corrected speed for speeds up to about 80 percent of design† and was essentially independent of pressure ratio at lower speeds as shown by the close agreement of data for the three separate operating lines. At high corrected speeds, the slope of the PNLT versus corrected speed curves was less than that for low speeds, and peak noise for the high operating line was up to 3 PNdB greater than that for the wide-open operating line. Peak aft noise, Figure 18b, increased almost linearly over the entire corrected speed range, and the effect of pressure ratio was very small, generally less than 2 PNdB. The peak aft noise was slightly higher than peak inlet noise and was probably more critical than the inlet noise because the sonic inlet should provide more effective noise suppression than the exit duct acoustic treatment.

Both low-frequency "rolloff" corrections and the occassional spurious tone corrections which were applied to the data of Figure 18 had relatively small effects on the resulting PNLT values. Figures 19a and 19b show, for inlet and aft angles, respectively, the variation with fan speed of the following quantities: unadjusted peak PNL, unadjusted peak PNLT, and adjusted values of PNLT. The difference between PNLT before and after adjustment, represented by squares and circles, is seen to be usually less than one PNdB. Adjusted data are used as a basis for the bulk of the information presented in this report.

The acoustic behavior of the baseline configuration of the Q2S fan is presented in more detail in Figures 20 through 26. Each of these figures is divided into parts a, b, c, and d. Parts a and b show the directivity patterns of PNLT and PNL respectively. Parts c and d give spectral information for the inlet and aft quadrants, respectively. The inlet and aft spectra shown are for the respective angles where adjusted PNLT was a maximum. All curves show both adjusted and unadjusted data. Figures 20 through 23 present the wide-open throttle line data for 40, 63, 75, and 94.5 percent of design speed. The 63 percent speed point is representative of noise at standard approach operation, and 94.5 percent is the takeoff fan corrected speed. The 75 percent speed corresponds closely to the speed required to choke the sonic inlet for approach conditions in configurations B and C.

The angles for peak PNLT and peak PNL as taken from parts a and b of Figures 20 through 23 are given in Table IV.

†Since PNLT is a psychoacoustic scale it does not transform in a simple manner as fan size is changed. Thus, in using baseline spectral data to obtain results for scaled-up versions of the fan, PNLT will not necessarily retain the linear form represented in rig size.

TABLE IV — ANGLES FOR PEAK PNLT AND PNL FOR BASELINE CONFIGURATION A

Percent	Inlet Angle		Aft Angle	
Corrected	PNLT	PNL	PNLT	PNL
40	40°	40°	115°	115°
63	50°–70°	70°	120°	120°
75	60°	80°	120°	120°
94.5	–	–	100°	100°–115°

Table IV shows that the angle for peak PNLT increased with speed and that at a corrected speed of 94.5 percent of design there was no defined forward quadrant maximum. There was little change in the aft angle for maximum PNLT. There were no significant differences between angles for maximum PNLT and those for maximum PNL. Aft noise was higher than inlet noise by a small to moderate amount at all speeds. A comparison of Figures 20a and 23a indicates that aft noise predominance was greater at higher speeds.

Examination of Figures 20c, 21c, 22c, and 23c shows strong inlet quadrant tones which correspond to 1st-stage rotor fundamental and 1st-stage rotor first harmonic frequencies (28E and 56E). The aft quadrant spectral data (Figures 20d, 21d, 22d, and 23d) show a predominance of the first harmonic of the 2nd-stage rotor blade-passage-frequency (2x35E = 70E). The spectra shown in Figures 23c and d for 94.5 percent corrected speed show less prominence of discrete tones than the spectra for lower speeds. The aft spectra, Figure 23d, show evidence of a significant tone at the fundamental of the 2nd-stage rotor blade frequency. At high speed, the interaction mode between the 1st-stage stator and the 2nd-stage rotor blade-passing-frequency tone will propagate, and may account for this tone in the farfield.

Figures 24, 25, and 26 present the angular and spectral distribution of farfield noise for nominal operating line conditions for corrected speeds of 63, 75, and 94.5 percent of the design value. Comparisons of Figures 24, 25, and 26 with Figures 21, 22, and 23 show that no significant effect of increased pressure ratio on either the angular or spectral distribution of farfield noise for the subject fan.

At takeoff speed, the rotor blade tip region relative flow was slightly supersonic. Under such conditions shock waves emanate from the blade tips. Because of small manufacturing variations from blade to blade, the shock waves have slightly different strengths. Combination tone noise, "buzz-saw" noise, is generated as a result of unequal shock strengths. For fans tested with cylindrical inlets, the combination tone noise radiates forward from the inlet to the farfield. However, when fans are equipped with inlets having contoured profiles suitable for flight performance, the combination tone noise amplitude at low supersonic tip speeds decays in the inlet due to the throat contraction and also due to airflow velocity gradients and high local Mach numbers at the inlet throat.

Detection of combination tones requires narrowband (32 Hz bandwidth) spectral analysis. Figures 27 and 28 show the narrowband spectral analysis results for the wide-open operating line points at corrected fan speeds of 94.5 and 100 percent of the design value. Figure 29, presented for comparison, shows a typical high-speed fan farfield spectrum containing a plurality of tones spaced at shaft rotation frequency. These tones constitute "buzz-saw" noise, a name suggested by the sound. The Q2S fan spectra (Figures 27 and 28) contained no such prominent tones. Because of the distinctive characteristic of combination tone noise, its presence is very easily detected by observers acquainted with aircraft engine noise. At no time during the operation of the Q2S fan was combination tone noise noted by any of the several experienced personnel present.

Another discrete frequency characteristic that has been noted during the operation of other two-stage fans was anticipated to occur with the Q2S fan. Due to the interaction between one rotor in scattering the stator-rotor interaction modes generated by the other rotor, a set of new discrete frequency tones is generated. These tones are separated by multiples of the frequency between the two sets of rotor blades (ref. 5). In the Q2S fan, such tones were separated by multiples of 35 - 28 = 7 times rotor speed. While such tones do not always propagate, some can propagate at subsonic rotor tip speeds, as with rotor-stator noise. The blade-vane ratio selections in the Q2S fan helped reduce these so-called "linear combination tones" since the primary interactions were generally below cutoff. Large axial spacing between components, as employed in the Q2S fan design, also reduced the tendency for these extra tones to form. Figures 30 and 31 were selected from the available narrowband data to illustrate spectra containing these tones. The relative lack of "linear combination tones" for the Q2S fan is noteworthy for a two-stage fan.

Internal wall-microphone data were taken in addition to the farfield acoustic surveys. Location of the inlet and discharge duct transducers is shown in Figure 32. Sample spectra from two inlet and two discharge microphones at approach and takeoff conditions are shown in Figure 33.

Information was obtained on the acoustic power radiated from the fan by weighted integration of the farfield microphone data. This material is presented in the Acoustic Data Report (ref. 4).

In the design of the Q2S fan, blade and vane numbers were selected so that acoustic modes excited by the interaction of wakes from the rotors with the downstream stators would be below cutoff and hence tones at blade-passage frequency would not propagate. The inlet tone at the fundamental 1st-stage rotor blade frequency presumably was due to a source of interaction other than a stator. Such sources typically are present in static ground test facilities, and result from interactions of the rotor blades with long axial scale turbulence ingested into the inlet during static operation and with the ground vortex. Both these inlet flow disturbances are thought to be absent or substantially reduced in normal aircraft flight. Therefore, the tone at 1st-stage rotor fundamental can be expected to be reduced substantially under flight conditions. The level of this tone has not, however, been altered in any of the scaling and simulated flight noise predictions that are given later in this report. As a result, estimated flyover noise levels are conservative.

The tones which were the first harmonics of either 1st-stage or 2nd-stage rotor blade-passing-frequency were above cutoff frequency. These tones were generated by a propagating rotor-stator interaction mode and hence cannot be expected to attenuate significantly in flight. Suppression of these tones depends on changes in fan design features or the use of sound suppression devices. To obtain cutoff of these first harmonic tones would require using more than four times as many stator blades as rotor blades. And this would require either an extremely low number of rotor blades or extremely high aspect ratio stator blades. The first alternative is undesirable from a weight standpoint and the second from a stator stress and vibration standpoint.

Depending on whether the source of 2nd-stage rotor noise was associated with interaction between the stator upstream and 2nd-stage rotor or the downstream stator assembly, a redistribution of the available spacing could be expected to change the level of these tones. Other approaches had been explored previously in other programs with varying degrees of success. These approaches included slanting and tilting vanes, and also configurations that involved using upstream and downstream stators designed to have the same vane number and then so arranged that their interaction modes were out of phase so that the pressure fields cancelled to produce a lower level resulting sum.

RESULTS OF SUPPRESSED TWO-STAGE FAN TESTS

Fully Suppressed Configurations B and C

Configuration B was designated the suppressed "flight" configuration and incorporated the sonic inlet and fan discharge duct acoustic treatment. As is shown in Table III, tests on configuration B were conducted to determine the fully suppressed acoustic characteristics of the Q2S fan and to evaluate the effectiveness of inlet and exit noise suppression devices. In addition the forward diffracted noise from the fan discharge duct was evaluated, and the aft noise increase due to the use of the sonic inlet was checked. Tests were run with configuration C to determine the potential of the sonic inlet by minimizing the effects of aft noise on the inlet quadrant.

Figure 34 compares 61 meter [200 ft.] sideline directivity patterns of PNLT for the suppressed configurations B and C and the baseline configuration A. The fully suppressed data of Figure 34a were taken with the inlet centerbody in the approach position and fan running on the wide open operating line with the sonic inlet choked. The baseline data on Figure 34a was taken with the fan operating on the wide open operating line at standard approach corrected speed (63 percent of design). Figure 34b shows fully suppressed data with the inlet in the takeoff position and the inlet choked. The baseline data for Figure 34b was taken on the nominal operating line at 94.5 percent of design corrected speed. Comparison of the fully suppressed configuration B data with the baseline data shows a nominal reduction of PNLT at all angles for both the approach and takeoff operating conditions. A comparison of data from suppressed configuration B and suppressed configuration C, incorporating the aft facility shield, shows that the sonic inlet was very effective in suppressing forward noise when operating choked, and that the forward quadrant data for configuration B was dominated by aft generated noise.

Sonic Inlet Suppression

An objective of this portion of the program was the evaluation of means for suppressing the inlet noise generated by the baseline fan. A translating centerbody sonic inlet device with acoustical treatment in the diffuser section was selected to provide suppression of noise radiated from the inlet of the fan. The noise-suppression characteristics of the sonic inlet were evaluated primarily by comparison of data from tests of configurations A and C. Separate positions of the movable centerbody were provided for approach, takeoff, and cruise. With the centerbody in the cruise position, sonic throat velocities were well below sonic. Since sonic inlets are known to be highly effective devices, the test program was structured to provide background noise levels as low as possible in order that meaningful inlet noise data could be obtained. Two steps were taken to provide these low levels of environmental noise: 1) the sound-absorbing treatment was installed in the fan discharge ducts and 2) the special aft acoustic facility shield, represented schematically in Figures 5b and 16, was erected to block the forward microphone field as much as possible from residual fan discharge noise, fan jet mixing and scrubbing noise, and other assorted facility drive system noise sources.

As throat Mach number of a sonic inlet is increased toward unity, inlet-radiated noise drops in a manner that depends on details of the design. However, when the throat is fully choked, radiation of fan noise from the inlet is essentially blocked, and the only possible noise radiation from the inlet must result from wave propagation in the very thin throat section boundary layer. Noise leakage through the thin inlet wall boundary layer is not significant. Therefore, at full choke, the farfield noise reduction measured for most sonic inlets is simply a measure of how well the environmental *background* noise or fan casing transmitted noise has been suppressed by test stand and facility construction, and is not a measure of how much *inlet* noise has been reduced. The more significant questions are whether *aft* noise increased as a result of poor inlet flow interacting with the fan to generate additional noise, and whether the fan aerodynamic performance was severely limited by the use of the sonic inlet device. Effect of the inlet on aft noise levels is discussed in a later section on aft noise suppression.

To provide some degree of noise suppression for conditions where the sonic inlet was operated unchoked, a moderate amount of wall treatment was incorporated into the inlet wall and centerbody surfaces downstream of the inlet throat. Such treatment would be most beneficial if the sonic inlet when operating at sonic throat Mach number had an extremely adverse effect on fan performance. However, as has been described in the Aerodynamic Performance section, the Q2S fan had no difficulty in operating with the sonic inlet fully choked. There were no significant losses in efficiency or surge margin, and speed control was excellent on both sides of the fan speed at which full choke was reached. No evaluation was made of the effectiveness of the inlet acoustic treatment on noise suppression.

Inlet noise levels were recorded using both the 45.7 meter [150 ft.] radius farfield microphone system and a special nearfield monitor microphone positioned at centerline height about 4.6 meters [15 ft.] away from the inlet at an angle of about 45 degrees. The purpose of installing this microphone was to provide an indication by on-line monitoring of its output that full-choke operation of the throat had been reached, insteady of depending on setting fan speed to a value that had been determined from previous aerodynamic tests. Spectra from this nearfield monitor microphone demonstrated the sonic inlet acoustic behavior more clearly than the farfield 45.7 meter [150 ft.] distance microphones since it was nearer the inlet noise source and better shielded from extraneous background noises.

Figures 35a and 35b present spectra for various throat Mach number settings in the approach and takeoff operating configurations, respectively. These figures present on-line narrowband (50 Hz) spectral levels as a function of frequency for throat Mach numbers of 0.7, 0.8, 0.9, and 1.0. The clearest behavior pattern may be discerned from the approach setting data for configuration C, shown in Figure 35a. Starting with the spectrum for a throat Mach number of 0.7, the discrete tones protruding above the broadband noise level correspond to harmonics of 1st-stage rotor blade-passage-frequency. As in the standard inlet tests on configuration A, there was little evidence of 2nd-stage rotor noise radiation from the inlet. As the rig speed was increased to induce throat Mach numbers of 0.8 and 0.9, three effects may be noticed: 1) the discrete tones become less prominent and shift to the right as blade-passage frequency increases due to increased rig speed, 2) the broadband noise levels drop significantly in the range above 2 or 3 kHz, and 3) relatively little change occurs in the lower frequency range of the spectrum. At fully choked operation, M = 1, even greater reductions are evident. Here, the discrete tones that can be observed in the M = 1 spectrum were not generated by the Q2S fan, and have been identified as a facility noise coming from the compressor stage of the fan-rig drive engine. The failure to detect corresponding reductions in low frequency levels is evidence that this noise was not coming from the inlet but rather was comprised of background noises from the fan discharge and facility sources. For the baseline and suppressed farfield data, these low frequency noise values were reduced by the linear adjustments that were described under Data Reduction Procedures.

The monitor microphone indicated similar behavior with the sonic inlet positioned in the takeoff power position, as shown by the narrowband spectra in Figure 35b. It should be noted that the data for Figure 35a is for the wide open operating line; whereas the data for Figure 35b is for the nominal operating line. This difference was not significant because the effect of increased pressure ratio on acoustic characteristics was very small. The most notable difference between takeoff and approach operation is that the spectrum sound pressure levels reached at M = 1 for takeoff were on the order of 10 dB higher than the corresponding approach sound pressure levels. This circumstance was due to the higher background levels generated by rig discharge and facility noise at higher operating speeds. Consequently, the small increment in reduction measured between M = 0.9 and 1 for takeoff compared to the larger approach sound pressure level reduction in this range does not mean that the sonic inlet was any less effective in reducing inlet-radiated noise, but simply that at M = 1 the background floor level was higher at takeoff than at approach and prevented measurement of further reductions of inlet-radiated noise as M = 1 was approached.

To illustrate the variation of inlet noise with throat Mach number, spectrum levels from Figure 35 are shown as a function of throat Mach number in Figure 36a and 36b. In each case, the spectrum levels were selected at 9 kHz to provide a sample representation. This frequency was chosen in a range where the absence of discrete tones would allow a clear view of the broadband noise behavior. It can be seen that inlet noise reductions of 10 dB at the nearfield microphone location were achieved at a throat Mach number of about 0.85. Further inlet noise reductions were achieved rapidly as choking was approached, but measurement of these reductions was limited by the background noise floor levels of the environment. These floor levels permitted measurement of a 30 dB reduction between M = 0.7 and M = 1 for the approach position data. At takeoff, the higher background or floor level limited measurement of the corresponding reduction to about 22 dB at the selected frequency.

The nearfield monitor microphone results show that the measured suppression of inlet-radiated noise with the inlet fully choked for approach and takeoff settings of this sonic inlet device were limited by background, or floor, level noise. It is indicated, however, that nearly complete suppression was achieved for the fully choked conditions.

Figures 37a and 37b present 1/3-octave band spectra for the farfield 45.7 meter [150 ft.] radius microphones at angles where peak PNLT levels were measured with the hardwall baseline inlet. These data have been adjusted to provide a one dB per 1/3-octave band rolloff for levels two bands below that containing blade-passage frequency to remove excess jet and scrubbing noise, but spurious tones were not corrected for. In Figure 37a for approach, the prominence in the 2500 Hz band for the M = 0.7 curve was produced by 1st-stage rotor blade frequency. As speed was increased to raise the throat Mach number, all band levels dropped and the blade tone prominence shifted to the right. The tone indicated in the M = 1 spectrum at 2500 Hz is *not* associated with the Q2S fan. Narrowband spectra indicated that this tone was a facility noise produced by the compressor of the drive engine. Although inclusion of this facility tone falsely raised inlet PNLT, this factor did not affect predictions for a full-scale Q2S fan installation using the sonic inlet as explained in the section on full-scale comparisons.

The two tones shown on Figure 37b for the inlet in the takeoff position correspond to the fundamental and first harmonic of the 1st-stage rotor blade-passing-frequency. As the inlet approached the fully choked condition, these tones were suppressed to or below the level of broadband noise in this frequency range.

Figures 38a and 38b show the 45.7 meter [150 ft.] radius angular directivity patterns of PNLT at throat Mach numbers of 0.7, 0.8, 0.9, and 1.0 for approach and takeoff settings, respectively. About 18 PNLT reductions are indicated from 20 to 50 degrees in going from M = 0.7 to full choke with the inlet in the approach setting. With the inlet in the takeoff setting, choking produced a measured reduction of about 15 PNLT. The degree of attenuation in the takeoff position was probably limited by background noise. The rear-angle levels rose slightly as speed was increased to produce choke because of higher aft noise associated with higher speed operation. The fact that inlet directivity peaked toward the on-axis direction at low inlet Mach number conditions was a consequence of the constant radius rather than constant sideline distance plot.

Sample inlet internal wall microphone spectra are shown in Figure 39 for sonic operation at approach and takeoff. For choked operation with the inlet in the approach setting, transducer position No. 4, which was near the fan face, received strong tones at 1st-stage rotor blade-passing-frequency and the first harmonic of rotor blade-passing-frequency (Figure 39a). A comparison of these data with those of Figure 39b for transducer location No. 1, which is near the inlet throat, shows a strong attenuation of the 1st-stage rotor blade fundamental and first harmonic frequency tones. Data with choked operation of the inlet in the takeoff position also shows strong attenuation of the 1st-stage rotor blade fundamental and first harmonic frequencies between the fan face and the inlet throat (Figures 39c and 39d).

In summary, the results of these tests indicate that the sonic inlet, when choked, essentially eliminated noise propagation from the inlet and did not lead to unstable fan operation. The effect of the inlet on aft quadrant noise is discussed in the section on aft noise suppression. Inlet noise levels were suppressed so effectively that the farfield microphones were not responding to inlet noise, but rather to fan discharge noise scattered into the inlet quadrant and to facility environmental noise. It should be noted that the sonic inlet reported herein did have a modest amount of wall treatment to increase suppression for conditions where the inlet was not choked. The tests and analysis of this study were not adequate to evaluate the effectiveness of this suppression treatment.

Aft Noise Suppression

Figure 40 shows the variation of 112.8 meter [370 ft.] sideline peak aft PNLT as a function of fan speed for the baseline, configuration A, and for fully suppressed configuration B with the sonic inlet in the approach position. Both curves are for the wide open nozzle operating line. As shown previously, there was little variation of noise level with pressure ratio at a given speed. Therefore, the wide open throttle data gives a valid evaluation of suppressor effectiveness. Figure 40 shows a reduction in PNLT of 11.5 PNdB at 40 percent of design corrected speed. At 75 percent corrected speed, a reduction of 8.5 PNdB was obtained. These values are appreciably below the predicted values of 16 and 11 PNdB, respectively. The maximum speed run with the sonic inlet in the approach position was 78.5 percent of design. Similar data for higher speeds with the inlet in the takeoff position have not been included because these higher speed data are believed to be adversely affected by scrubbing and facility noise.

The fan discharge duct treatment tested incorporated a treated circumferential splitter and had an effective treated-length-to-passage-height (L/H) ratio of about 12. The treatment was tuned to maximize the reduction in aft arc PNdB when installed on the test rig rather than tuned to frequencies that would minimize PNdB if the liner and rig were both geometrically scaled to full-scale engine size. Figure 41 shows the liner construction parameters and the calculated attenuation versus frequency characteristics at 40 and 75 percent of design speed. These calculations were based on extensive liner empirical test data rather than upon solutions of the wave equation with wall impedance boundary conditions. Experience indicates that such empirically based attenuation predictions are more conservative than the theoretical attenuations. The calculated results should, therefore, be considered as the minimum expected results. The perforated facings and backing depths were selected and the liner was fabricated before baseline test data were available, based on predictions of the fan noise spectrum that would have to be suppressed. In order to obtain updated predicted attenuations to compare with the test results, a recalculation was made by applying the predicted attenuation-vs-frequency liner characteristics to the actual measured baseline Q2S fan spectra at the two speeds. Measured attenuations were established by subtracting 1/3-octave band spectra levels for the suppressed configuration B from corresponding levels in the baseline configuration A tests at the 40 percent speed points. Data at angular locations of 105, 110, 115, and 120 degrees were used. Figure 42 shows measured attenuation and the predicted attenuation for 40 percent speed from Figure 41. Measured peak attenuations range from about 13 dB to 20 dB and occurred in the 4 kHz band. The predicted attenuation had a broad peak with values between 21 dB and 22 dB ranging from 2000 Hz to 3150 Hz. The measured peak attenuation was only slightly lower than predicted, but it occurred at a frequency that was almost an octave too high. Additionally, the measured attenuation had a very narrow bandwidth compared with the predicted characteristic. At high frequencies, *negative* attenuations were indicated. The significance of this anomaly will be discussed later.

Figure 43 presents identical information for 75 percent speed. At this speed the measured performance was significantly worse than predicted. Peak measured attenuations ranged from 14 dB to 16 dB. But more importantly, the peak tuning was at 8 kHz instead of in the 2 kHz to 3 kHz range. Again, the bandwidth was significantly narrower than predicted. Based on predicted levels of total attenuation the liner should have produced reductions in PNLT of 16 PNdB at 40 percent and 11 PNdB at 75 percent speeds. The corresponding measured values were 11.5 and 8.5 PNdB, and represent deficiencies of 4.5 PNdB at 40 percent and 2.5 PNdB at 75 percent speed.

From these results, liner attenuation appears to have fallen short of predicted performance. Detailed analyses of the test data were made to determine if attenuation of the liner was indeed below expectations, or if some feature of the test facility prevented the true performance of the liner from being measured.

Because the liner was evaluated by comparing baseline data with data for configuration B, which included the sonic inlet in addition to discharge duct treatment, it is not likely that noise from the inlet was radiated toward aft angles to limit the apparent attenuation of the liner. The sonic inlet, as discussed previously, essentially blocked the forward propagation of inlet noise.

It is possible, however, that aft noise was increased significantly because of poor flow from the sonic inlet interacting with the fan. To evaluate this possibility, data from configurations B and D were compared. These configurations were the same except for the inlet – configuration D used the standard flight inlet, and configuration B used the sonic inlet. Differences in aft quadrant noise for these two configurations should therefore be due only to inlet geometry effects. No aft facility wall was used so as to properly measure aft radiated noise.

Representative spectral results are shown in Figure 44 for the 40 percent speed conditions and in Figure 45 for the 75 percent speed choked-approach condition. In each case information for two angles, 105 degrees and 115 degrees, is considered. In both figures, the solid curves are the configuration A spectrum; the dashed line curves the configuration B spectrum; and the long broken line curves are the configuration D spectrum. It is evident that the configuration B and D spectra were essentially the same and that the presence of the sonic inlet did *not* increase aft-radiated noise. The negative attenuations noted at 40 percent speed were the result of extraneous noise present in both configurations B and D and were therefore generated by some mechanism in the duct liner and not by the sonic inlet. These noises disappear in the 75 percent data – 63 percent approach design speed data, not included here, does not show this noise either. Figure 46 presents the variations of peak aft PNLT as a function of speed for configurations B and D. This figure does not show an increase in aft noise with use of the sonic inlet. Therefore, failure of the aft duct treatment to achieve predicted noise attenuation cannot be attributed to adverse effects of the sonic inlet.

At the onset of the program it was realized that jet scrubbing noise from the rig discharge and other facility noises would tend to obscure the results of the fan duct treatment suppression and that this extraneous noise would be minimized by running at speeds where the fan efflux velocity was low. Accordingly, data were acquired at 40 percent and 50 percent of design speed to provide the best environment for detecting liner suppression. At these points, a reduction on the order of 11 PNdB was attained. To decide whether this suppression was reasonable, it was necessary to examine narrowband spectra for the low speed conditions.

Figure 47 shows the 105 degree spectra at 40 percent speed for configurations A, B and D. For configuration B, the sonic inlet was at the approach setting. For configurations B and D, the "hill" of broadband noise around 10 kHz, from which a cluster of discrete tones protrudes, is characteristic of spectra with the liner installed. It has been determined that these tones were not multiples of rotor speed and, together with the "hill" of broadband noise, probably were of aerodynamic origin. It may be speculated that vortex shedding from the circumferential splitter and its supporting radial structure, excitation of higher mode cavity resonances in the liner, or turbulent flow interacting with the splitter surfaces may have been the sources of this noise. Positive identification of the nature of these phenomena will require additional work which was beyond the scope of this program. In any case the extra generated noise, which appears to have been of significance only at speeds below the normal operating range of the fan, was one factor that contributed to the poor performance of the liner and was responsible for the anomalous *negative* attenuations observed in the 1/3-octave band spectra.

Two procedures were used to determine if extraneous broadband noises from the facility were masking the true liner performance. Instead of relying on broadband noise differences between baseline and treated configurations, discrete tone data were examined. As described in the baseline fan section, a two-stage fan generally produces discrete tones that are multiples of the difference frequency between blade-passage rates in the two rotors. These tones, in addition to the obvious harmonics of each rotor blade frequency, produced narrowband spectra with several discrete frequencies that protruded above the broadband noise, and the source of these tones unquestionably was the fan. The corresponding amplitudes of these fan generated tones were compared between configurations to define their attenuation as a result of propagation through the treated duct. Narrowband spectra for configurations A and D were examined at angles of 105, 110, and 115 degrees for 40, 50, and 63 percent of fan design speed. Each pair of spectra contained several common tones that protruded far enough above the broadband noise to be identified and to allow their levels to be read. Differences between these common tones were plotted against frequency in the 1 to 10 kHz range to produce a plot of tone attenuation versus frequency from the liner. The plot resulted in excessive scatter, probably due to the relatively poor statistical sampling inherent in the measurement of farfield tones, and has not been included in this report. The envelope of the scatter in this curve, which could be considered the maximum possible liner attenuation, confirms the poor liner performance and does not support the possibility that the liner was performing up to expectations but that its performance was masked by extraneous noises in the test environment and not within the fan.

During the test programs on configurations A and B, flush-mounted wall pressure transducers were installed in the inlet and fan discharge ducts. Six of these were mounted downstream of the fan in the outer duct casing. Data from these aft duct microphones were examined to determine performance of the liner. Figure 48 presents spectra from a wall mounted microphone near the end of the treatment for baseline and treated configurations at 40 percent speed. The attenuation spectrum obtained from the difference of the two curves is also shown. Similar information for 75 percent speed is given in Figure 49. It will be observed that the attenuations indicated by these internal measurements confirm the farfield observations. Figure 50 shows the variations with downstream distance in the hardwall and treated ducts of sound pressure levels in the 1/3-octave bands containing the fundamental and harmonic of the 2nd-stage rotor blade-passage-frequency. Moderate attenuations of both 2nd-stage rotor blade fundamental and first harmonic frequencies are noted.

Although it was not possible within the scope of this program to identify the cause of poor performance of the liner, the variety of data shows conclusively that the liner's performance was well below expectations. A review of the liner design procedure did not disclose any obvious errors, and inspection of the liner construction, both before and after the test, failed to reveal any manufacturing defects or any indication that mechanical failure occurred during testing that could have caused degradation of liner performance. Although the reasons for poor liner-performance are not known, its deficiencies may be summarized as follows:

(1) Peak measured attenuations were significantly less than predicted.

(2) Measured attenuation bandwidth was very much narrower than predicted.

(3) Tuning was on the order of a full octave higher than predicted.

(4) At low speed, the construction generated extra broadband and discrete frequency noise.

FULL-SCALE STATIC NOISE COMPARISONS

Comparison Procedures

Comparisons were made of the farfield acoustic characteristics of the following five fan configurations in typical static test hardware: the JT3D engine fan, the JT8D engine fan, the predicted noise for the STF 433 fan from the ATT study, and the scaled noise levels from the two-stage fan tested under this contract in both the unsuppressed and fully suppressed configurations. These comparisons were made at static fan operating conditions that simulated takeoff thrust and conventional three degree approach thrust operation. In addition, fan noise levels from the fully treated Q2S fan (including sonic inlet) were compared with FAR 36 noise limits. Results of these comparisons, along with other comparisons to further illustrate the noise characteristics of the Q2S fan, are presented in the following subsections.

In making the comparisons, it was required that test data from the Q2S fan be scaled in size to predict the noise levels of a larger size fan of geometrically similar design.

The following procedures were used to scale the acoustic results from the Q2S fan. At a given Q2S fan RPM, the measured spectra were scaled by holding linear fan tip speed constant as fan diameter and RPM were changed. The resulting change in RPM caused the spectra to shift to frequencies that were lower than those measured during tests of the Q2S fan rig. The frequency shifting was performed in a computer by transposing rig data the integer number of 1/3-octave band registers that corresponded most closely to the rig-to-engine-diameter ratio. The diameter ratios used in these comparisons closely approximate the frequency ratios corresponding to successive 1/3-octave band shifts. All 1/3-octave band levels were then increased by 20 log D_{eng}/D_{rig}. For convenience, Table V presents information used in scaling the Q2S fan rig to JT8D, JT3D, and STF 433 fan diameters.

TABLE V – QUIET TWO-STAGE FAN SCALING RELATIONS

Config.	Diameter (m)	Diameter (in.)	Dia./0.836m (32.9 in)	No. of 1/3 Octave Band Shifts	Frequency Shift Ratio $(\sqrt[3]{2})^n$	Size Correction, dB, 20 Log Dia./0.836 m [32.9 in]
Q2S	0.836	32.9	1	0	---	---
JT8D	1.03	40.5	1.23	1	1.260	1.8
JT3D	1.28	50.5	1.54	2	1.587	3.7
STF 433	1.82	71.6	2.18	3	2.000	6.8

Comparisons of Q2S Fan Scaled to STF 433 Size With JT8D and JT3D Fans

The noise levels measured from the Q2S fan in the unsuppressed configuration and scaled in size to that of the STF 433 ATT study engine are compared in Table VI with JT3D and JT8D fan noise levels. Peak inlet and aft quadrant PNLT are listed for a 112.8 meter [370 ft.] sideline distance. For convenience, Q2S fan improvements with respect to the current two-stage engine fans are given. It should be noted that there is a progressive increase in size and thrust between the JT8D, JT3D, and the STF 433 fans (as seen in Table V) so that the improvements listed in Table VI were achieved despite the assumption of a much larger diameter fan.

Spectrum levels at the angles of peak tone-corrected noise for these fans are shown in Figure 51. JT3D and JT8D fan noise data were obtained from P&WA conducted tests of these engines in outdoor static noise test facilities that were comparable to the facility used to test the Q2S fan. Typical static test hardware, consisting of an untreated bellmouth inlet and hardwall fan exhaust ducts, were installed on the JT3D and JT8D test engines. The effects of identifiable jet noise have been removed from all spectra by a consistent procedure described in the Data Reduction section of this report.

TABLE VI – BASELINE Q2S FAN SCALED TO STF 433 SIZE COMPARISONS WITH JT8D & JT3D ENGINE FANS

Peak 112.8m [370 ft] Sideline PNLT (PNdB)

	APPROACH			
	Inlet		Aft	
	JT8D	JT3D	JT8D	JT3D
Measured Engine Fan	106.5	114.4	112.4	116.6
STF 433 Size Q2S	105.2		111.0	
Improvement	1.3	9.2	1.4	5.6
	TAKEOFF			
Measured Engine Fan	115.4	118.7	116.6	122.1
STF 433 Size Q2S	114.1		115.7	
Improvement	1.3	4.6	0.9	6.4

In Figure 51a, approach-inlet, the tone in the 1250 Hz band for the scaled Q2S fan, corresponds to the fundamental of 1st-stage rotor blade-passage-frequency. As discussed previously, blade-vane interaction theory predicts that there should be no propagating tone at this frequency when the fan is operated in an inflight airflow environment and the rotor is subsonic. The presence of this tone is ascribed to inlet flow distrubances present in the ground test environment. Therefore this prominence in the inlet spectrum of the scaled Q2S fan at 1250 Hz can be expected to be reduced in actual flight. On the other hand, the tone concentrations in the spectra of the JT8D and JT3D should not be significantly altered in flight since their interaction modes, generated between inlet guide vanes and stators with the rotor, are well above cutoff even at approach powers. Consequently, the noise benefit in flight of the Q2S fan may be even greater than that shown at static conditions.

Figure 51b compares spectra at approach power in the rearward direction. The 1st-stage rotor tones are not noticeable from the Q2S fan in a 1/3-octave bandwidth analysis, and the fundamental of the 2nd-stage rotor blade frequency (35 blades), which was similarly designed to be cutoff, is not discernable in the spectrum – it would be present in the 1600 Hz band. A tone at twice 2nd-stage rotor frequency is prominent in the 3150 Hz band. This tone may have been generated by interaction of the 2nd-stage rotor with either or both the upstream and downstream neighboring stators, both of which can generate propagating modes at twice blade frequency. Flight effects should not influence this tone. However, further refinements of the Q2S fan geometry, such as varying the allocation of blade-vane spacing, could result in an arrangement having reduced levels of this tone. Despite this rearward-radiated 2nd-stage rotor harmonic, the approach power spectra of the STF 433 size scaled Q2S fan has notably less discrete frequency content than either the JT8D and JT3D fans.

At takeoff power the scaled Q2S fan spectra (Figures 51c and 51d) are lacking in conspicuous 1/3-octave prominences produced by tones. This lack of tone prominence is different from the JT8D and JT3D cases, where fundamentals and harmonics of both rotor stages are amply evident. Thus, at both approach and takeoff powers the Q2S fan tends to have fewer prominent blade-passage-tones compared with the two-stage fans of the JT8D and the JT3D engines.

Comparisons of Q2S Fan Baseline Scaled to JT8D and JT3D Fan Sizes

To provide further indications of the acoustic performance of the Q2S fan, the following comparisons were made by successively scaling unsuppressed Q2S fan data to the fan sizes of the JT8D and JT3D engines. Standard values of approach and takeoff power were used. The resulting comparisons with measured engine fan data are shown in Table VII.

TABLE VII – QUIET TWO-STAGE FAN NOISE COMPARISONS WITH JT8D AND JT3D ENGINE FANS (Q2S FAN SCALED TO COMPARISON FAN SIZE)

PEAK 112.8m [370 ft] Sideline PNLT (PNdB Units)

	APPROACH			
	Inlet		Aft	
	JT8D	JT3D	JT8D	JT3D
Measured	106.5	114.4	112.4	116.6
Scaled Q2S	99.6	102.3	104.1	106.9
Improvement	6.9	12.1	8.3	9.7
	TAKEOFF			
Measured	115.4	118.7	116.6	122.1
Scaled Q2S	109.4	111.6	110.0	112.4
Improvement	6.0	7.1	6.6	9.7

This table indicates significantly lower noise levels produced by scaled versions of the Q2S fan. However, these indicated improvements represent only part of the story since the higher bypass ratio Q2S fans produce significantly more thrust than the JT8D or JT3D fans. These thrust differences are accounted for in the next set of comparisons.

Equal Thrust Comparisons of Scaled Q2S Fan With JT8D and JT3D Fans

To provide noise comparisons that consider thrust differences, fan thrust was calculated over the speed range of the Q2S fan scaled up to corresponding JT8D and JT3D fan diameters. Values of scaled Q2S fan peak PNLT were computed and plotted against the scaled Q2S fan thrust in the range from approach to takeoff. The measured values of JT3D and JT8D peak (aft) PNLT were entered on the appropriate plot at the values of fan thrust for approach and takeoff conditions. These comparisons are shown in Figure 52.

The figure shows that the JT8D size Q2S fan improvement is about 6.5 tone-corrected PNdB at takeoff conditions. However, if the Q2S fan thrust were reduced to that of the actual JT8D, the scaled Q2S fan would be 9.5 PNdB quieter.

Similarly, comparing Q2S fan results at takeoff conditions with the JT3D fan shows the Q2S fan to be about 9.5 PNdB quieter, and at the same thrust to be 13.5 PNdB quieter than the JT3D fan. At approach conditions the corresponding Q2S fan benefits are about 8.5 PNdB compared to the JT8D and 9.5 PNdB compared with the JT3D engine fan.

Scaled Baseline Q2S Fan Versus 1972 Predicted STF 433 Fan

Using the scaling procedures previously described, the unsuppressed, baseline configuration A Q2S fan acoustic data were scaled to the fan diameter, 1.82 meters [71.6 in.], of the STF 433 engine fan. Spectral information for the STF 433 was predicted for the 1972 ATT study (ref. 1) using procedures based on modified JT3D engine fan spectra. The results of these comparisons are summarized in Table VIII.

TABLE VIII – BASELINE Q2S FAN SCALED TO STF 433 FAN SIZE COMPARED WITH PREDICTED STF 433 FAN NOISE USING 1972 ATT STUDY METHOD
Peak 112.8m [370 ft] Sideline PNLT
(PNdB Units)

	Inlet	Aft
APPROACH		
STF 433 Predicted (1972 Method)	104.4	108.0
Baseline Q2S Fan Scaled to STF 433 Size	106.3	111.0
(Predicted - Scaled Q2S fan)	-1.9	-3.0
TAKEOFF		
STF 433 Predicted (1972 Method)	114.4	118.7
Baseline Q2S Fan Scaled to STF 433 Size	115.0	115.7
(Predicted - Scaled Q2S Fan)	-0.6	3.0

The results show that the method used in 1972 to predict STF 433 engine noise gives levels not too different from scaled data for the Q2S fan test program.

Figure 53 presents spectral information used in the peak PNLT calculations. The differences in spectral shape between predicted and scaled Q2S fans reflect the fact that the JT3D engine fan data were used in the 1972 predictions. Since the ratio of the numbers of blades in the second stage to the first stage is 32/35 = 0.91 in the JT3D and the STF 433 has a corresponding ratio of 35/28 = 1.28, the prominences in the spectra do not correspond.

Projected Suppression of STF 433 Size Q2S Fan

The method of scaling unsuppressed Q2S fan baseline data to STF 433 fan size was described previously. A more complicated procedure was needed to obtain projections for a fully-suppressed STF 433 including a sonic inlet and fan duct absorbing treatment. This complication follows from the fact that while the Q2S fan rig and the sonic inlet were geometric scale models of an STF 433 installation the duct lining tested in configuration B was not geometrically similar to what would be used in the STF 433. The lining tested in configuration B was designed to optimize perceived noise in rig size. Because perceived noise (PNL or PNLT, etc.) is a psycho-acoustic measure, a lining designed for a larger size fan would have parameters such as backing depth, perforated facing hole diameter, etc., that are different from scaled-up values of the rig parameters. For this reason, scaled acoustic data obtained from tests on the fully-suppressed configuration B would not provide the best estimate of the performance of a suppressed STF 433 installation. In Appendix B, scaled configuration B data are presented for record purposes.

The method used in projecting values for the suppressed STF 433 installation involved analytically selecting a liner designed for full-scale suppression, predicting its attenuation versus frequency characteristics and applying these predicted attenuations to the STF 433 scaled baseline spectra. The liner geometry and attenuation characteristics are shown in Figure 54. To obtain the attenuation at various angles in the farfield, these attenuations were multiplied by the directivity factors shown in Figure 55. In the directions forward of 90 degrees, 1/3-octave band directivity patterns, measured in the sonic inlet tests of configuration C were used, matching the levels at 90 degrees. An additional benefit of using this procedure was that the noise characteristics of the Q2S fan were not penalized unduly for the failure of the specific liner tested to meet predicted levels of performance. The following results should be representative of what could be expected for a fan installed with nacelle acoustic treatment that fully meets the level of performance for acoustic treatment designed using the state-of-the-art that exists in 1975.

As discussed earlier, the sonic inlet essentially blocked inlet noise propagation when operated in the choked condition. The specific sonic inlet tested was designed with a relatively short inlet length, and the diffusion angle downstream of the throat was selected to insure against flow separation on the walls. This geometry defined a minimum throat area that was too large to choke at the airflow required for approach thrust along the nominal (fixed duct exit nozzle) operating line. To achieve choked inlet condition, a variable duct exit nozzle was assumed, and approach thrust was achieved at a higher fan flow and a much lower fan pressure ratio than for fixed-nozzle operation. Corrected fan speed for approach was 75 percent of design for the variable exit duct nozzle as compared to 63 percent for the fixed nozzle.

Based on the above considerations, the differences in noise level between the suppressed and unsuppressed configurations were established and are shown in Table IX, which compares 112.8 meter [370 ft] sideline PNLT levels of the STF 433 size scaled baseline with those projected for the suppressed STF 433 installation to establish the inlet and duct suppression levels. The same speeds (94.5 percent) were used for takeoff of both configurations. For approach, the baseline results were taken at the standard approach speed (63 percent), and the projected suppressed results used a 75 percent elevated speed for sonic inlet choking. The peak PNLT levels for each configuration were attained in the aft quadrant. In the inlet quadrant, peak PNLT values are listed for the baseline. For the suppressed fan with the sonic inlet installed, the values listed are those at the angles where the baseline inlet PNLT peaked. This procedure was followed since the forward quadrant noise with the sonic inlet choked fell continuously with angle and had no true peak value in the inlet quadrant.

TABLE IX – BASELINE STF 433 FROM SCALED Q2S FAN BASELINE
COMPARED WITH
PROJECTED SUPPRESSED STF 433 INSTALLATION
Peak 112.8m [370 ft] Sideline PNLT
(PNdB Units)

	Inlet	Aft
APPROACH		
Scaled Baseline STF 433	105.2	111.0
Projected Suppressed STF 433	90.9	103.4
Suppression	14.3	7.6
TAKEOFF		
Scaled Baseline STF 433	114.1	115.7
Projected Suppressed STF 433	103.4	105.4
Suppression	10.7	10.3

The peak aft PNLT values are more significant than the inlet because they were higher and had greater influence on the flyover noise characteristics to be described subsequently. The relatively low PNLT suppression at approach conditions (7.6 PNdB) compared to the 10.3 PNdB suppression at takeoff was due partly to the baseline noise increase associated with the 75 percent corrected fan speed used for choked inlet operation versus the standard 63 percent baseline approach speed. This penalty in aft noise amounted to 5.4 PNdB and will be discussed later. In effect, the treatment was therefore producing 7.6 + 5.4 = 13 PNdB reduction of PNLT at a common 75 percent elevated speed. Spectral information used in obtaining Table IX is shown in Figure 56.

In the aft angle takeoff spectra, Figure 56d, the effect of the assumed liner is clear. Attenuation begins in the 630 Hz band so that below this band both configurations follow the same low-frequency linear rolloff characteristic described in the Data Reduction section. Above 630 Hz, the baseline spectrum rises and the suppressed spectrum levels fall as the peak liner attenuation is approached. Between 2500 Hz and 4000 Hz the liner is attenuating about 19 dB from the baseline. Although not shown on this figure, beyond 4000 Hz the suppressed spectrum was essentially flat due to the combination of falling baseline noise and diminishing liner attenuation. As noted, these data apply to a sideline distance of 112.8 meter [370 ft]. In flight comparisons to be shown later, high thrust operation is associated with distances from the noise measuring stations that are at least 314.8 meter [1000 ft] greater. Because of extra air-attenuation effects, the high frequency portions of the spectra will be reduced relatively more than the low frequency levels. Consequently, at flight distances the takeoff suppressed spectrum levels around 500 Hz control peak PNLT.

The approach power spectra in Figure 56b are more difficult to follow due to the fan speed change discussed previously. In the baseline spectrum at 63 percent speed, the significant tone around 3150 Hz corresponds to twice 2nd-stage rotor blade-passage-frequency. For the suppressed configuration operating at 75 percent speed, this tone is moved up to the 4000 Hz band. In addition, the unsuppressed level of this tone band increased 6 dB or 7 dB. Therefore, while it may appear from the figure that the liner was reducing this tone by about 10 dB, the liner was really absorbing 16 dB or 17 dB since the source level increased.

By referring to Figures 56 and 51, the spectra of the suppressed configuration of the rig scaled to ATT study engine size can be compared with JT3D and JT8D fan noise levels in typical static test hardware without acoustic suppression.

ATT AIRPLANE FAR 36 FLYOVER NOISE CALCULATIONS

Airplane Characteristics and FAR 36 Noise Limits

For a given engine, the aircraft in which it is installed affects both the resulting EPNdB and the FAR 36 noise limits that must be met. The resulting EPNdB are affected by the variation of airplane altitude and engine power requirements with aircraft weight and operating characteristics. Noise limits established in FAR 36 are functions of aircraft takeoff gross weight.

In the following presentation of scaled STF 433 information, a takeoff gross weight of 1.361×10^5 kg [3.0×10^5 lbm] was used for the ATT aircraft. Three STF 433 engines were employed, each developing 1.38×10^6N [3.0×10^4 lbf] total (fan plus primary) static takeoff thrust. Fan diameter was 1.82 meter [71.6 in.].

Table X presents pertinent information applicable to the fan noise characteristics of this installation.

TABLE X – FAR 36 REQUIREMENTS FOR FLYOVER NOISE THREE STF 433 ENGINES 1.82m (71.6 in.) DIAMETER FAN

Condition	Sideline	Approach	Cutback	Takeoff
FAR 36 Limit	105 EPNdB	106 EPNdB	103 EPNdB	103 EPNdB
Altitude or Distance	487.7m [1600 ft]	112.8m [370 ft]	429.8m [1410ft)	448.1m [1470 ft]
Percent Design Fan Speed	94.5	63/75*	90	94.5
Air Speed	78.6m/sec[285 ft/sec]	79.2m/sec[260 ft/sec]	88.4m/sec [290 ft/sec]	88.4m/sec [290 ft/sec]

*75 percent speed required to choke sonic inlet

STF 433 Scaled Q2S Fan Baseline Flyover Noise

Before comparing the fan noise levels of the fully treated Q2S fan with FAR 36 noise limits, it is instructive to first examine how the fan noise from an unsuppressed installation compares with FAR 36 noise limits. EPNdB values were obtained by simulating on a computer the time histories of the flight conditions given in Table X in a manner described in the Data Reduction section. These values are given in Table XI together with the FAR 36 limits.

TABLE XI – CALCULATED Q2S FAN SCALED BASELINE FLYOVER NOISE ATT AIRPLANE WITH THREE STF 433 ENGINES (EPNdB Units)

Condition	Sideline	Approach	Cutback	Takeoff
FAR 36 Limit	106	106	103	103
Q2S Fan Scaled Baseline STF 433	100.5	106.3	100.0	101.3
FAR 36 - STF 433	5.5	-0.3	3.0	1.7
avg diff = 2.7	←		→	
avg diff = 2.5	←			→

Table XI makes it clear that the Q2S baseline fan when scaled to STF 433 size is generally better than FAR 36 limits by significant amounts at sideline, cutback, and full takeoff power conditions and that it essentially meets the approach requirements. The average improvement over requirements is 2.5 EPNdB for the four conditions and when averaged for sideline, approach, and cutback amounts to a 2.7 EPNdB margin. These fan noise levels, scaled to STF 433 size, are lower than were predicted for the unsuppressed fan of the ATT study engine in 1972.

Figure 57 (reproduced from Figure 8 of reference 1) shows the levels that had been predicted for the STF 433 ATT installation. The tops of the bar-graphs represent the basic engine noise levels which were controlled by fan noise at all three FAR 36 conditions. The predicted values are, approximately: 1 EPNdB above FAR 36 for sideline, 1 EPNdB below at approach, and meeting the FAR 36 limit at cutback power, thus just meeting FAR 36 limits on the average – full power takeoff is not presented. These results illustrate that the basic fan source-noise of the Q2S fan is less than was predicted in 1972, particularly at the sideline condition.

Projected Suppressed STF 433 Flyover Noise

In this section, results of flyover calculations leading to EPNdB levels are given for the projected suppressed STF 433 configuration described in a previous section. In the previous section static peak noise levels are presented for a full-scale Q2S fan incorporating a sonic inlet device and assuming attenuations for a discharge duct liner tuned to STF 433 size frequency requirements. This configuration is designated the "projected" suppressed STF 433.

In the "Statement-of-Work" for the subject contract (NAS3-16811), the following sentence was included: "A reduction of 20 dB below current requirements shall be a goal." This 20 dB (EPNdB) figure should be considered in the context of the results of the 1972 ATT study which motivated the current experimental Q2S fan program. A four-step series of EPNdB levels may be extracted from the ATT study report (ref. 1). The STF 433-powered ATT airplane was predicted to meet the following noise levels with respect to FAR Part 36 requirements:

1. FAR 36 minus 20 EPNdB, by using a combination of special noise abatement maneuvers and advanced (1985) acoustic liner technology.

2. FAR 36 minus 15 EPNdB, by employing advanced (1985) acoustic liners alone.

3. FAR 36 minus 10 EPNdB with current (1972) liner technology.

4. FAR 36 requirements could be met with the baseline STF 433 engine without employing inlet or fan discharge duct suppression.

The difference between FAR 36 minus 20 EPNdB and FAR 36 minus 15 EPNdB is due to special flight maneuvers, and achievement of FAR 36 minus 15 EPNdB depends on the development of advanced acoustic liner technology that will be available for use by 1985. The contract goal of 20 dB quoted previously corresponds by inference to item 1 in the four-step chain of levels listed above, and is therefore equivalent to attaining FAR 36 minus 15 EPNdB without recourse to special flight maneuvers. As discussed in the previous section, the Q2S fan data without inlet or fan discharge duct suppression was projected to be an average of 2.7 EPNdB below FAR 36 limits, thus surpassing the requirements stated in item 4 above.

The acoustic treatment attenuation assumed in making the following projection for the suppressed STF 433 was selected as representing the best current (1975) technology, not speculative 1985 liner-technology. It should be noted that the treatment tested in this program did not meet the levels of attenuation assumed in this evaluation. The 1975 levels of attenuation used are warranted on the basis of data from other investigations. Item 3 above, asserting that FAR 36 minus 10 EPNdB can be achieved with current technology, does not appear explicitly in reference 1, but is based on the tables in reference 6 (pp 1-12, 2-12, and 3-12) which contain background information for reference 1. Based on material presented in reference 6, it is evident that 1971-1972 liner technology was predicted to provide reductions of about 10 EPNdB.

Table XII presents the calculated EPNdB levels for the "projected suppressed" STF 433 installation and compares them with FAR 36 limits.

TABLE XII – PROJECTED SUPPRESSED CALCULATIONS
ATT AIRPLANE WITH THREE SUPPRESSED STF 433 ENGINES
(EPNdB Units)

Condition	Sideline	Approach	Cutback	Takeoff
FAR 36 Limit	106	106	103	103
Projected Suppressed STF 433	94.0	97.8	93.8	94.7
Difference	12.0	8.2	9.2	8.3
avg. diff. = 9.8	←——	————	——→	
avg. diff. = 9.4	←——	————	————	——→

It is seen that averaging sideline, approach, and cutback results shows the projected suppressed STF 433 to be about 10 EPNdB below FAR 36 limits. Since these calculations incorporated assumed attenuations for 1975 liner technology, the projected suppressed configuration essentially meets the characteristics predicted in 1972 for use of "current" suppression technology. Using average figures, it appears that achievement of the 1985 technology goal of FAR 36 minus 15 EPNdB depends on obtaining an additional suppression increment of a little more than 5 EPNdB through development of acoustic liner technology by 1985. Additional discussion of the gap between current results and the 1985 goal, together with possible means for narrowing it, is contained in the following two sections.

Noise Estimates With Sonic Inlet Redesign

As shown in Table XI, a level of only 8.2 EPNdB below FAR limits was achieved at the approach condition. To understand the cause it is necessary to recall that the baseline engine operates at 63 percent of design speed, but the suppressed engine speed must be increased to about 75 percent of design speed in order to choke the sonic inlet. Figure 58 shows peak aft PNLT generated by the baseline fan as a function of speed for both the Q2S fan and the scaled STF 433 – the change in shape from small to large scale is a result of shifting spectra into different annoyance bands as scale is changed. It can be seen in Table XIII that the source tone-corrected noise level increases 5.4 PNdB due to this speed increase and the EPNdB was increased by 3.6 units.

TABLE XIII – BASELINE NOISE SOURCE INCREASE WITH ELEVATED APPROACH SPEED ATT AIRPLANE WITH THREE STF 433 ENGINES

	PNLT	EPNdB
Standard approach 63% speed	115.8	106.3
Choked inlet approach 75% speed	121.2	109.9
Source noise increase	5.4	3.6

To evaluate the fan discharge duct liner performance isolated from the effects of speed change, a comparison was made between baseline and projected suppressed configurations, both operating at the common elevated 75 percent of design speed, in Table XIV.

TABLE XIV – APPROACH POWER COMPARISON BASELINE AND SUPPRESSED FAN AT 75 PERCENT SPEED ATT AIRPLANE WITH THREE STF 433 ENGINES

	PNLT	EPNdB
Scaled baseline - 75% speed	121.2	109.9
Projected Suppressed - 75% speed	108.2	97.8
"True" Suppression	13.0	12.1

This comparison provides a better indication of the liner performance. The effect of the liner was evaluated at a common engine speed so that its performance is not biased by the change in source noise occasioned by the engine speed increase involved in the first comparison in Table XII. This suggests that a possible "systems" solution is to employ a more sophisticated sonic inlet design that would allow adequate noise suppression at approach with little or no fan speed increase requirement. A more aggressive approach to the sonic inlet design, involving boundary layer control or more wall treatment, could probably lead to a more sophisticated device in which no significant fan speed increase would be required. Presuming the existence of such a device, it is possible to estimate the projected noise levels that would be achieved. This estimate is made by applying the suppression provided by the discharge treatment, given in Table XIV, to the scaled baseline data at the standard 63 percent approach speed. The results are shown in Table XV.

TABLE XV – ESTIMATED APPROACH NOISE USING NEW SONIC INLET CHOKED AT 63 PERCENT SPEED ATT AIRPLANE WITH THREE STF 433 ENGINES

	PNLT	EPNdB
Scaled Baseline, 63% Speed	115.8	106.3
Liner Suppression (Table XIV)	13.0	12.1
Estimated Suppressed STF 433	102.8	94.2
FAR 36 Approach Limit		106.0
Result with Respect to FAR 36 Limit		11.8

This estimate now projects a suppressed STF 433 installation that is 11.8 EPNdB below FAR 36 at approach, as compared with the 75 percent speed operation giving FAR 36 minus 8.2 EPNdB (Table XII). The 3.6 EPNdB improvement is of course just the reduction in baseline noise achieved by dropping fan speed from 75 percent to the standard 63 percent approach condition (Table XIII).

These estimates were made based on a new sonic inlet which would give adequate suppression at 63 percent corrected approach fan speed. The aft noise at approach was appreciably higher than the inlet noise. Therefore, a sonic inlet with some acoustic treatment, but operating unchoked, might be used with little change in the approach noise level. This technique, however, would increase duration of high noise levels and might adversely affect EPNdB.

A tabulated summary of the projected suppressed STF 433 with a new sonic inlet design is given in Table XVI in terms of EPNdB reductions relative to current FAR 36 requirements, and compares these estimates with the 1985 program goals.

TABLE XVI – ESTIMATED REDUCTIONS WITH RESPECT TO FAR 36 AND 1985 TECHNOLOGY GOALS (NEW SONIC INLET FOR APPROACH) ATT AIRPLANE WITH THREE SUPPRESSED STF 433 ENGINES USING 1975 TECHNOLOGY TREATMENT

(UNITS: EPNdB Below FAR 36 Limits)

	Sideline	Approach	Cutback
1985 Technology Goals	15	15	15
1975 Technology Estimated Performance	12	11.8	9.2
Required Improvement	3	3.2	6.8

These figures reflect the previously discussed result that the scaled baseline fan was quieter than predicted, and show what improvements must be accomplished to meet the 1985 goal. It is reasonable to expect that the additional 3.2 EPNdB required at approach can be achieved, either by liner technology advances or by fan source noise improvements. At approach, there is significant energy associated with the first harmonic of the 2nd-stage rotor blade-frequency, a tone which probably could be reduced in the unsuppressed baseline fan by techniques that have been developed for fan noise control at the source and were discussed previously.

The 6.8 EPNdB deficit at cutback power is another matter, however. It is not simply that the improvement needed here is twice that required at approach, but rather that the means for achieving any substantial improvement in the fan source noise at high power are not evident because prominent tones that could be reduced by fan design changes are not present in the high power spectra. The achievement of further reductions at this condition depends on improvements in acoustic liner technology as discussed in the following section.

Improved Liner Requirements

As previously described, the application of assumed liner attenuation to the aft fan spectra resulted in noise in the range of 500 Hz being the factor that controlled peak PNdB at realistic flight distances for takeoff operation. The problem therefore is essentially one of residual low-frequency fan noise. This area has received relatively little attention both with respect to the nature of the generating mechanisms in the fan responsible for the source noise and also in the area of acoustic duct treatment designed for low-frequency absorption. It is therefore clear that it would be unrealistic to predict that a further reduction of 6.8 EPNdB can be achieved through routine developmental work. Rather, a new, intensive program is required to examine this problem area and to formulate programs for studying the nature of the noise generating mechanisms involved to determine whether noise source reductions are possible and to determine whether liners with substantially better low-frequency absorption characteristics can be devised without sacrificing the required high-frequency suppression capability. Based on 1975 technology, the high frequency attenuation of the assumed liner used in the flyover noise projections was excellent. The peak attenuations were on the order of 20 dB and held for about a full octave, from about 2000 Hz to 4000 Hz. These high attenuations and wide bandwidths could not have been attained by a primitive design. Equally impressive was the observation that a *minimum* of 15 dB attenuation was provided between 1600 Hz to 6300 Hz at approach – a range of two octaves.

In addition to the spectral attenuation properties required to provide more attenuation, attenuation directivity also presents a problem in the reduction of EPNdB in flight. Figure 55 shows the assumed variation of attenuation with farfield directivity that was used, and some of the source data that entered into this selection. Between 90 and 115 degrees, full-liner attenuation was attained. This covers the range where peak PNLT occurred for the baseline configurations at both approach and takeoff power. Therefore, the liner attenuation directivity cannot be the cause of poor peak PNLT reductions. However, the fairly rapid fall-off of liner attenuation at angles aft of 120 degrees should be noted. This lack of attenuation is typical of all known liner configurations and does not affect peak PNLT, but it does have an effect on calculated duration corrections for a flyover and hence has an adverse effect on EPNdB.

The effect on suppression of duration is well known. With a suppressed configuration, the noise is always lower at any instant in the flyover than it is at the corresponding time for the unsuppressed engine. However, EPNdB is obtained by essentially integrating the instantaneous PNLT over a time interval during which the noise is within 10 PNdB of its peak value. If a suppressor reduces noise uniformly in all directions, the resulting time history would have the same shape as the baseline with constant reductions at each instant, so that the integration time would be the same in both baseline and suppressed configurations and the numerical value of suppression would be the same in EPNdB units as in peak PNLT units. But with actual duct lining, peak suppression is greater than suppression when the airplane is well past the overhead position. The resulting PNLT versus time curve is "flatter" so the integration time during which the noise is within 10 PNdB of its peak is longer, and the reduction in EPNdB may be significantly less than the peak PNLT reduction due to this apparent increase in duration. To improve this basic situation, new research efforts in duct lining directivity are needed. An added problem is that no improvements in directivity can be allowed at the expense of reduced peak attenuations or bandwidth, for, as was discussed above, these also must be improved.

SUMMARY OF RESULTS

Acoustic characteristics of the 0.836 meter [32.9 in.] diameter Q2S fan, a geometrically scaled version of the STF433 engine fan, were evaluated. Acoustic design features of the basic fan included absence of inlet guide vanes, low tip speed to minimize combination tone or "buzz saw" noise, moderate stage pressure loading, large axial spacings between blade rows, choice of blade and vane numbers to provide cut-off fundamental rotor blade frequencies, and acoustic treatment in the interstage cases. Tests were also conducted in a fully suppressed configuration which included, in addition, a sonic inlet with translating center body and a downstream treated circumferential splitter and extensive acoustic treatment on the walls of the discharge duct. Acoustic results were scaled to predict noise for the 1.82 meter [71.6 in.] STF433 fan. Static noise comparisons were made between the scaled Q2S fan and two current production two-stage fans. Flyover noise calculations were made for an advanced transport aircraft utilizing three STF 433 engines. Calculations were made for both unsuppressed and fully suppressed configurations, and the results of these calculations were compared to FAR 36 limits.

BASELINE Q2S FAN RESULTS

The essential acoustic results from tests of the baseline Q2S fan were as follows:

1. Inlet noise spectra revealed tones at the fundamental and first harmonic frequency of the 1st-stage rotor blade-passing-frequency. These tones are believed due to flow disturbance peculiar to ground tests and may not be present in flight.

2. There was no combination tone, "buzz saw", noise in the noise spectra.

3. Under all test conditions, peak aft noise levels exceeded inlet levels by small to moderate amounts.

4. Aft peak PNLT increased essentially linearly with fan speed, and was relatively insensitive to pressure ratio at any given speed.

5. Aft radiated noise spectra showed a significant tone at twice 2nd-stage rotor blade-passing-frequency at low speeds and a prominent fundamental 2nd-stage rotor blade-passing-frequency tone at takeoff speed.

6. Neither the inlet nor exit spectra showed any significant tones corresponding to multiples of the difference between fundamental 1st-stage and 2nd-stage rotor blade-passing-frequency.

FULLY SUPPRESSED Q2S FAN ACOUSTIC RESULTS

The following overall acoustic results were obtained from tests of the Q2S fan with the sonic inlet and treated discharge duct:

1. With the sonic inlet centerbody in either the approach or takeoff position and operating with the inlet choked, the sonic inlet essentially eliminated noise radiated from the fan inlet.

2. Adverse effects of the sonic inlet on fan efficiency and stall margin were small. The rig was operated at 150 rpm above the fan speed for complete choking of the inlet with no fan operating or speed control problems.

3. The sonic inlet had no measurable effect on aft radiated noise.

4. For operation with the inlet choked, aft quadrant noise was predominant and forward quadrant noise was primarily due to noise radiated from the fan exit.

5. The noise attenuations achieved by the treated exit duct walls and treated splitter were less than predicted values. At 75 percent of corrected design fan speed, the measured attenuation of peak PNLT, at a 112.8 meter [370 ft.] sideline distance was 8.5 PNdB compared to a predicted value of 11 PNdB. And at 40 percent of corrected fan speed, the measured value was 11.5 PNdB as compared to a predicted value of 16 PNdB. Narrow band analysis ruled out background noise as an apparent cause of poor treatment attenuation.

6. Peak measured one-third octave band noise reductions were on the order of 15 dB versus an expected 22 dB. Narrowband analysis similarly showed lower than expected reductions in discrete frequency tones.

7. Measured attenuation bandwidth was narrower than expected. Measured peak attenuation was generally confined to a single one-third octave band and dropped to about half peak attenuation in adjacent bands. Predictions indicated large attenuations over a full octave frequency range.

8. The measured frequency where peak attenuation occurred departed from predictions by about one octave. Peak attenuation was predicted in the 2 kHz to 3 kHz range, whereas, measured peak attenuation occurred around 4 kHz at 40 percent of design corrected fan speed and between 6.3 kHz and 8 kHz at 75 percent speed.

9. At 40 percent of design corrected fan speed, the exit duct treatment actually generated extra noise in the high frequency range. This noise appeared as a broadband spectrum increase between 8 kHz to 10 kHz. In addition, a cluster of prominent discrete tones extended above this broadband spectrum. This high frequency noise may have been caused by vortex shedding from the splitter and its support struts due to the impact of turbulent flow on the splitter or by aerodynamic excitation of liner cavity resonances.

FULL-SCALE STATIC NOISE COMPARISONS

Acoustic data comparisons were made between the fan source noise estimates for the STF 433 engine fan and the current JT8D and JT3D two-stage fans. Comparisons were also made between JT8D and JT3D fan noise and Q2S fan data scaled to these engine fan diameters. Only aft noise is presented because it always exceeded inlet noise. These data comparisons are for static ground tests with standard inlets and hardwall (untreated) exit ducts. Comparisons are based on maximum tone-corrected perceived noise levels (PNLT) for a 112.8 meter [370 ft.] sideline distance. Results were as follows:

1. When scaled to the 1.82 meter [71.2 in] fan diameter of the STF 433 engine, the Q2S fan is about 1.4 PNLT quieter than the current JT8D fan at approach and about 0.9 PNLT quieter at takeoff conditions. Since both size and thrust of the 1.82 meter [71.6 in] diameter scaled Q2S fan are larger than in the JT8D, the noise improvements were actually greater than listed above. Rescaling the Q2S fan to the 1.03 meter [40.5 in.] diameter of the JT8D fan, and comparing noise at the approach and takeoff thrusts developed by the JT8D fan, shows that this scaled Q2S fan was about 8.5 PNLT quieter than the JT8D at approach and 9.5 PNLT quieter at takeoff.

2. Comparing the 1.82 meter [71.6 in.] diameter scaled Q2S fan with the current JT3D engine fan indicates improvements of 5.6 PNLT at approach and 6.4 PNLT at takeoff conditions. Rescaling the Q2S fan to the 1.28 meter [50.5 in.] diameter of the JT3D fan and comparing noise at the fan thrusts of the JT3D indicates that the JT3D size Q2S fan was quieter than the current JT3D by about 9.5 PNLT at approach and 13.5 PNLT at takeoff.

3. 'In a 1972 NASA study contract, predictions based on modifications to JT3D engine acoustic data were made for the STF 433 engine fan. These predictions were compared with static Q2S fan data scaled to STF 433 fan size and show that approach noise had been underpredicted by 3 PNLT and takeoff noise had been overpredicted by the same amount. This comparison indicates that the method used in 1972 to predict STF 433 noise gave results that were in reasonable agreement with scaled data measured in the actual Q2S fan test program.

FLYOVER NOISE COMPARISONS WITH FAR 36 LIMITS

Flyover noise calculations were made for an Advanced Technology Transport aircraft using three two-stage fan STF 433 engines in unsuppressed and suppressed configurations and assuming current flight maneuver patterns. These engines used Q2S fans scaled to a tip diameter of 1.82 meters [71.6 in.].

Because exit duct treatment was designed in rig size and because the duct treatment tested gave much lower attenuations than generally achieved by similar treatments, current attenuation predictions were used to obtain exit duct attenuation in these calculations. The results of comparisons of the calculated flyover noise levels with FAR 36 limits are as follows:

1. Comparison of the calculated flyover noise values for the aircraft with three unsuppressed STF 433 engines with FAR 36 limits showed the STF 433 powered aircraft to be 5.5 EPNdB below limits at the sideline condition, 0.3 EPNdB higher at approach, 3 EPNdB lower at cutback, and 1.7 EPNdB lower at takeoff. These values are believed to be conservative because no corrections were applied for such factors as ground induced inlet distortion effects.

2. Comparisons of calculated flyover noise values for the aircraft with three fully treated STF 433 engines with FAR 36 limits showed the STF 433 powered aircraft to be 12, 8.2, 9.2, and 8.3 EPNdB below limits for the sideline, approach, cutback, and takeoff conditions respectively. The calculation for the choked inlet approach condition was based on a higher than normal fan corrected speed (75 percent vs. 63 percent of design) and assumed the use of a variable duct exhaust nozzle.

3. Use of a more sophisticated sonic inlet that would permit a corrected fan speed of 63 percent of design for approach resulted in a calculated STF 433 powered aircraft approach noise level which was 11.8 EPNdB below FAR 36 limits.

4. A 1985 noise level for transport aircraft of FAR 36 minus 20 EPNdB is desired. This goal includes special flight maneuvers which were not considered in the subject study. With conventional flight patterns, a level of FAR 36 minus 15 EPNdB is desired. Based on the projected noise values for the STF 433 powered transport, improvements in noise suppression of about 3 EPNdB at sideline and approach and about 7 EPNdB at cutback power are required if 1985 noise goals are to be met.

RECOMMENDATIONS

1. The acoustic performance of the baseline Q2S fan concept indicates that this design has potential for future applications. Further optimization of acoustic development features, such as variations in stator design and spacing can be expected to give additional noise reductions. A program for further optimizing these features should be implemented.

2. Programs for advancing the state-of-the-art of discharge duct liner technology must be reexamined and intensified significantly beyond presently planned levels if the 1985 goals of FAR 36 minus 15 dB and FAR 36 minus 20 dB (using special flight procedures) are to be approached.

3. Further diagnostic tests should be conducted to establish why the attenuation characteristics of the test liner, predicted using methods that have proved reliable when applied to less extensively treated ducts, were unsatisfactory in this case.

4. Further work is required on sonic inlets to permit higher suppression at low flows so that fan speed at approach can be minimized. This will not only reduce approach noise, but will permit use of a fixed area duct exit nozzle. Consideration should be given to both short length, high diffusion ratio inlets and to combinations of high throat Mach numbers and acoustic wall treatment.

APPENDIX A

SYMBOLS AND DEFINITIONS

A	area, meters^2 [ft^2]
CA	circular arc
D	diameter, meters [in.]
dB	decibels
dB(A)	decibels, A-scale measurement
E	excitation per rotor revolution
EPNdB	effective perceived noise, dB
F	degrees Fahrenheit
FAR 36	Federal Aviation Regulation, Part 36
H	height, meters [in.]
Hz	hertz, cycles per second
in	inch
k	1000 Hz
L	length; meters [in.]
M	average inlet throat Mach number
m	meters
MCA	multiple circular arc
N	rotor speed, rpm
Noy	perceived noisiness
OASPL	overall sound pressure level dB (50 Hz - 10 kHz)
P	total pressure, N/m^2 [lbf/in.^{2}]
PNdB	perceived noise, dB
PNL	perceived noise level, PNdB
PNLT	perceived noise level tone corrected, PNdB
R	rotor
r	number of rotor blades
rpm	revolutions per minute
S	stator
s	number of stator vanes
SPL	sound pressure level, dB re 0.0002 dynes/cm^2
W	weight flow, kg/sec [lbm/sec]

δ	ratio of total pressure to standard pressure of 1.013×10^5 N/m² [2116 lbf/ft²]
θ	ratio of total temperature to standard temperature of 288.2°K [518.7°R]
1/3 OCT	one-third octave
Corrected Speed	$N/\sqrt{\theta}$, rpm
Corrected Flow	$W\sqrt{\theta}/\delta$, kg/sec [lbm/sec]

APPENDIX B

SCALED CONFIGURATION B RESULTS

In the section on full-scale comparisons, it was explained that the acoustic duct liner had been tuned to obtain the best results in the Q2S fan rig size and was therefore not geometrically similar to a realistic liner for absorbing noise in a full-scale engine. Therefore, scaling the suppressed configuration test results in the manner that the baseline configuration data were processed would not, a priori, give realistic information about a suppressed STF 433 size fan.

Furthermore, the test results for the actual liner used on the Q2S fan were both disappointing and, more importantly, cannot be explained without further work beyond the scope of this program, Therefore, it cannot be assumed that a full-size version of the test liner would obey the scaling laws since it failed to satisfy several other predicted behavior patterns.

Despite these considerations, the data from the fully suppressed configuration B were put through the computer scaling and flyover noise program as a matter of interest. The resulting figures are presented here solely to report the work done. It is evident that they should not be used outside of the context of the discussion in the preceding two paragraphs.

TABLE XVII – SCALED BASELINE AND SUPPRESSED CONFIGURATION B RESULTS
ATT AIRPLANE WITH THREE STF 433 ENGINES
(Both PNLT & EPNdB Units)

	SIDELINE		APPROACH		CUTBACK	
	PNLT	EPNdB	PNLT	EPNdB	PNLT	EPNdB
Scaled Baseline A	102.2	100.5	115.8	106.3	102.3	100.0
Scaled Config. B	98.3	96.6	110.6	110.0	100.2	97.9
Suppression (A-B)	3.9	3.9	5.2	–3.7(!)	2.1	2.1
FAR 36 Limits	106		106		103	
FAR 36 – Scaled Config B.	9.4		–4.0(!)		5.2	

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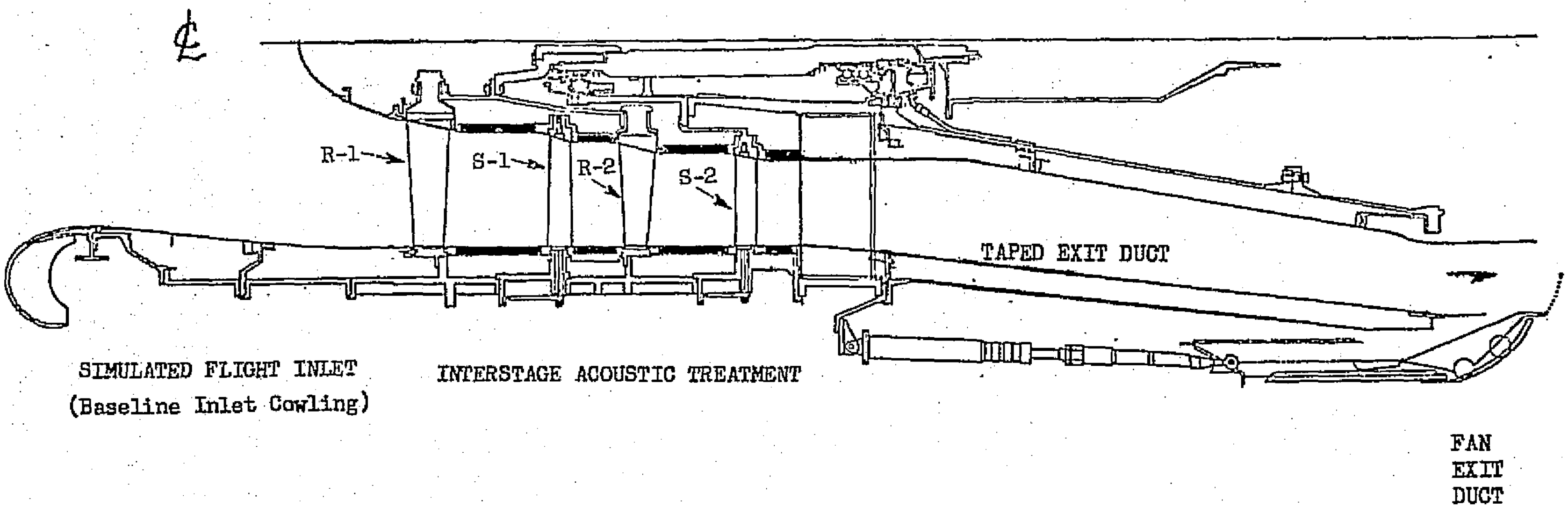


Figure 1 NASA Quiet Two-Stage Fan, Baseline Configuration

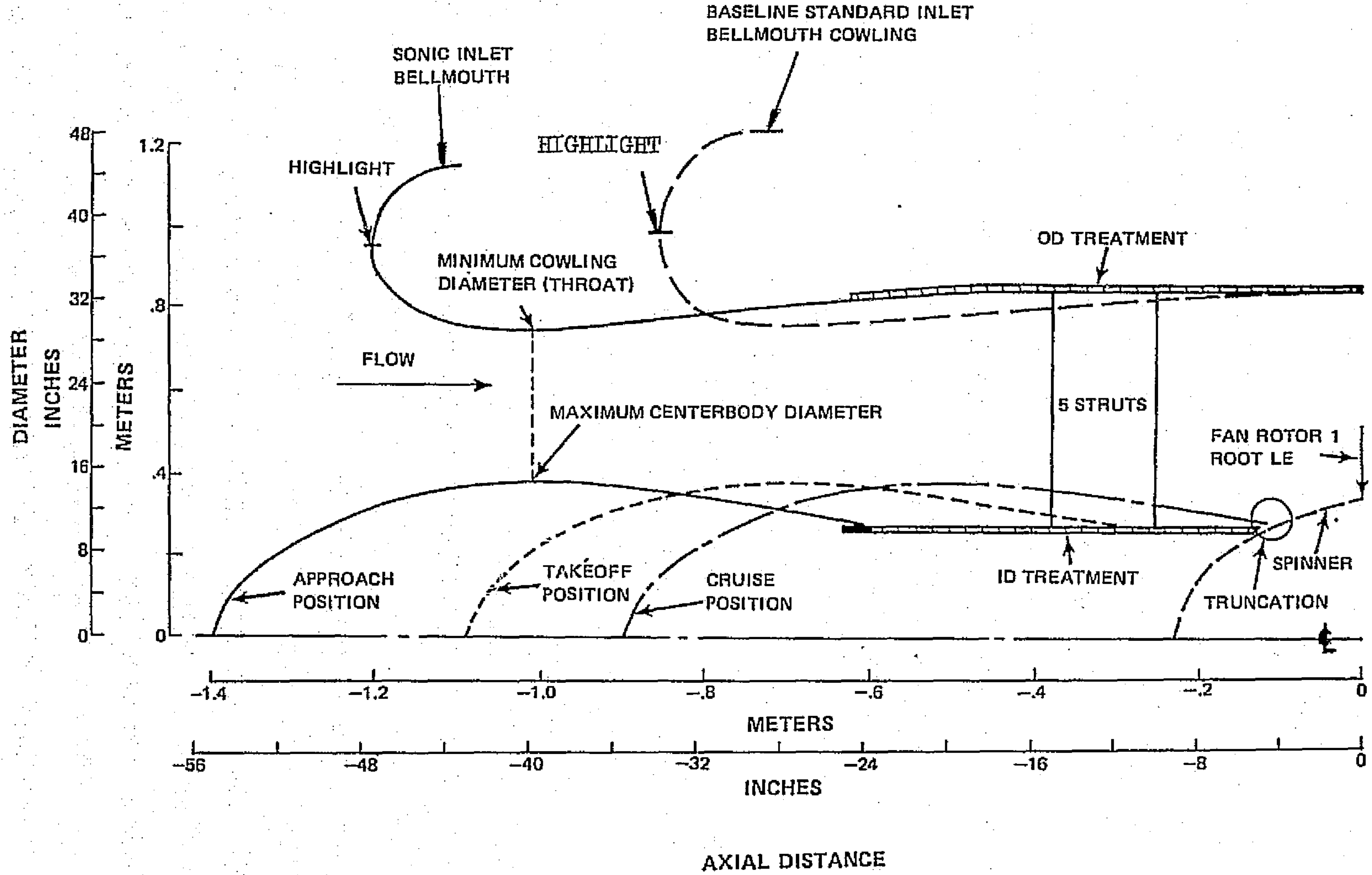
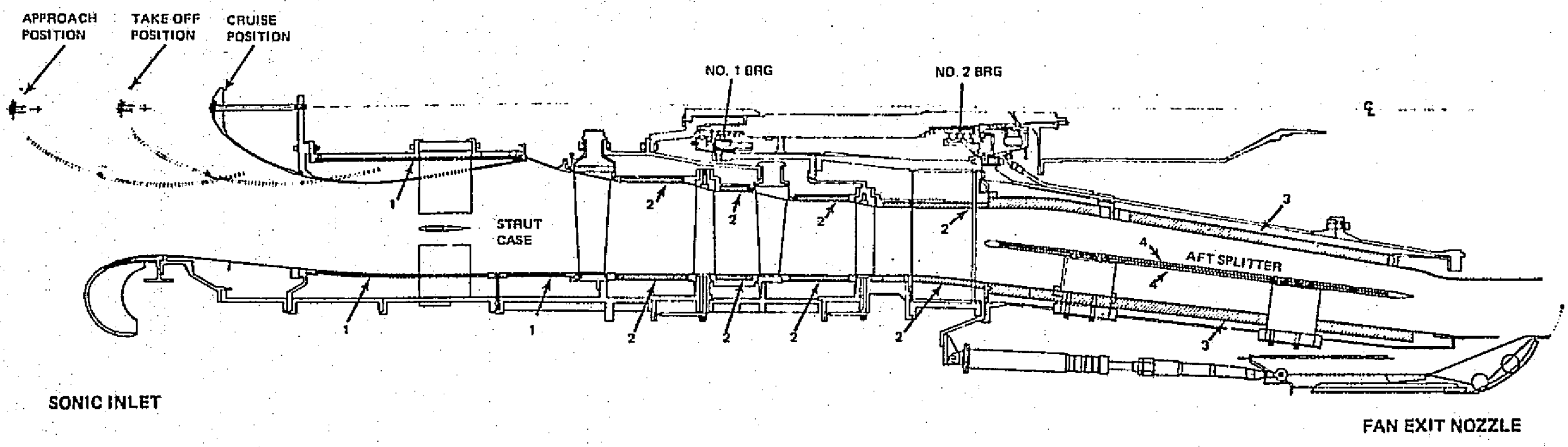


Figure 2 Baseline and Sonic Inlet Geometries



ITEM NO.	LOCATION	HONEYCOMB DEPTH, METERS (IN.)	H/C CELL SIZE, METERS (INCHES)	FACING SHEET RESISTANCE (NORMALIZED)	FACING SHEET % OPEN AREA)
1	SONIC INLET ID & OD	0.006 (1/4)	0.0095 (3/8)	2	6
2	INTERSTAGE ID & OD	0.013 (1/2)	0.0095 (3/8)	1	14
3	EXIT WALLS ID & OD	0.025 (1)	0.0095 (3/8)	1.5	9
4	EXIT SPLITTER	0.006 (1/4)	0.0095 (3/8)	1.5	9

Figure 3 Summary of Fan Acoustic Treatment

View From North

View From East

View From South

View From West

Figure 4 Aerial Views of X-308 Stand

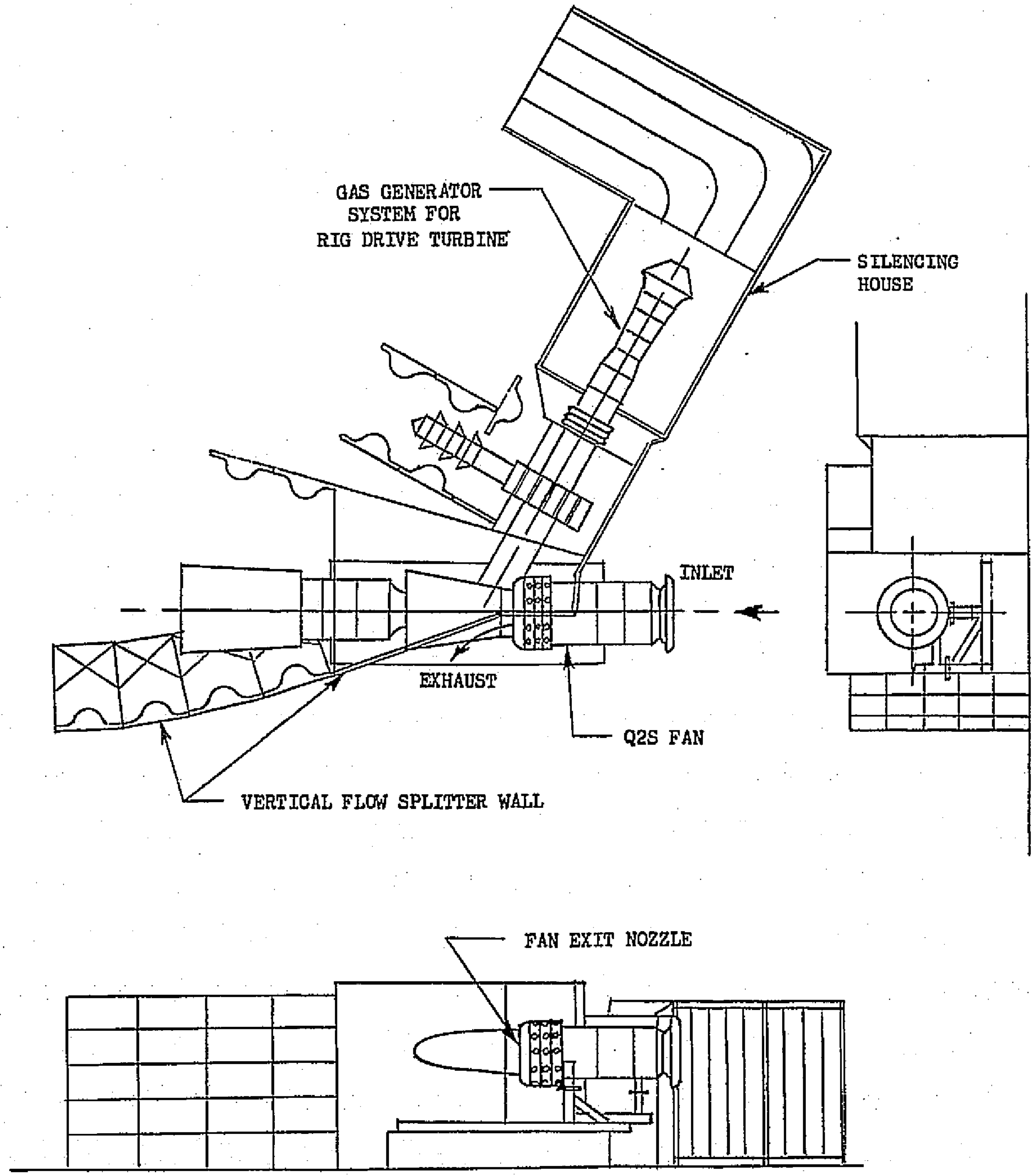


Figure 5a Schematic of X-308 Stand Showing Drive System and Rig Exhaust Configuration

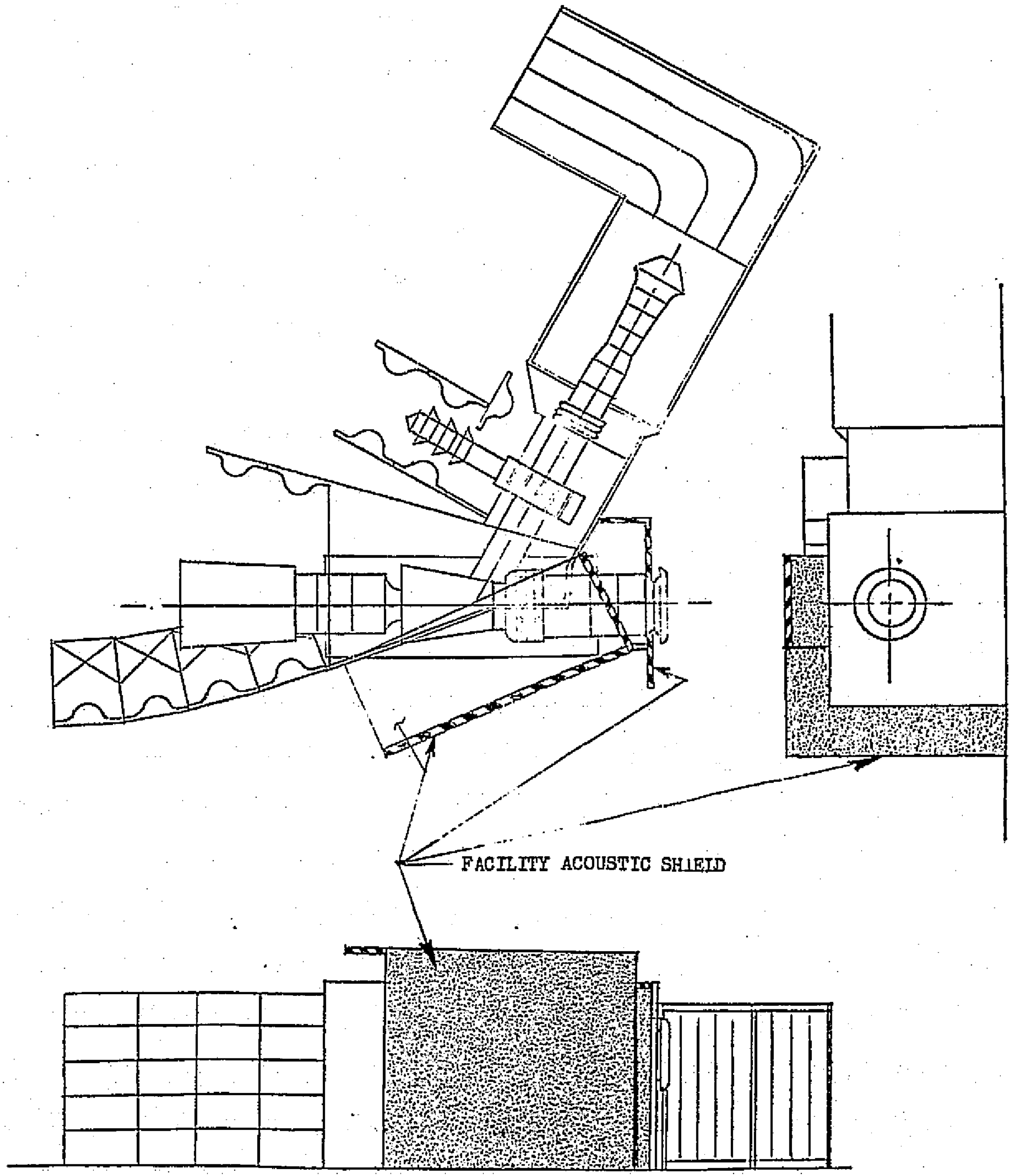
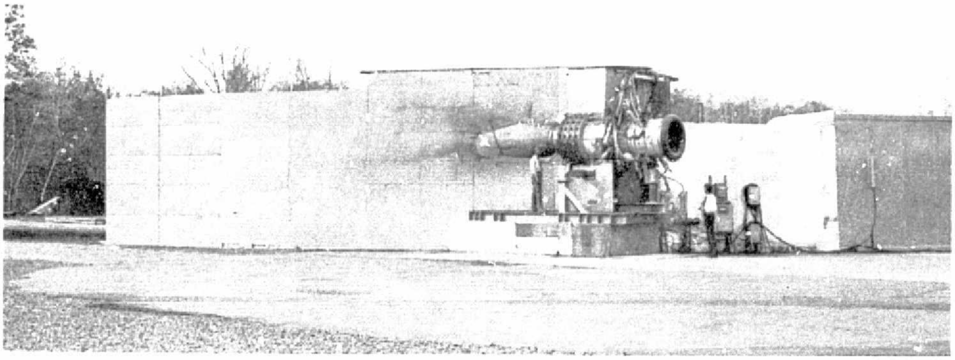
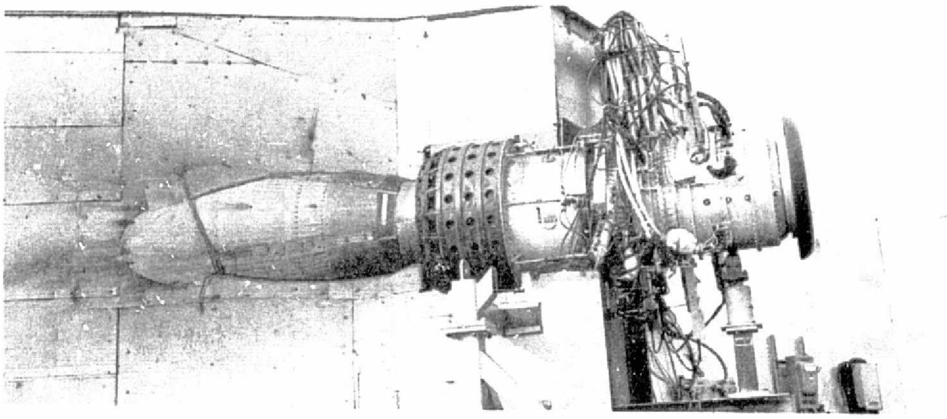


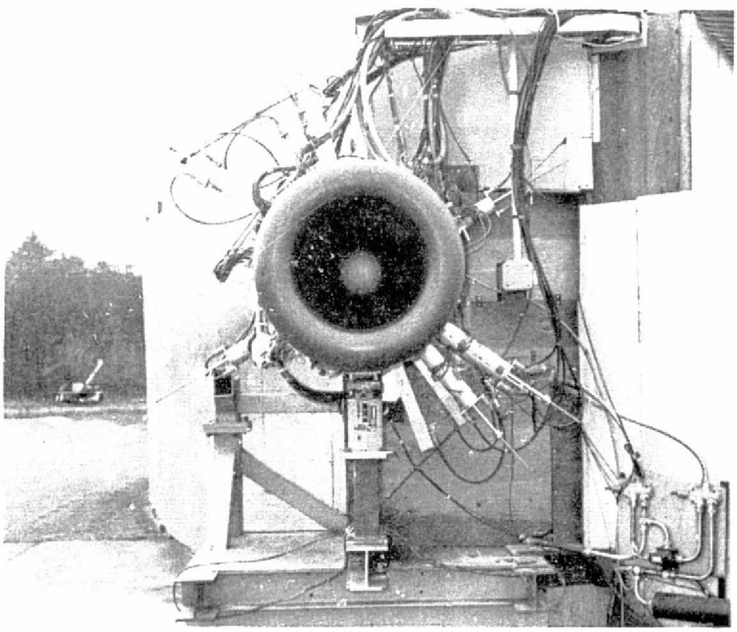
Figure 5b Schematic of X-308 Stand Showing Acoustic Shield



Side View

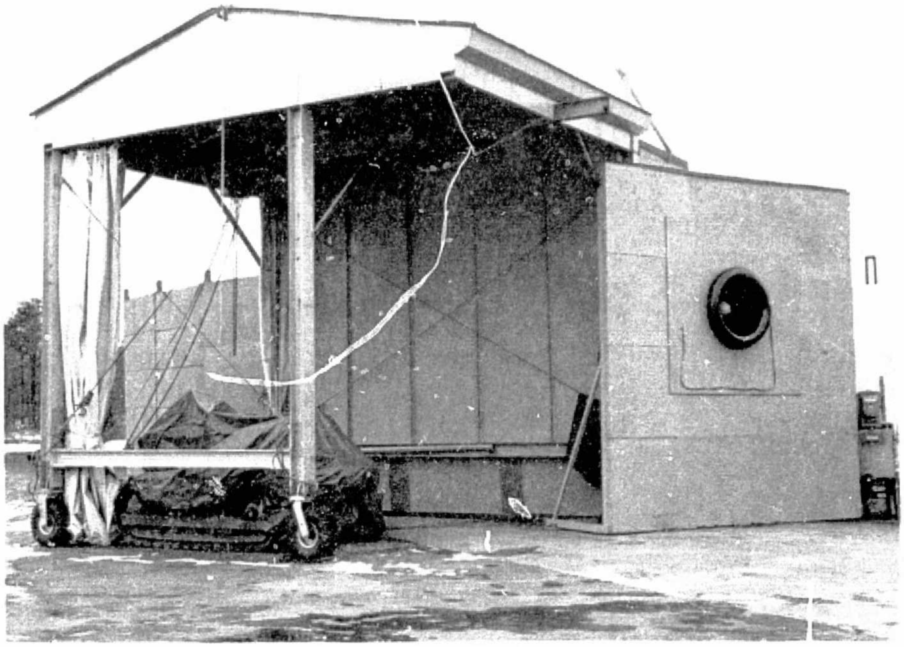


Side View Closeup

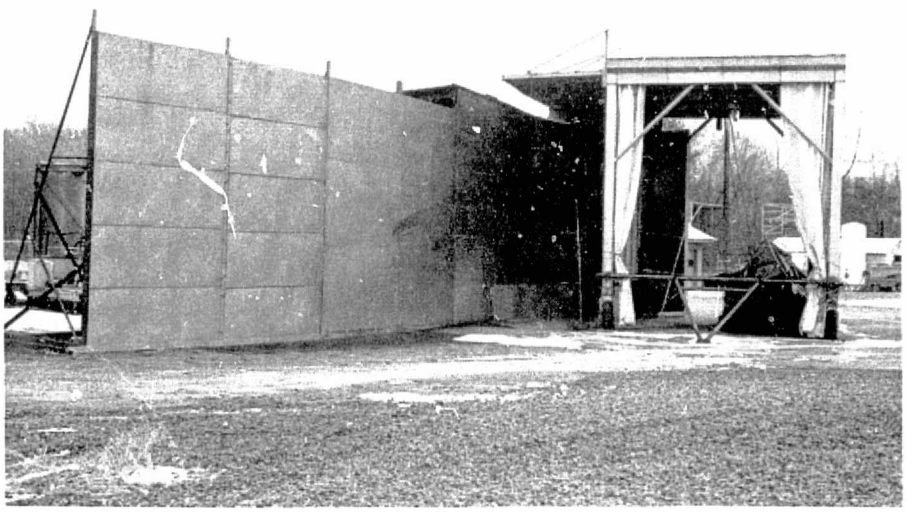


Front View

Figure 6 NASA Quiet Two-Stage Fan Installed in X-308 Stand



Forward View



Side View

Figure 7 X-308 Stand Showing Acoustic Shielding

Figure 8 X-308 Stand Showing Far Field Microphone Installation

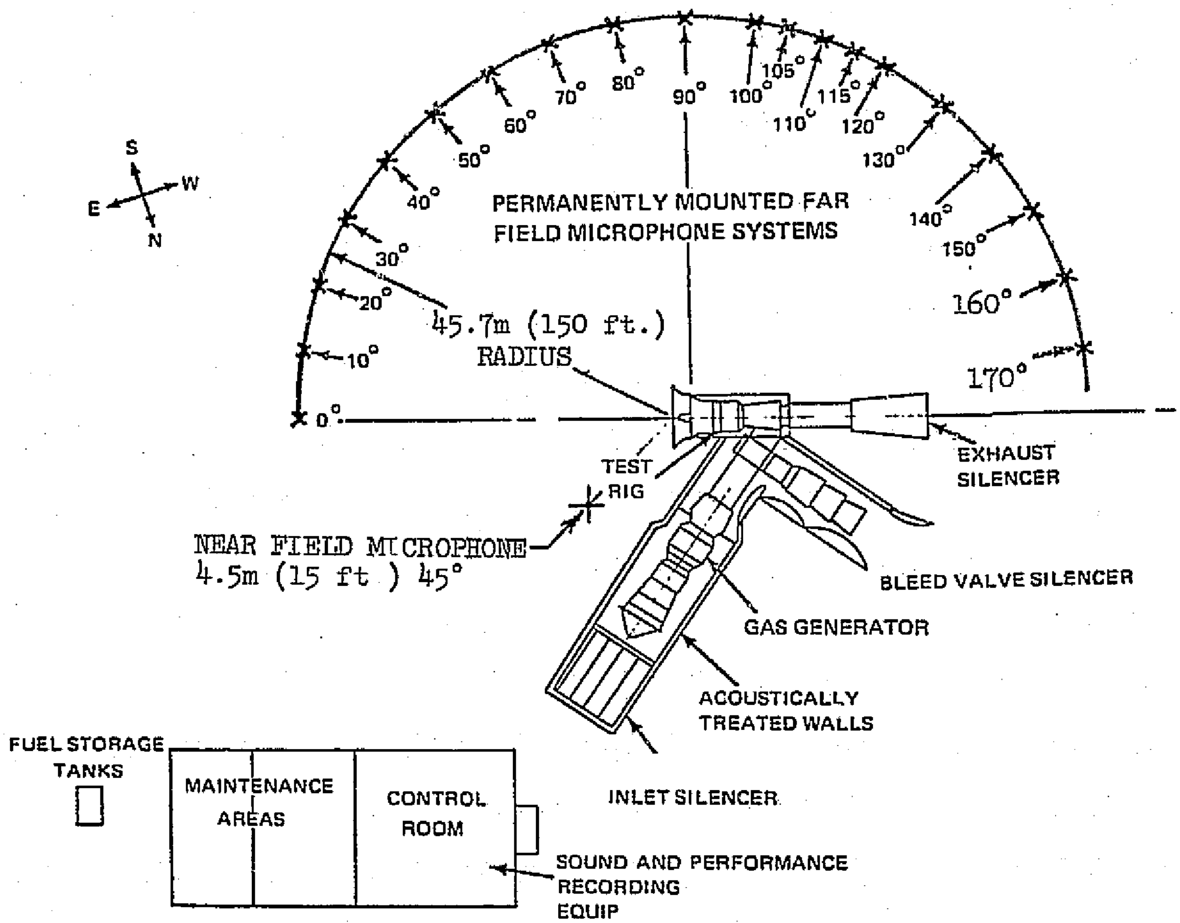


Figure 9 General Arrangement of X-308 Stand Showing Microphone Locations

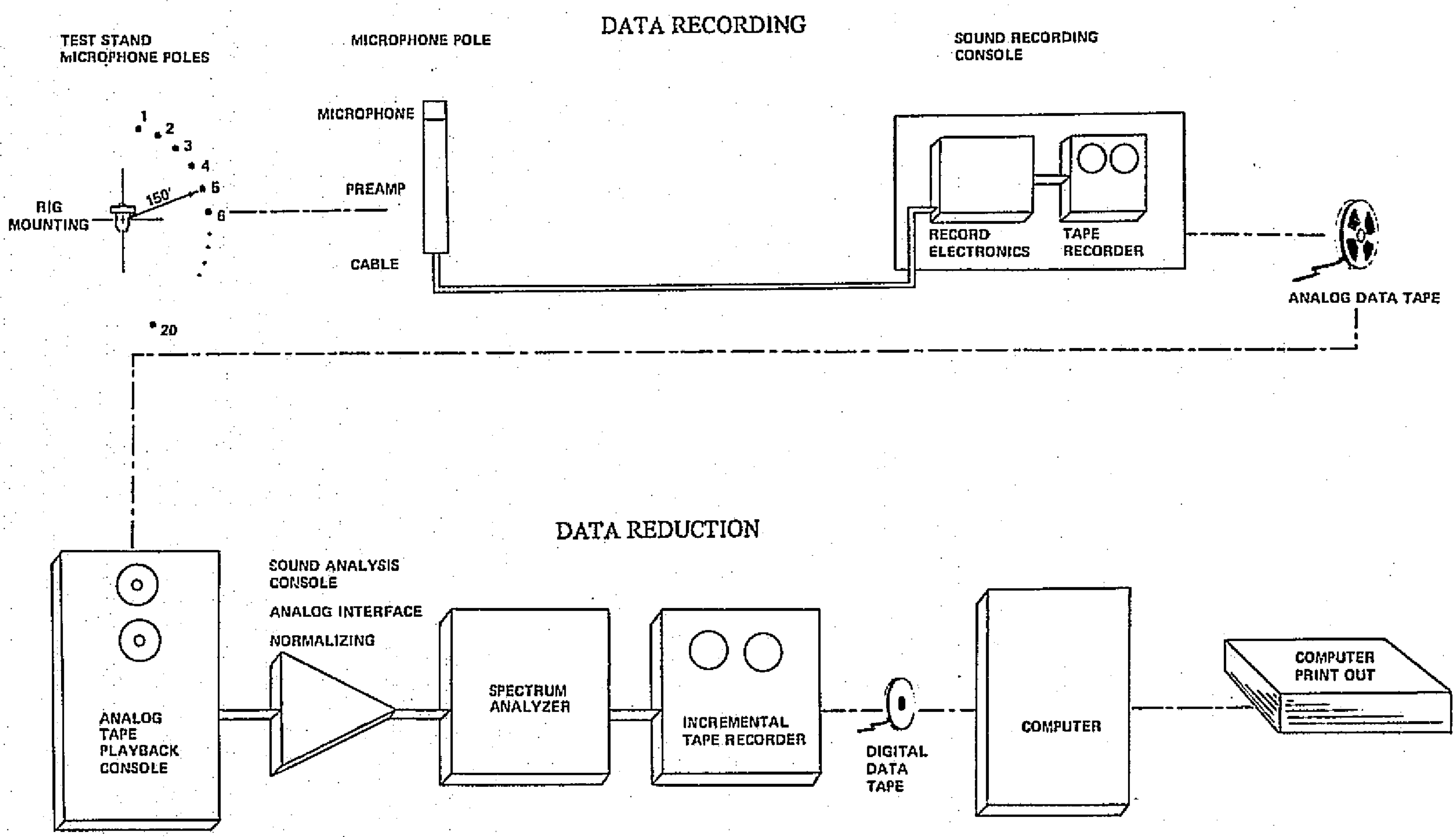


Figure 10 Schematic of Sound Data System

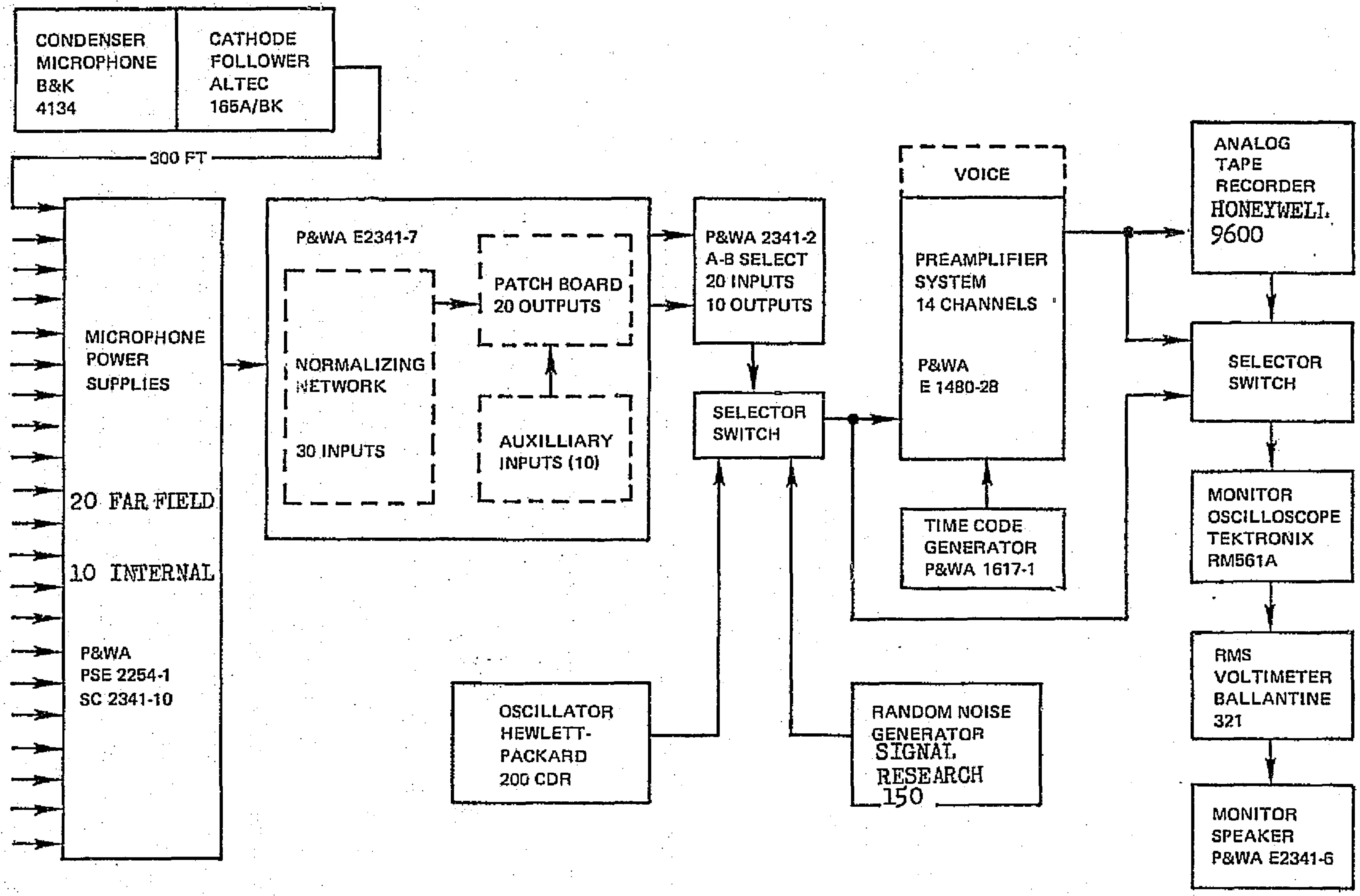
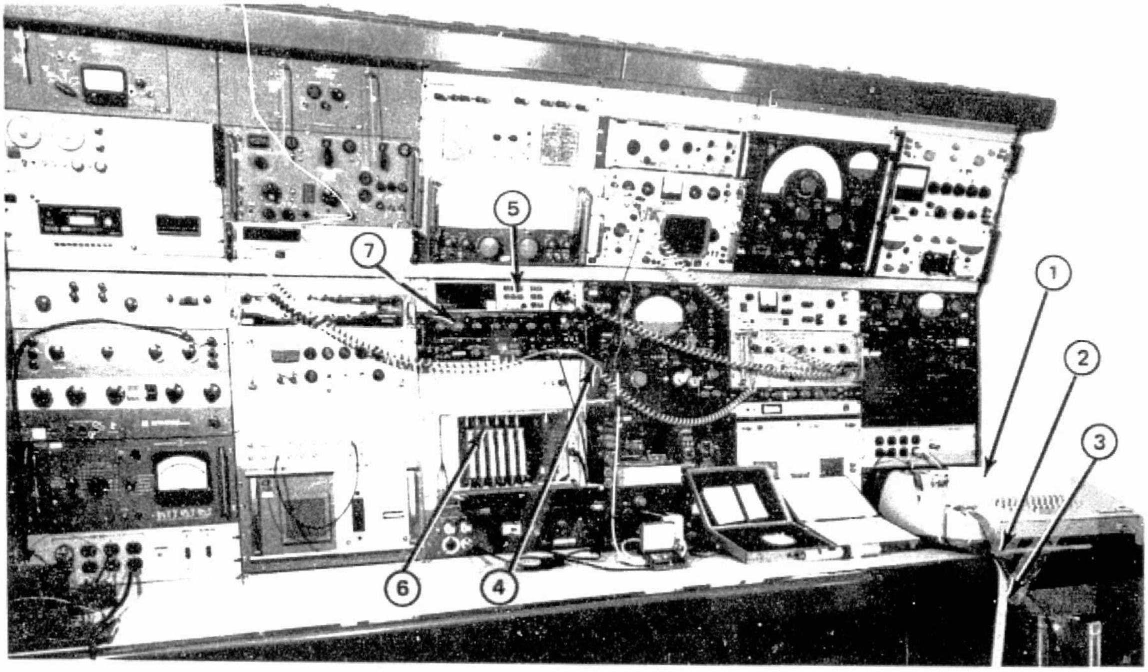


Figure 11 Schematic Diagram of P&WA Sound Recording System



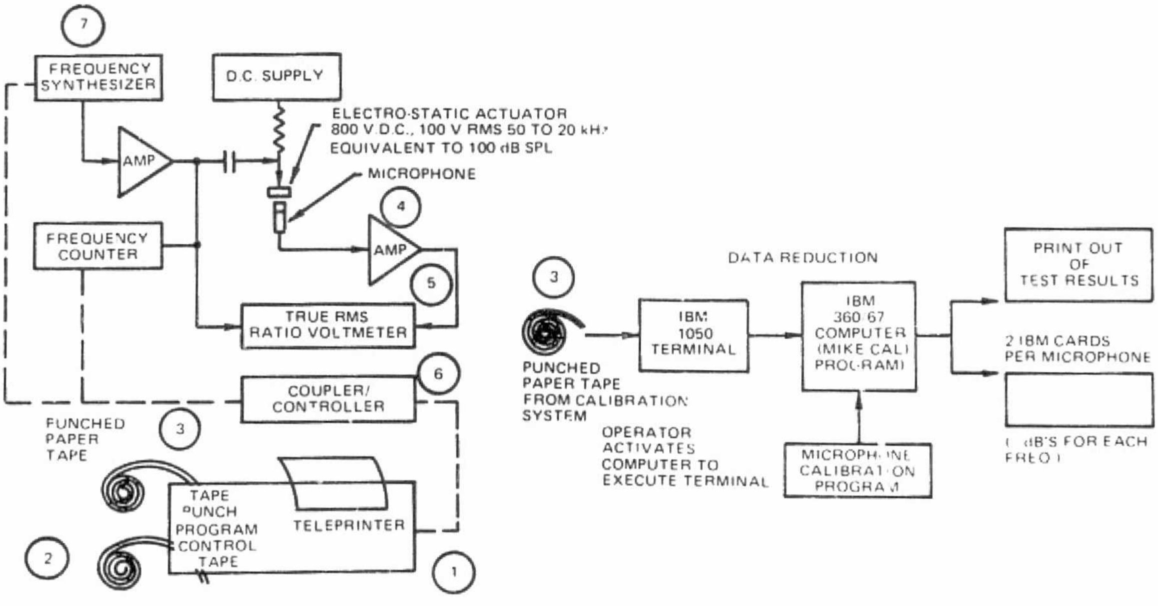


Figure 12 Microphone Calibration System

TEMPERATURE = 35.0 F	ENGINE MODEL	= -00	INLET TEMP	= 29.00 F
HUMIDITY = 77.0 PER CT.	ENGINE NUMBER	= 704741	TIME OF DAY	= 2022
	CAL LEVEL	= 124. DB.	BARM. PRESSURE	= 29.75 IN. HG.
	STAND	= X-308	WIND DIRECTION	= S
CONDITION = 3268	DATE	= 01/24/75	WIND VELOCITY	= 3 MPH

STANDARD REFERENCE DAY CORRECTED SPL IN DB — RADIUS = 150.0 FT.

1/3 OCT FREQUENCY (HZ)	MICROPHONE ANGLES IN DEGREES 0	10	20	30	40	50	60	70	80	90	100	105	110	115	120	130	140	150	160	170
50	70.1	66.3	69.9	67.8	69.8	67.9	67.5	66.7	69.2	66.8	68.9	66.2	69.7	67.8	69.9	68.6	70.4	69.6	71.5	70.8
63	79.1	76.9	78.5	76.9	78.8	77.8	74.5	77.1	78.2	77.5	78.4	77.1	79.4	78.7	79.6	79.2	79.6	79.2	80.0	77.8
80	76.1	65.9	71.4	66.3	79.4	64.6	69.5	63.6	68.9	63.6	69.2	62.7	68.2	62.2	68.4	64.8	69.8	66.9	70.6	68.1
100	75.8	63.8	71.9	62.2	71.2	63.4	70.6	62.5	70.1	62.3	69.5	61.9	69.6	61.7	69.7	64.4	71.5	66.0	70.7	65.3
125	75.8	65.3	75.2	66.4	74.3	63.3	72.6	66.4	73.5	68.3	73.8	69.8	72.5	65.4	74.5	68.7	74.2	68.2	73.6	67.0
160	75.6	65.0	75.5	64.6	75.1	65.3	73.2	65.6	74.1	66.7	73.0	66.8	74.1	67.7	74.3	70.1	75.3	71.7	76.2	68.7
200	74.1	67.0	75.4	67.3	74.8	68.1	73.5	68.1	74.2	68.5	73.9	68.8	74.4	76.0	74.3	72.1	75.7	76.1	76.6	71.6
250	74.0	68.9	75.2	69.8	73.7	68.0	73.2	69.9	73.7	73.7	74.3	72.1	72.9	68.2	75.3	71.7	74.6	73.5	75.7	72.9
315	73.7	69.6	73.3	68.9	73.5	70.2	73.0	69.2	73.2	76.9	72.8	70.3	73.2	70.0	73.4	71.0	75.1	76.2	77.9	76.3
400	72.7	67.4	72.9	66.8	72.6	69.0	71.8	68.5	72.0	70.1	71.9	69.7	71.9	68.0	72.7	69.9	74.6	75.7	80.6	73.8
500	73.4	66.8	71.7	66.8	71.6	67.6	70.9	68.8	71.8	68.0	70.6	68.2	70.4	67.6	71.7	69.6	74.0	76.3	79.7	74.5
630	69.9	66.1	71.6	66.8	71.5	67.1	69.7	67.1	70.4	66.9	70.2	68.0	70.1	67.6	71.6	69.6	72.6	75.9	77.2	72.2
800	68.6	65.1	69.1	66.3	69.2	66.3	68.8	65.8	68.9	65.8	68.6	66.5	69.3	67.7	69.9	66.1	71.3	73.1	74.4	69.3
1000	68.1	66.6	69.5	67.3	69.2	66.9	68.0	65.3	67.7	65.5	67.7	66.3	67.8	65.8	69.3	67.0	69.3	72.3	73.1	68.6
1250	70.1	69.6	71.4	69.8	70.4	68.6	68.3	66.6	67.2	65.2	66.1	64.9	66.4	65.2	67.7	65.6	68.3	71.3	72.1	68.2
1600	75.4	76.2	78.5	78.3	78.2	77.0	75.3	73.5	70.1	69.6	68.5	67.7	67.9	67.3	68.1	66.8	68.4	72.1	72.8	69.1
2000	71.6	71.0	70.9	70.2	73.1	69.0	67.2	65.9	65.5	65.0	65.0	65.6	66.1	65.1	66.5	65.6	68.3	71.9	72.8	69.0
2500	71.8	71.6	71.6	71.6	7 .8	69.5	68.1	66.3	65.2	64.6	64.5	64.7	65.2	65.4	66.9	67.7	72.8	79.3	77.2	72.4
3150	74.9	75.4	77.1	77.3	77.5	74.9	73.2	71.2	67.6	66.3	65.4	65.1	64.9	64.7	65.4	65.9	70.3	74.9	74.7	70.9
4000	74.2	75.3	75.8	76.5	82.8	74.7	72.0	69.9	68.5	66.1	64.4	64.6	66.2	65.2	65.0	64.6	68.3	73.0	72.1	68.9
5000	73.4	73.8	74.8	74.5	74.8	72.7	71.6	69.6	66.5	65.0	65.2	65.7	67.1	66.0	65.7	67.0	69.6	74.6	72.9	68.6
6300	72.3	72.5	73.7	73.3	73.1	70.9	69.5	68.1	65.2	64.9	66.0	67.3	69.4	68.4	67.9	67.9	66.9	68.7	67.9	65.2
8000	72.9	72.4	73.9	72.6	72.1	70.0	68.5	67.6	67.2	69.7	70.0	71.3	73.7	72.7	73.9	70.1	67.0	66.6	65.4	62.0
10000	69.3	68.8	69.8	69.6	72.4	69.5	68.5	70.2	72.2	75.5	75.0	76.5	79.6	76.7	79.1	73.1	70.4	67.8	65.5	62.2
12500	65.3	65.3	66.4	65.2	65.7	64.3	62.6	61.6	61.6	61.9	64.6	66.2	67.7	65.7	68.3	65.8	62.6	59.6	57.5	54.6
16000	61.2	60.0	62.1	60.7	60.6	59.6	58.5	57.4	57.8	57.5	60.2	61.2	61.9	60.5	62.2	61.4	56.7	54.7	5.3	5.6
20000	60.9	8.7	62.8	59.5	9.5	9.5	9.6	8.7	60.1	60.3	60.8	61.9	9.7	10.2	63.6	60.6	10.9	8.7	10.6	10.2
TSPL	87.0	85.2	88.0	86.0	88.7	85.0	85.3	83.3	85.2	83.4	85.3	83.7	86.3	84.0	86.8	84.3	86.7	87.9	89.4	85.2
OASPL	87.5	85.1	87.9	85.9	88.6	85.0	85.2	83.2	85.2	83.3	85.3	83.6	86.2	83.9	86.7	84.2	86.7	87.9	89.4	85.2
PNLT	100.7	100.1	103.0	102.1	105.7	100.4	99.8	97.4	96.3	95.2	95.6	95.8	97.7	96.0	98.0	95.6	98.6	102.6	101.9	97.3
PNL	99.2	98.2	100.5	99.3	103.6	97.7	97.3	95.8	94.8	93.2	94.1	93.7	95.9	93.7	96.2	93.5	97.0	100.7	100.4	95.9
DBA	84.3	84.3	85.9	85.4	87.5	83.8	82.7	80.8	80.4	79.5	80.2	79.9	81.8	80.1	82.2	79.7	82.3	85.9	86.2	81.8
BAND	16	16	16	16	16	16	16	16	2	2	2	2	2	2	2	2	2	18	2	2
TCORR	1.5	2.3	2.4	2.8	2.6	2.7	2.5	2.4	1.5	2.1	1.6	2.1	1.7	2.3	1.7	2.1	1.6	2.0	1.5	1.4

MAXIMUM OASPL = 89.37	COMPOSITE SPL = 91.30
MAXIMUM PNLT = 105.66	COMPOSITE PNL = 104.75
MAXIMUM PNL = 103.01	PNLT (INTEGRATED) = 113.06
MAXIMUM DBA = 87.49	

Figure 13 Sample Radius Printout Corrected to Standard Day Conditions

CONDITION = 3268

ALTITUDE = 200. FT SIDELINE

1/3 OCT FREQUENCY (HZ)	MICROPHONE ANGLES IN DEGREES 10	20	30	40	50	60	70	80	90	100	105	110	115	120	130	140	150	160	170
50	48.5	58.0	59.3	63.4	63.1	63.7	63.7	66.6	64.3	66.3	63.4	66.7	64.4	66.1	63.8	64.0	61.1	59.6	53.0
63	59.1	66.6	68.4	72.4	73.0	70.7	74.1	75.6	75.0	75.8	74.3	76.4	75.3	75.8	74.4	73.2	70.7	68.1	-60.0
80	48.1	59.5	57.7	64.0	59.8	65.7	60.5	66.3	61.1	66.6	59.9	65.1	58.8	64.6	60.0	63.4	58.3	58.7	50.3
100	45.9	60.0	53.6	64.8	58.6	66.8	59.4	67.5	59.8	66.9	59.1	66.5	58.3	65.9	59.6	65.1	57.4	58.6	47.4
125	47.4	63.3	57.8	67.9	58.5	68.8	63.3	70.9	65.8	71.2	67.0	69.4	62.0	70.7	63.9	67.6	59.6	61.7	49.1
160	47.1	63.6	56.0	68.7	60.5	69.4	62.5	71.4	64.2	71.1	64.0	71.0	64.3	70.5	65.3	68.9	63.1	64.3	50.8
200	49.0	63.4	58.7	68.4	63.2	69.7	65.0	71.5	65.8	71.2	66.0	71.3	66.6	70.5	67.2	69.3	67.5	66.6	53.6
250	50.8	63.2	61.2	67.3	63.1	69.4	66.8	71.6	68.2	71.6	69.3	69.8	64.8	71.5	66.8	60.2	64.9	63.7	54.8
315	51.4	61.3	60.3	67.1	65.3	69.2	66.1	70.5	68.4	70.1	67.5	70.1	66.6	69.6	66.1	68.7	67.6	65.9	58.1
400	49.1	60.8	60.1	66.1	64.1	68.0	65.4	69.3	67.6	69.2	66.8	68.8	64.6	68.9	65.0	68.1	67.0	68.5	55.5
500	48.3	59.5	58.1	65.1	62.7	67.1	65.7	69.1	65.4	67.9	65.3	67.3	64.4	67.9	64.7	67.5	67.6	67.5	56.0
630	47.5	58.4	58.5	64.0	62.2	65.9	64.0	67.7	64.3	67.5	65.1	67.0	64.2	67.8	64.7	66.1	67.1	65.0	53.6
800	46.2	56.8	57.5	62.7	61.3	64.9	62.7	66.2	63.2	65.9	63.6	66.2	64.3	66.0	63.1	64.8	64.3	62.1	50.4
1000	47.4	57.0	58.4	62.6	61.9	64.1	67.2	65.0	62.9	65.0	63.4	64.7	62.3	65.4	62.0	62.7	63.4	60.6	49.4
1250	50.1	58.8	[illegible]	63.8	63.6	64.4	63.5	64.5	62.6	63.4	62.0	63.3	61.8	63.8	60.6	61.7	62.4	59.5	48.7
1600	56.1	65.6	69.2	71.5	71.9	71.4	70.3	67.3	67.0	65.7	64.8	64.7	63.8	64.2	61.7	61.7	63.0	59.9	49.0
2000	50.2	57.8	[illegible]	63.5	63.9	63.2	62.7	62.7	62.4	62.2	62.6	62.9	61.5	62.5	60.5	61.5	62.6	59.7	48.2
2500	49.9	58.3	62.1	63.8	64.3	64.1	63.0	62.4	61.9	61.7	61.7	61.9	61.0	62.9	62.5	65.8	69.8	63.7	50.7
3150	52.2	62.9	67.4	70.3	69.5	69.0	67.0	64.7	63.2	62.5	62.0	61.5	61.0	61.2	60.5	63.1	65.0	60.5	47.7
4000	49.9	60.7	66.1	75.2	69.0	67.6	66.4	65.5	63.2	61.4	61.4	62.7	61.3	60.6	58.9	60.7	62.6	57.0	43.5
5000	47.0	59.0	63.2	67.0	66.9	67.1	66.0	63.4	62.0	62.1	62.4	63.5	62.0	61.2	61.2	61.8	63.8	57.1	41.8
6300	42.1	56.4	61.6	64.7	64.7	64.8	64.3	61.9	61.8	62.7	63.8	65.6	64.2	63.2	61.7	58.5	57.0	50.6	34.8
8000	36.1	54.0	59.4	62.7	63.1	63.2	63.3	63.5	66.2	66.3	67.4	69.4	68.0	68.6	63.2	57.6	53.4	45.5	25.7
10000	23.9	46.2	54.3	59.7	61.7	62.6	65.5	68.2	71.7	71.0	72.2	74.3	71.5	73.2	65.3	59.7	52.5	41.9	17.3
CASPL	64.4	75.0	76.3	81.6	79.7	81.3	79.9	82.4	80.5	82.4	80.4	82.8	80.1	82.5	79.0	80.1	78.8	77.0	66.4
PNLT	76.9	88.7	92.1	98.2	94.9	95.6	94.0	93.3	92.1	92.3	92.2	93.8	91.7	93.2	90.1	91.4	92.9	88.1	75.3
PNL	74.9	86.2	89.3	95.6	92.2	93.0	91.6	91.8	90.0	90.8	90.1	92.0	89.4	91.4	88.0	89.8	90.9	86.6	74.0
DBA	62.0	72.0	75.5	80.2	78.4	78.6	77.4	77.5	76.5	77.1	76.5	78.0	75.9	77.6	74.1	75.3	76.5	73.2	61.5
BAND	16	16	16	16	16	16	16	2	2	2	2	2	2	2	2	2	18	2	2
TCORR	2.0	2.5	2.8	2.6	2.7	2.5	2.4	1.5	2.1	1.6	2.1	1.7	2.3	1.7	2.1	1.6	2.0	1.5	1.4

PNLT (INTEGRATED) = 105.61

Figure 14 Sample Extrapolated Sideline Printout

TEMPERATURE = 59.0 F		INLET TEMP	= 29.00 F
HUMIDITY = 70.0 PER CT.		TIME OF DAY	= 2022
CONDITION = 3268		BARM. PRESSURE	= 29.75 IN. HG.
		WIND DIRECTION	= S
		WIND VELOCITY	= 3 MPH

STANDARD DAY — 1/3 OCTAVE BAND MODEL NOISE DATA 150.FT — (SCALED ENGINE) SCALE= 2.2/1.0

MICROPHONE ANGLES IN DEGREES

BAND CENTER FREQ (KHZ)	0	10	20	30	40	50	60	70	80	90	100	105	110	115	120	130	140	150	160	170
.050	65.0	63.[illegible]	66.4	64.2	66.1	63.6	64.9	62.2	64.6	62.4	64.6	63.2	64.7	62.7	66.2	63.9	66.2	69.2	70.0	65.5
.063	66.[illegible]	64.[illegible]	67.4	65.2	67.1	64.8	65.9	63.2	65.6	62.4	65.6	64.2	65.7	63.7	67.2	64.9	67.2	70.2	71.0	66.5
.080	67.6	65.5	67.4	66.2	61.1	65.6	66.9	64.2	66.6	64.4	66.6	65.2	66.7	64.7	68.2	65.9	68.2	71.2	72.0	67.5
.100	68.[illegible]	66.5	69.4	67.2	69.1	66.8	67.9	65.2	67.6	65.4	67.6	66.2	67.7	65.7	69.2	66.9	69.2	72.2	73.0	68.5
.125	69.0	67.5	70.4	68.2	7[illegible].1	67.6	68.9	66.2	68.6	66.4	68.6	67.2	68.7	66.7	70.2	67.9	70.2	73.2	74.0	69.5
.160	70.0	68.6	71.4	69.2	71.1	68.6	69.9	67.2	69.6	67.4	69.6	68.2	69.7	67.7	71.2	68.9	71.2	74.2	75.0	70.5
.200	71.0	69.5	72.4	70.2	72.1	69.6	70.9	68.2	70.6	68.4	70.6	69.2	70.7	68.7	72.2	69.9	72.2	75.2	76.0	71.5
.250	72.0	70.5	73.4	71.2	73.1	70.6	71.9	69.2	71.6	69.4	71.6	70.2	71.7	69.7	73.2	70.9	73.2	76.2	77.0	72.5
.315	73.0	71.5	74.4	72.2	74.1	71.6	72.9	70.2	72.6	70.4	72.6	71.2	72.7	70.7	74.2	71.9	74.2	77.2	78.0	73.5
.400	74.0	72.5	75.4	73.2	75.1	72.6	73.9	71.2	73.6	71.4	73.6	72.2	73.7	71.7	75.2	72.9	75.2	78.2	79.0	74.5
.500	75.1	73.6	76.5	74.3	74.2	73.9	75.[illegible]	72.3	74.7	72.5	74.7	72.3	74.8	72.6	76.3	74.[illegible]	76.3	79.3	80.1	75.6
.630	77.1	76.6	76.4	76.8	77.4	75.0	75.3	73.[illegible]	74.2	72.2	75.1	71.9	73.4	72.2	74.7	72.6	75.3	76.3	79.1	75.2
.800	82.4	82.7	81.5	85.[illegible]	85.2	84.0	82.5	80.5	77.1	76.6	75.5	74.7	74.9	74.3	75.1	73.6	75.4	79.1	79.6	76.1
1.00	78.7	78.1	78.0	77.3	77.2	76.1	74.3	73.0	72.6	72.1	72.1	71.7	73.2	72.2	73.6	72.7	75.6	75.0	79.9	76.1
1.25	79.0	78.5	79.0	78.6	78.0	76.7	75.3	73.5	72.4	71.8	71.7	71.9	72.4	72.6	74.1	74.9	80.0	86.5	84.4	79.6
1.60	82.[illegible]	82.7	84.4	84.6	84.8	82.2	80.5	78.5	74.9	73.3	72.7	72.4	72.2	72.0	72.7	73.2	77.6	82.2	82.0	78.2
2.00	81.7	81.1	83.3	84.0	92.3	82.2	79.5	77.4	76.0	73.6	71.9	72.1	72.7	72.7	72.5	72.1	75.8	80.5	79.6	76.4
2.50	81.0	81.4	82.4	81.0	82.4	80.3	79.2	77.2	74.1	72.6	72.8	73.3	74.7	73.6	73.3	74.6	77.2	82.2	80.5	76.2
3.15	80.[illegible]	80.5	81.7	81.3	81.1	78.9	77.5	96.1	73.2	72.9	74.0	75.2	77.4	76.4	75.9	75.9	74.9	76.7	75.9	73.2
4.00	80.5	80.9	82.4	81.1	85.6	78.8	77.5	76.1	75.7	76.2	76.5	79.6	82.2	81.2	82.4	78.6	75.5	75.1	73.9	72.5
5.00	78.6	78.4	79.4	79.[illegible]	80.0	79.1	71.1	79.8	81.8	85.1	84.6	86.1	86.6	86.3	86.7	82.7	80.0	77.4	75.1	71.8
6.30	76.2	76.2	77.3	76.1	76.6	75.2	73.5	72.5	72.5	72.8	75.5	77.1	76.6	76.6	78.9	76.7	73.5	70.5	66.4	65.5
8.00	73.7	72.[illegible]	74.6	73.[illegible]	73.1	71.9	71.[illegible]	69.9	70.3	70.6	72.7	73.7	74.4	73.0	74.7	73.9	71.2	67.2	17.8	16.1
10.0	76.2	24.0	78.1	74.8	24.8	24.8	24.9	24.0	75.4	75.6	76.1	77.2	25.0	25.5	76.9	75.9	26.2	24.0	25.9	25.5
OSPL	91.3	91.4	93.0	92.5	94.2	90.6	89.5	88.6	87.9	86.5	88.7	89.5	91.3	89.5	91.7	88.3	88.7	92.2	91.7	87.5
PNLT	105.7	106.2	108.2	107.5	110.[illegible]	105.6	104.3	103.5	104.6	106.5	106.0	107.0	106.8	106.6	109.3	104.4	104.1	106.2	105.5	101.3
PNL	104.2	103.8	105.7	104.6	1[illegible]7.5	102.6	101.8	101.1	102.1	103.4	103.5	104.4	106.0	104.2	106.6	102.8	101.7	104.0	102.8	98.8
DBA	91.4	91.7	93.1	92.7	94.6	91.6	89.4	88.1	87.3	88.5	88.4	89.5	91.4	89.7	91.6	88.3	88.2	91.5	90.9	86.9
BAND	13	23	13	13	13	13	13	13	21	21	21	21	21	21	21	21	23	23	22	22
TCOR	1.5	2.[illegible]	2.4	2.3	2.6	2.7	2.5	2.4	2.6	3.1	2.5	2.5	2.7	2.5	2.7	1.7	2.4	2.2	2.7	2.5

MAXIMUM LAFPL = 94.23		COMPOSITE SPL	= 96.27
MAXIMUM PNLT = 110.19		COMPOSITE PNL	= 109.51
MAXIMUM PNL = 107.55		PNLT (INTEGRATED)	= 119.58
MAXIMUM DBA = 94.76			

THE FOLLOWING CONDITION HAS BEEN ADDED TO THE DATA BASE

BASE ID LD DATE ENG MTT ENC NC STND C OBS CORP TEMP HUM TTI TIME BARM WD WV RUN
6[illegible] 2 5.0 01/24/75 [illegible] 70.741 X30P [illegible] 3268 3268 59.0 70.0 29.0 2022 29.75 S 3 60.1 F H6566 NASA Q2S FULL TRT W/FLT INLET N
O HALL 150.1743

Figure 15 Sample of Q2S Fan Data Scaled to STF 433 Fan Size

CONDITION = 3268 ALTITUDE = 150. FT SIDELINE

OSPL	74.0	82.6	85.9	[illegible]	88.5	[illegible]	87.5	87.7	88.5	88.6	89.2	90.7	88.5	90.3	85.7	84.6	85.8	81.8	71.0
PNLT	87.4	97.1	100.7	[illegible]	[illegible]	103.0	102.9	104.5	106.5	105.9	106.6	[illegible]	105.7	107.9	101.8	99.7	99.6	95.1	83.0
PNL	[illegible]	[illegible]	97.9	[illegible]	[illegible]	103.4	[illegible]	101.9	103.4	103.4	104.1	105.4	103.2	105.2	100.1	97.3	97.4	92.4	80.9
DBA	74.0	82.6	86.1	93.6	88.5	88.1	87.5	87.2	88.5	88.3	89.1	90.8	88.7	90.2	85.4	[illegible]	85.4	80.9	69.9
BAND	23	13	13	13	13	13	13	21	21	21	21	21	21	21	21	23	23	22	22
TCOR	2.0	2.5	2.8	2.6	2.7	2.5	2.4	2.6	3.1	2.5	2.5	2.7	2.5	2.7	1.7	2.4	2.2	2.7	2.1

CONDITION = 3268 ALTITUDE = 200. FT SIDELINE

OSPL	[illegible]	79.7	82.1	87.4	85.6	85.5	84.7	84.9	85.6	85.7	86.2	87.8	85.6	87.4	82.7	81.8	83.1	79.0	66.1
PNLT	83.8	[illegible]	97.8	102.2	100.2	[illegible]	[illegible]	101.6	103.6	103.0	103.7	105.3	102.8	104.9	98.8	96.7	96.7	92.6	78.8
PNL	81.8	91.4	[illegible]	103.6	97.5	97.7	97.6	99.0	100.5	100.5	101.2	102.5	100.3	107.2	97.1	94.3	94.5	89.4	77.4
DBA	70.7	79.6	82.3	87.9	85.7	85.4	84.7	84.4	85.6	85.4	86.2	87.9	85.8	87.2	82.4	81.2	82.7	78.0	66.0
BAND	13	13	13	13	13	13	13	21	21	21	21	21	21	21	21	23	23	22	22
TCOR	2.0	2.5	2.8	2.6	2.7	2.5	2.4	2.6	3.1	2.5	2.6	2.8	2.5	2.7	1.7	2.4	2.3	2.6	1.4

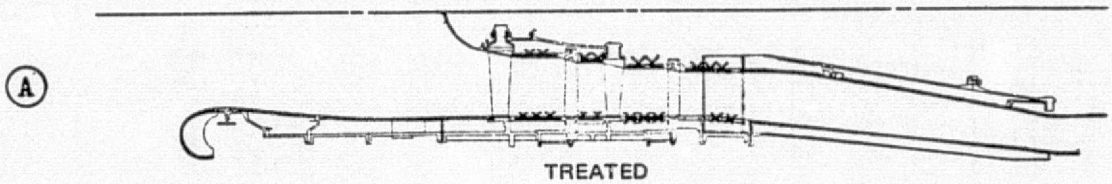
CONDITION = 3268 ALTITUDE = 370. FT SIDELINE

OSPL	67.5	77.1	76.7	81.2	79.6	79.6	78.7	78.8	79.2	79.3	79.6	81.2	79.6	80.6	76.2	75.7	77.1	72.9	61.4
PNLT	75.2	84.4	91.0	96.9	[illegible]	[illegible]	93.5	95.1	97.1	96.4	97.1	98.7	96.1	98.1	91.9	89.8	89.8	84.0	70.7
PNL	73.3	83.9	88.2	94.2	91.2	91.4	91.1	92.5	93.6	93.8	94.4	95.9	93.6	95.4	90.1	87.4	87.8	82.4	69.4
DBA	63.0	72.8	76.9	81.7	79.6	79.5	78.6	78.1	79.0	78.8	79.5	81.2	79.1	80.3	75.7	[illegible]	76.5	71.6	59.5
BAND	13	13	13	13	13	13	23	21	21	21	21	21	21	21	21	23	16	22	21
TCOR	2.0	2.5	2.8	2.7	2.7	2.5	2.4	2.6	3.3	2.6	2.6	2.8	2.6	2.8	1.8	2.4	2.0	1.6	1.3

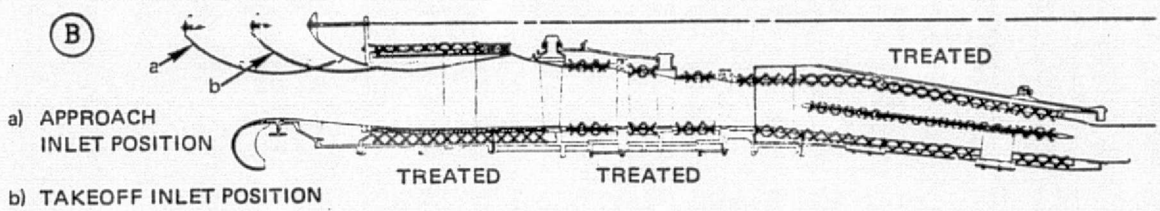
CONDITION = 3268 ALTITUDE = 1000. FT SIDELINE

OSPL	50.1	61.3	65.4	70.2	69.0	69.3	68.2	68.2	67.6	68.0	67.6	68.9	66.9	66.5	64.8	65.2	66.4	62.1	49.5
PNLT	58.2	72.2	77.9	84.9	82.5	82.4	81.5	82.5	84.2	83.5	84.0	85.6	83.0	84.6	78.1	77.0	77.0	70.4	53.3
PNL	56.2	69.8	75.1	82.2	79.6	79.2	79.1	79.6	80.7	80.7	81.1	82.6	80.2	81.5	76.0	74.7	75.6	68.6	53.3
DBA	[illegible]	60.1	65.6	70.2	68.7	68.5	67.8	66.8	66.6	66.6	66.8	68.1	66.1	67.1	63.3	63.6	65.1	59.6	45.5
BAND	13	13	13	13	13	13	13	21	21	21	21	21	21	21	21	21	16	21	24
TCOR	2.0	2.5	2.8	2.7	2.7	2.5	2.4	2.9	3.5	2.8	2.9	3.1	2.8	3.0	2.1	2.3	2.0	1.5	0.0

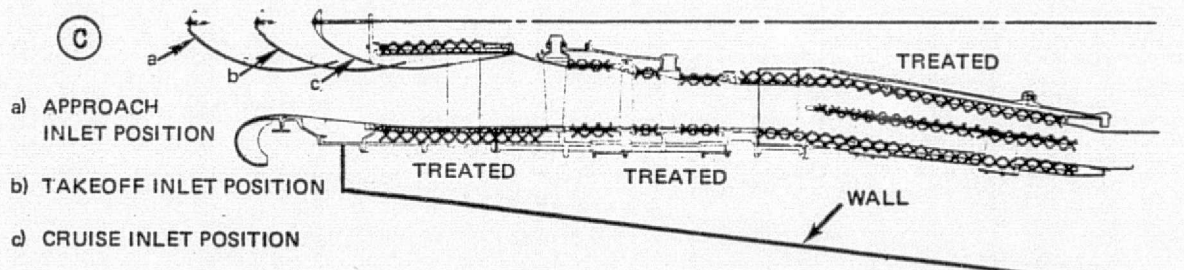
Figure 15 (Cont'd)



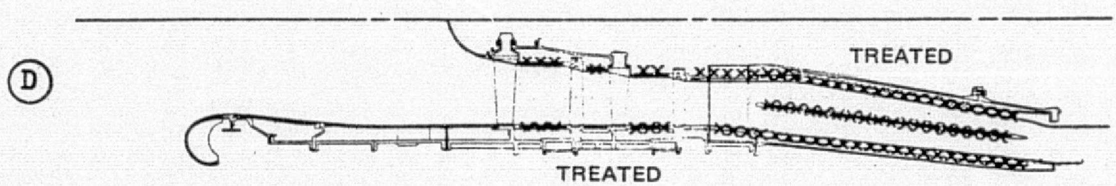
BASELINE CONFIGURATION: HARDWALL ENGINE INLET COWLINGS, TREATED INTERSTAGE, HARDWALL EXIT DUCTS.



FULLY TREATED CONFIGURATION: TREATED SONIC INLET, TREATED INTERSTAGE AND AFT DUCTS WITH AFT ACOUSTIC SPLITTER INSTALLED.



FULLY TREATED CONFIGURATION WITH AFT ACOUSTIC FACILITY WALL



MODIFIED B **CONFIGURATION: HARDWALL ENGINE INLET COWLING, TREATED INTERSTAGE AND AFT DUCTS WITH AFT ACOUSTIC SPLITTER INSTALLED.**

Figure 16 Configurations Tested

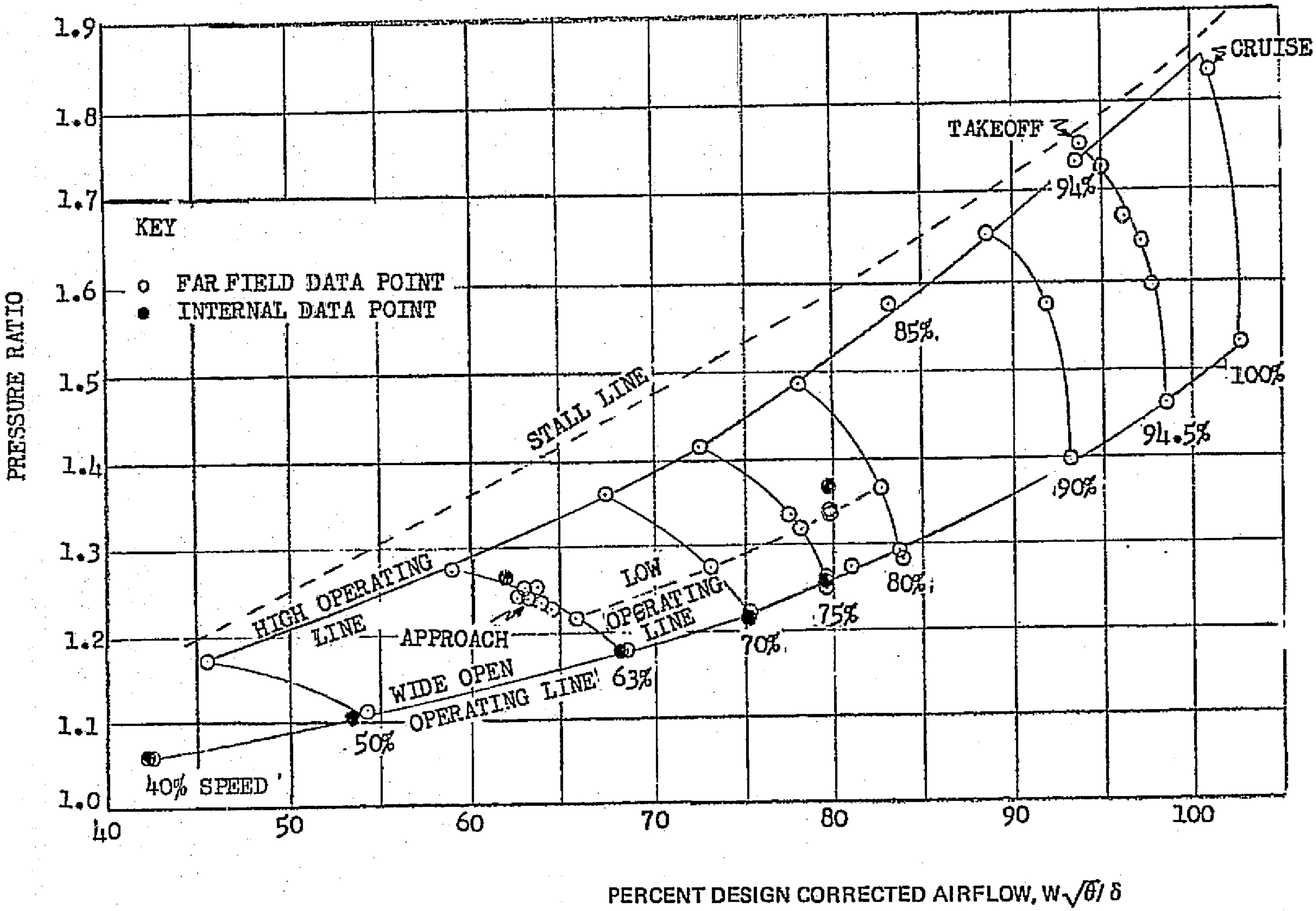
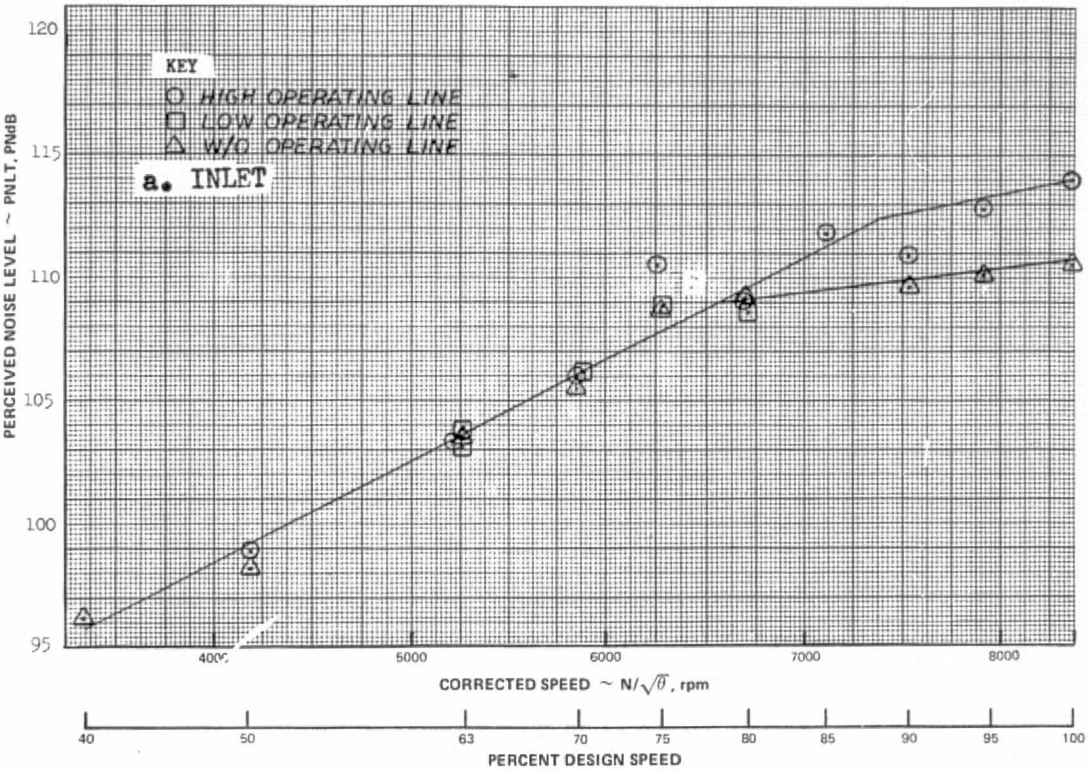


Figure 17 Q2S Performance Map Showing Acoustic Data Points



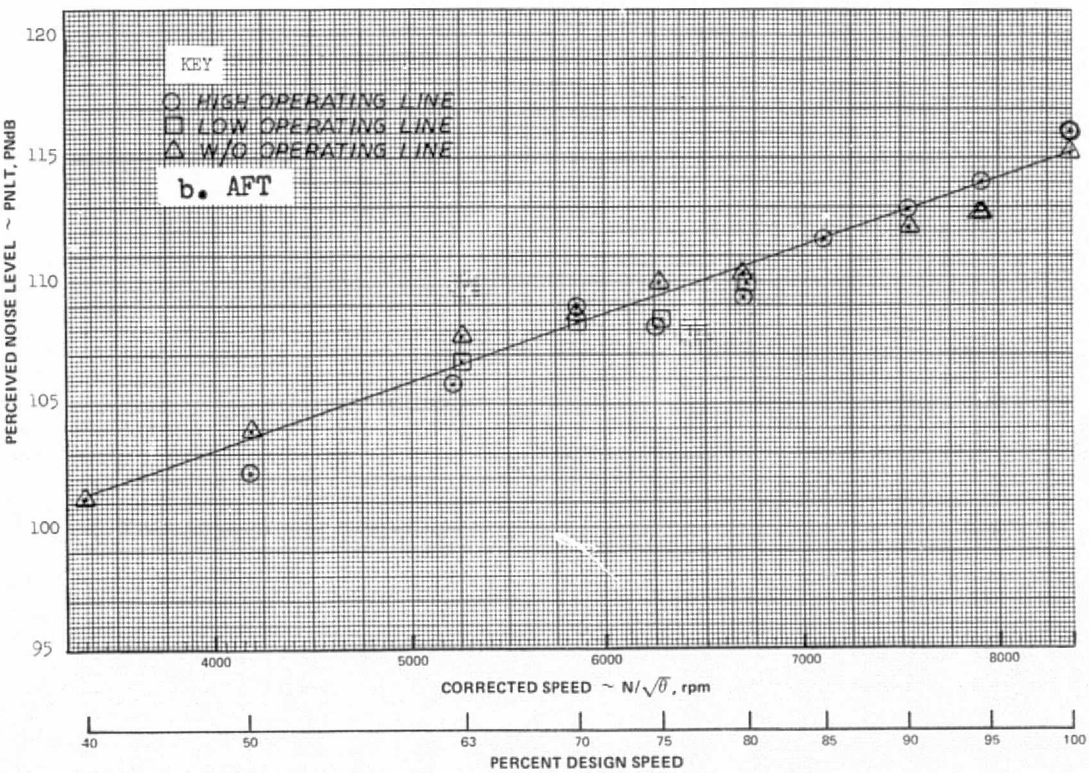


Figure 18   Peak Q2S Fan Inlet and Aft PNLT at 61 Meters [200 Feet] Sideline

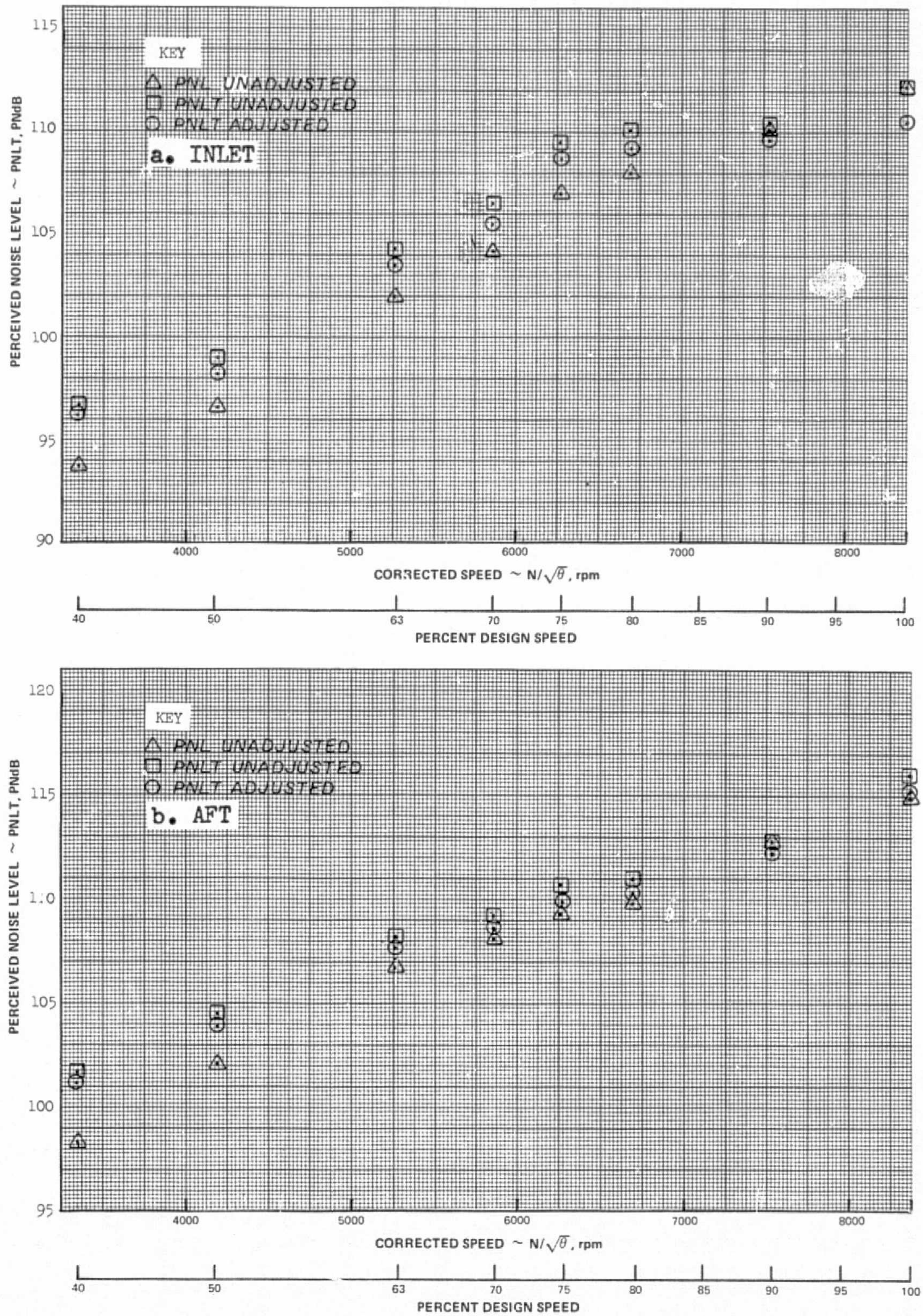


Figure 19 Adjusted and Unadjusted Sideline Inlet and Aft Data at 61 Meters [200 Feet]

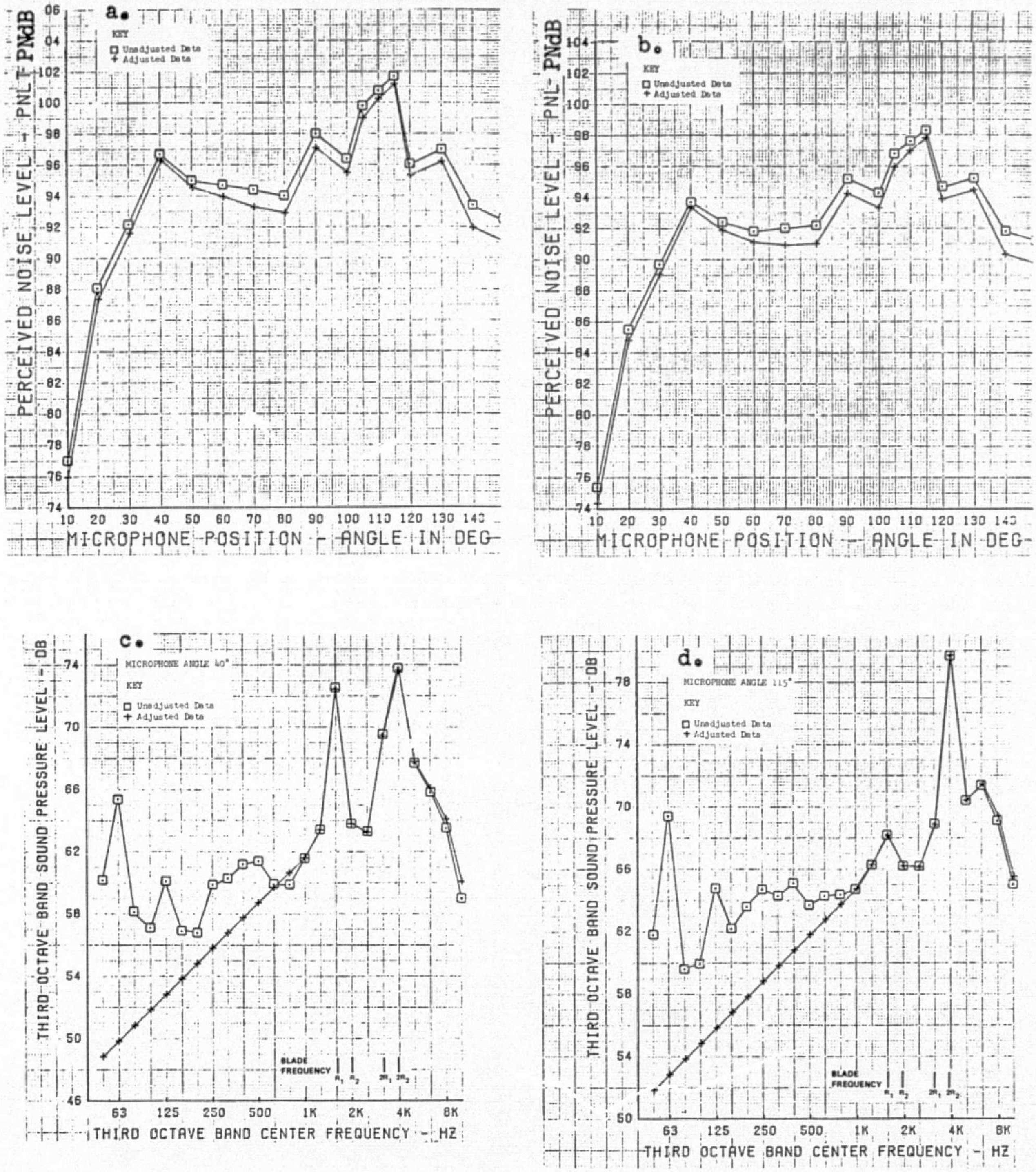


Figure 20 Baseline Q2S Fan Spectra and Directivity - 40 Percent of Design Speed, Corrected Speed 3348 rpm, Wide Open Operating Line, 61 Meters [200 Feet] Sideline Noise

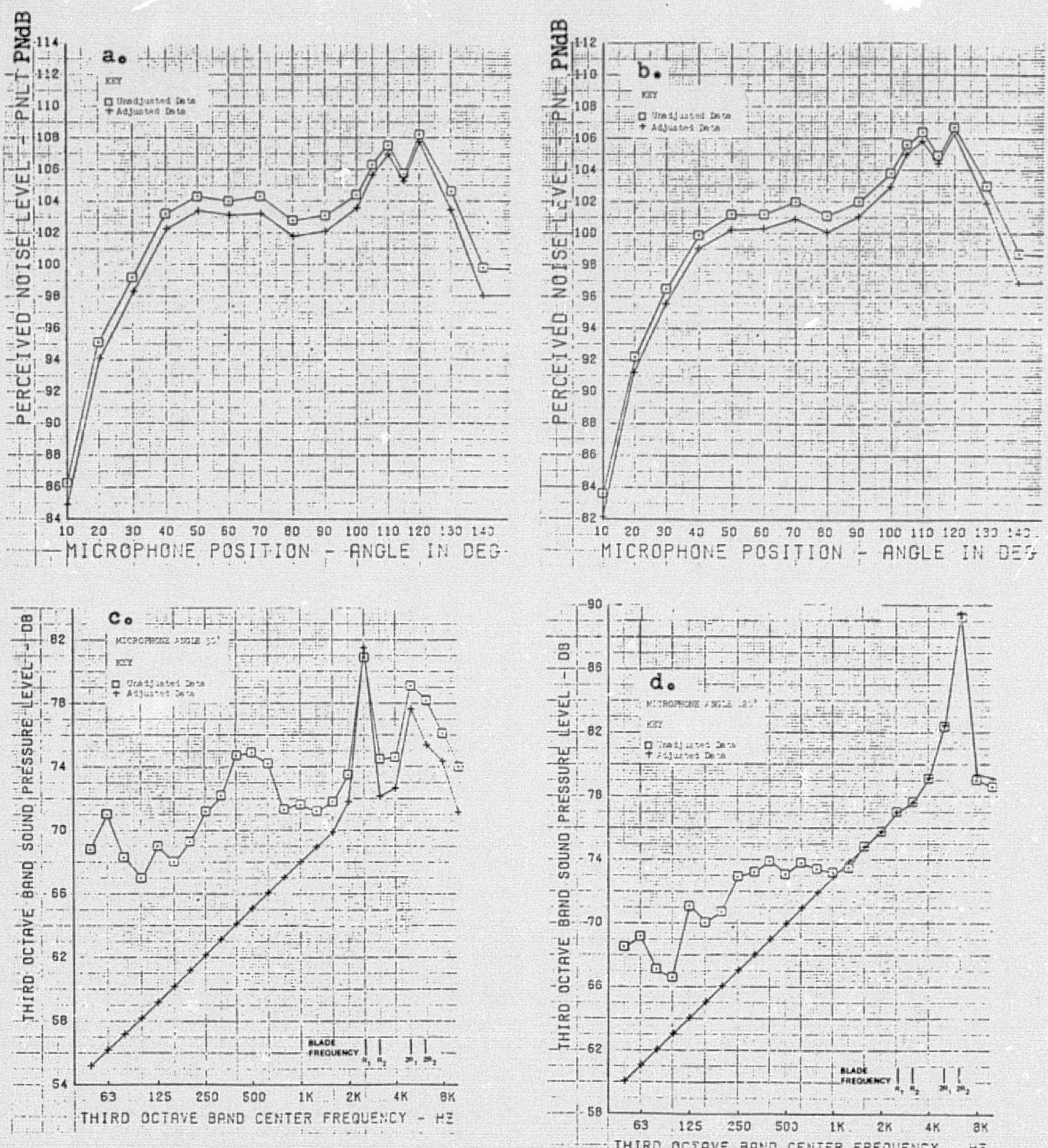


Figure 21 Baseline Q2S Fan Spectra and Directivity - 63 Percent of Design Speed, Corrected Speed 5260 rpm, Wide Open Operating Line, 61 Meters [200 Feet] Sideline Noise

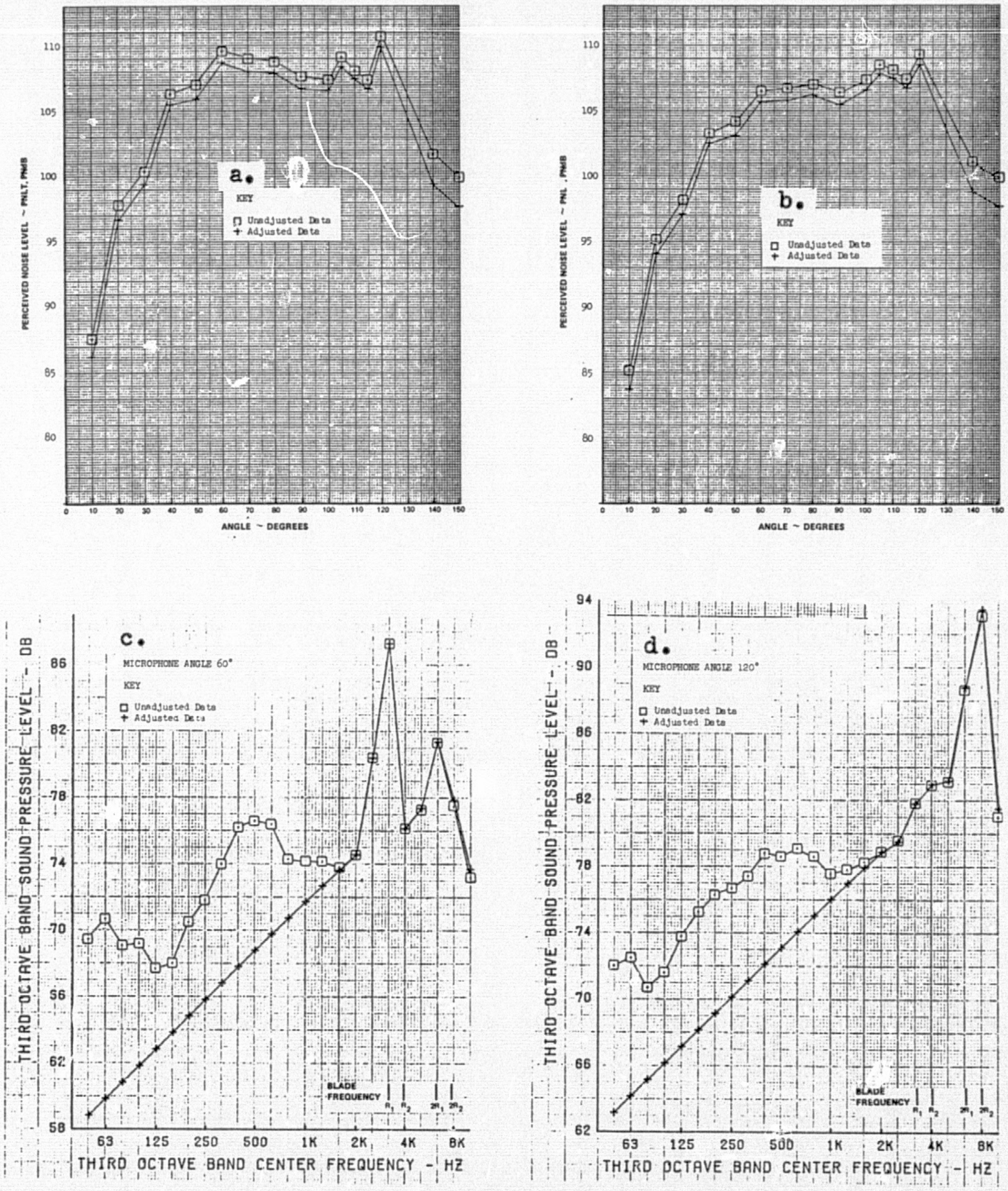


Figure 22 Baseline Q2S Fan Spectra and Directivity - 75 Percent of Design Speed, Corrected Speed 6275 rpm, Wide Open Operating Line, 61 Meters [200 Feet] Sideline Noise

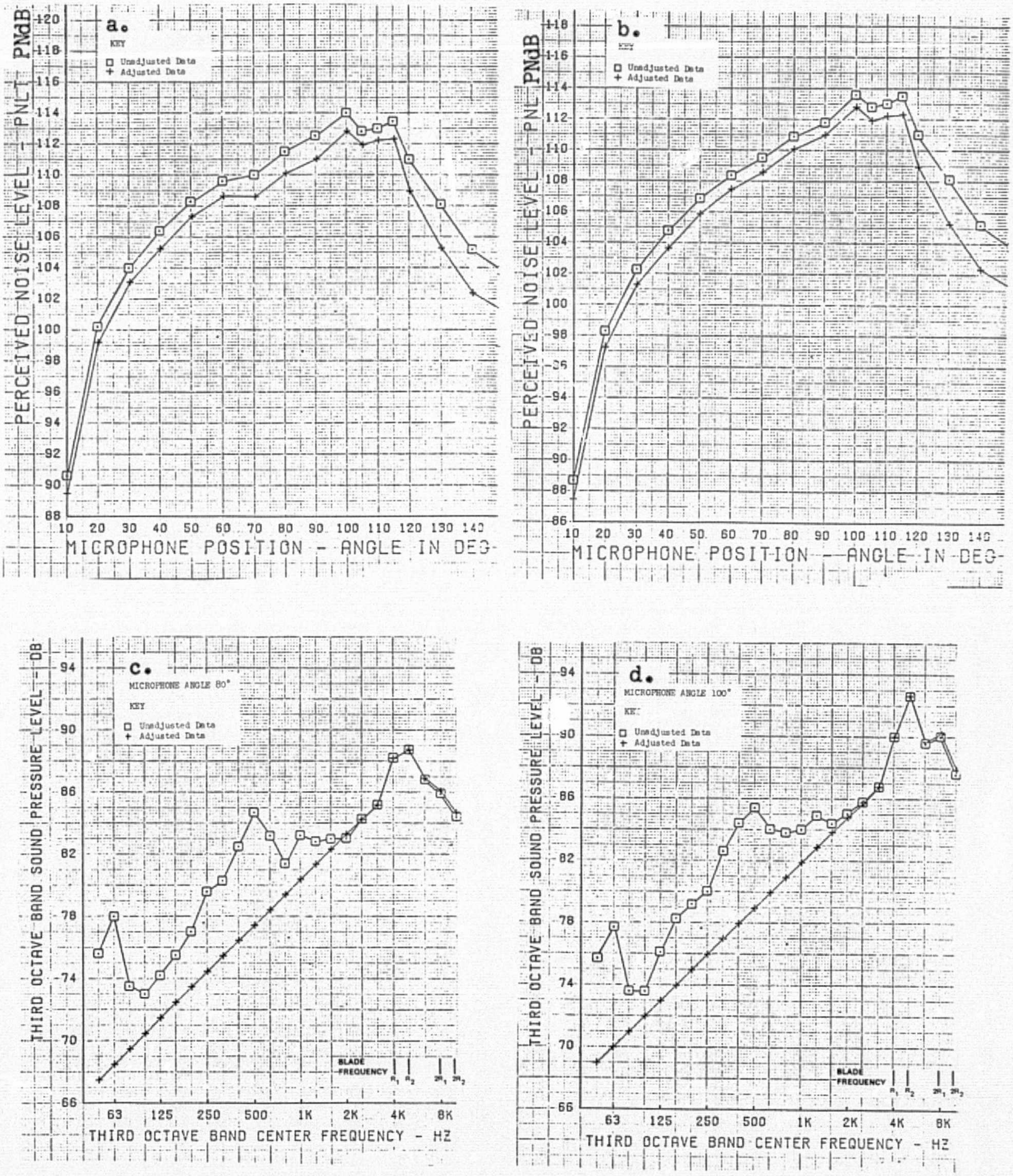


Figure 23 Baseline Q2S Fan Spectra and Directivity - 94.5 Percent of Design Speed, Corrected Speed 7897 rpm, Wide Open Operating Line, 61 Meters [200 Feet] Sideline Noise

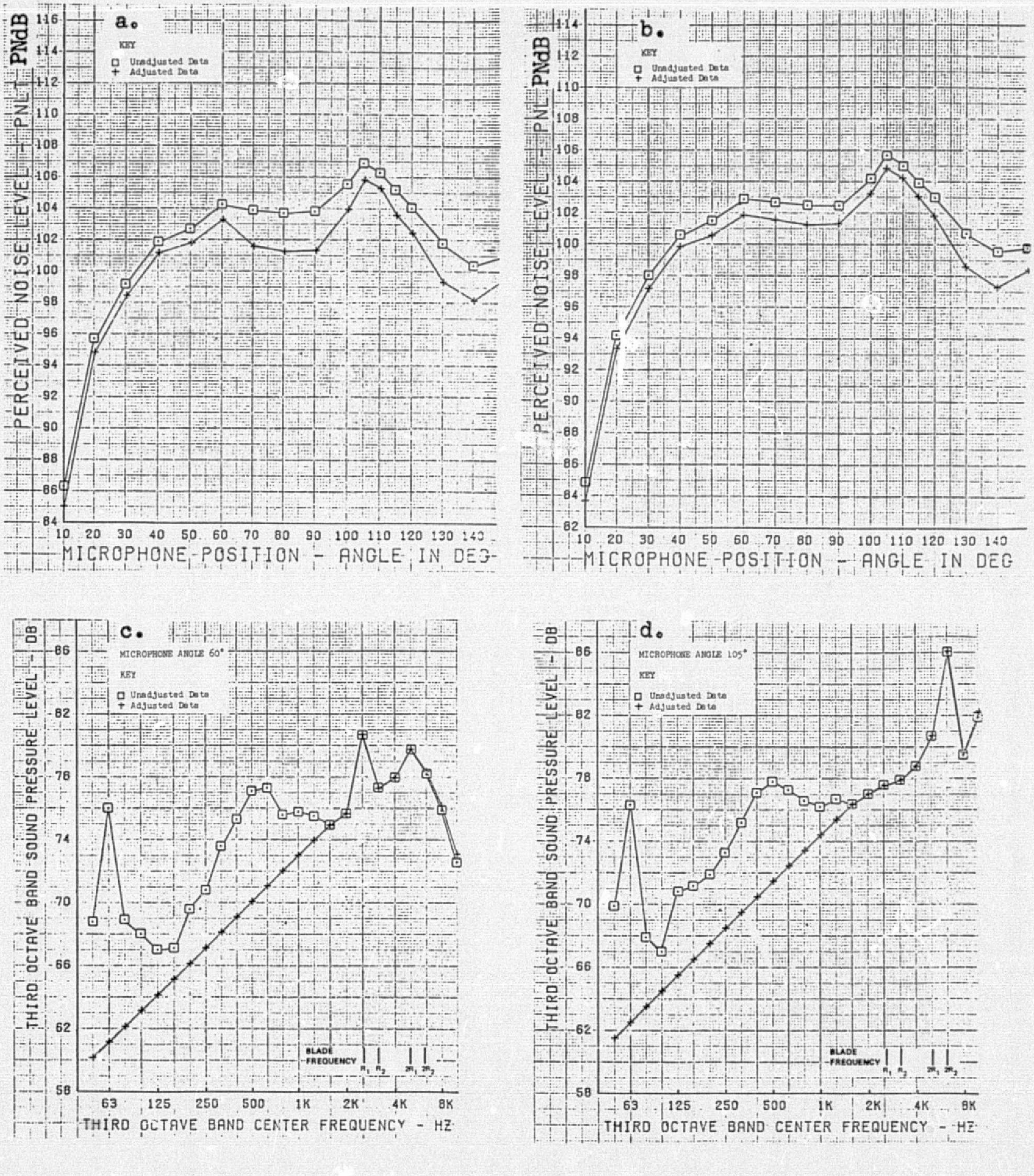


Figure 24 Baseline Q2S Fan Spectra and Directivity - 63 Percent of Design Speed, Corrected Speed 5214 rpm, Nominal Operating Line, 61 Meters [200 Feet] Sideline Noise

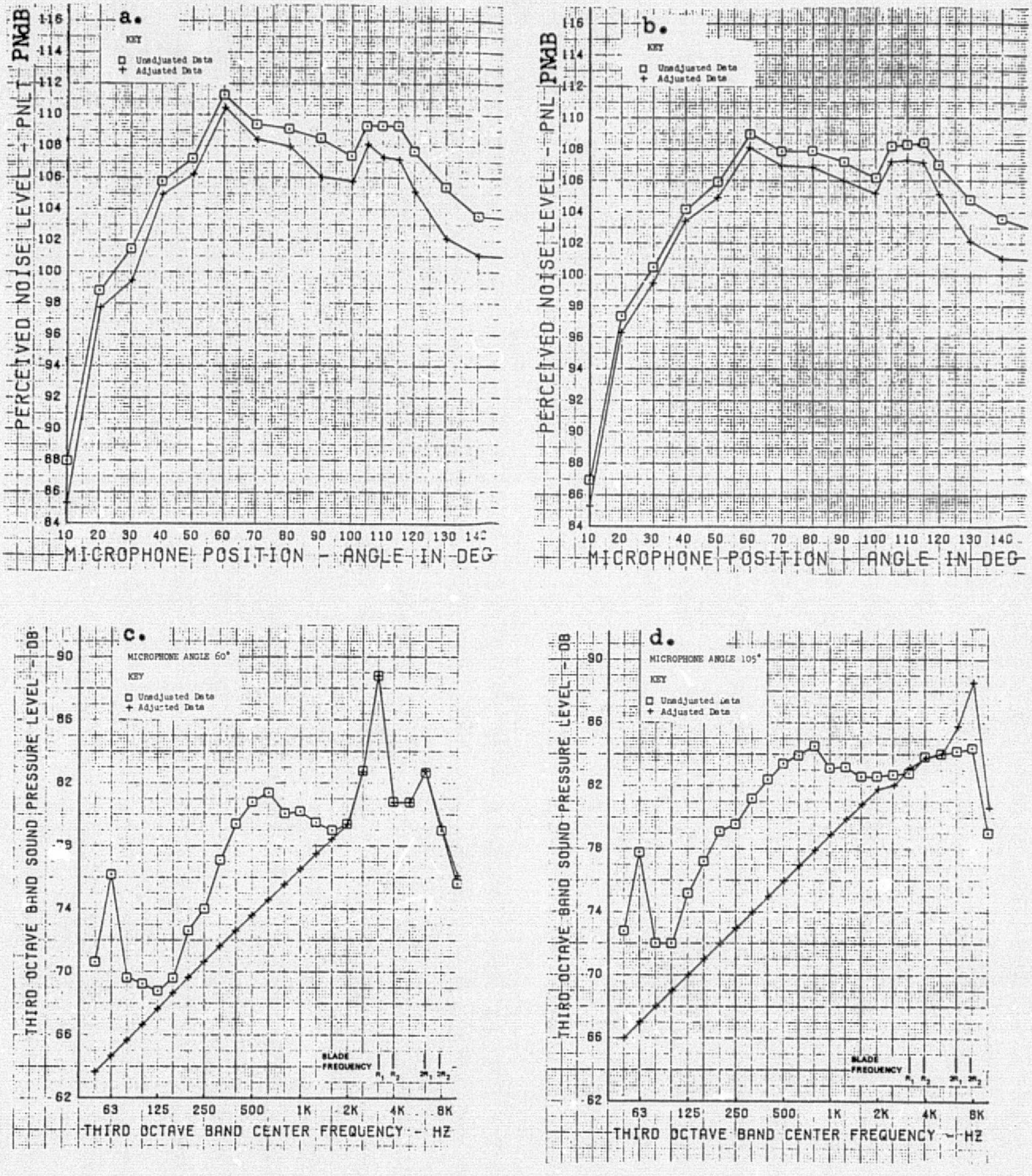


Figure 25 Baseline Q2S Fan Spectra and Directivity - 75 Percent of Design Speed, Corrected Speed 6257 rpm, Nominal Operating Line, 61 Meters [200 Feet] Sideline Noise

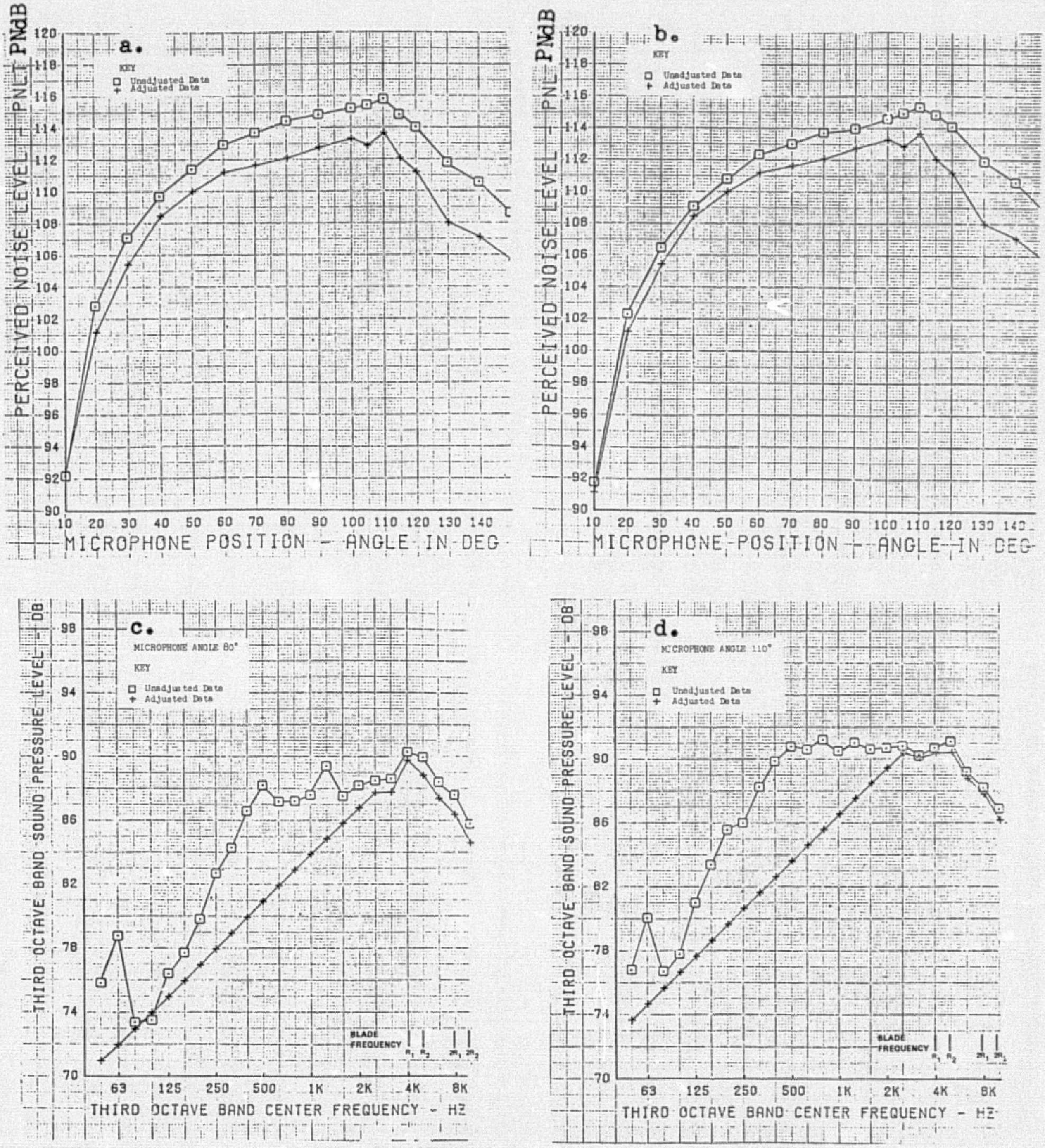


Figure 26 Baseline Q2S Fan Spectra and Directivity - 94.5 Percent of Design Speed, Corrected Speed 7916 rpm, Nominal Operating Line, 61 Meters [200 feet] Sideline Noise

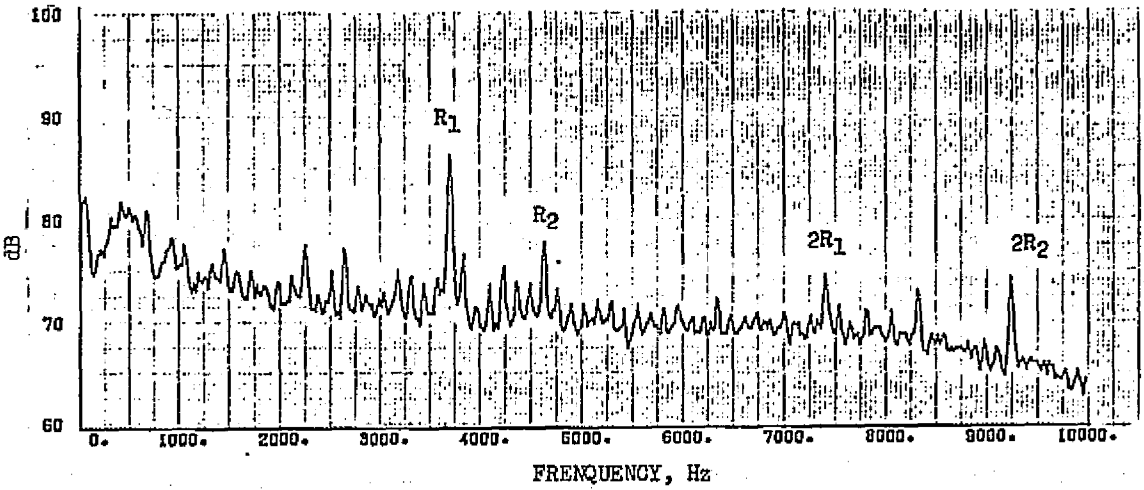


Figure 27 Q2S Fan 60 Degree Inlet Spectrum at 94.5 Percent of Design Speed

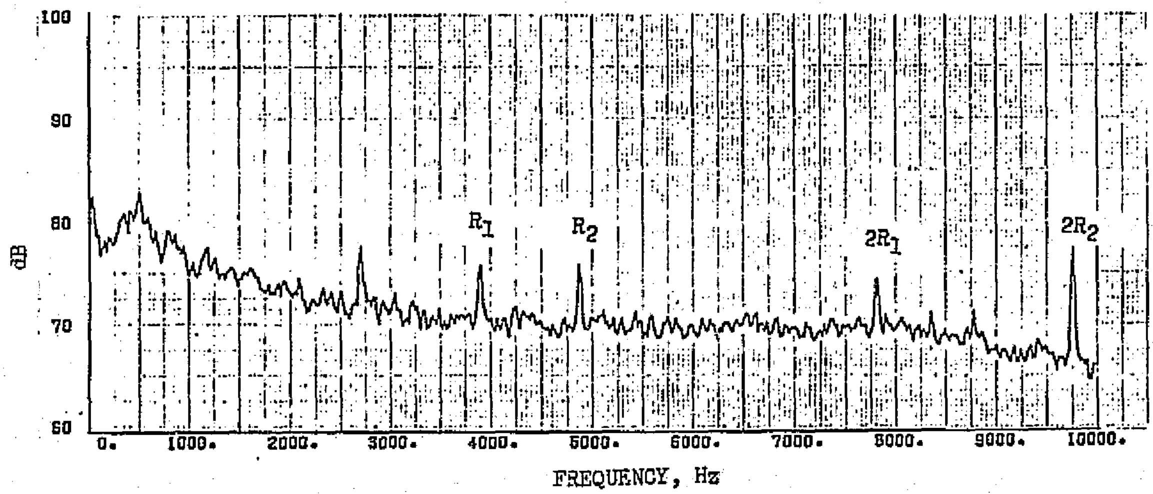


Figure 28 Q2S Fan 60 Degree Inlet Spectrum at 100 Percent of Design Speed

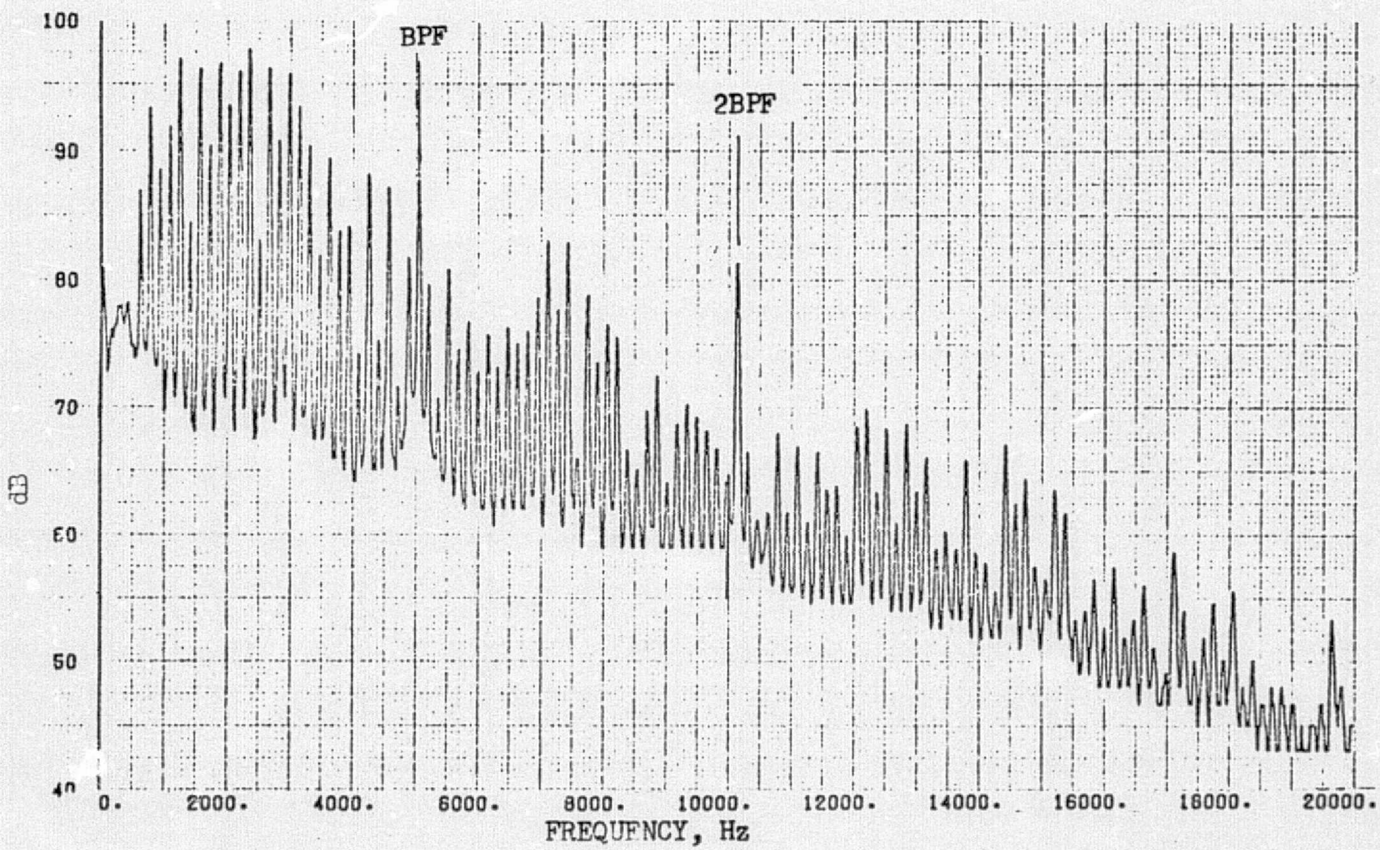


Figure 29 High Speed, Single-Stage Fan Inlet Spectrum Showing Combination Tone Noise

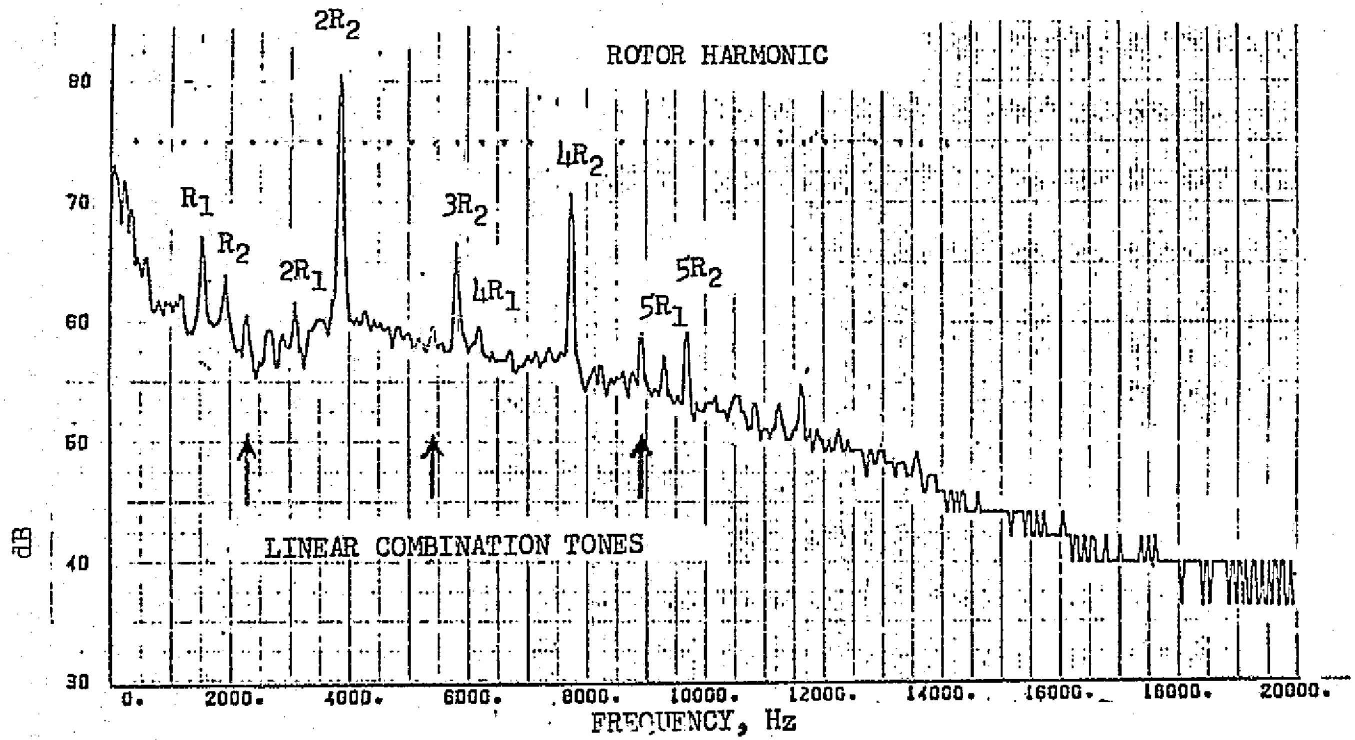


Figure 30 Illustration of Linear Combination Tones, Baseline Q2S Fan - 40 Percent of Design Speed, Observed Speed 3345 rpm, Nozzle Area 100 Percent, Microphone Angle 105°

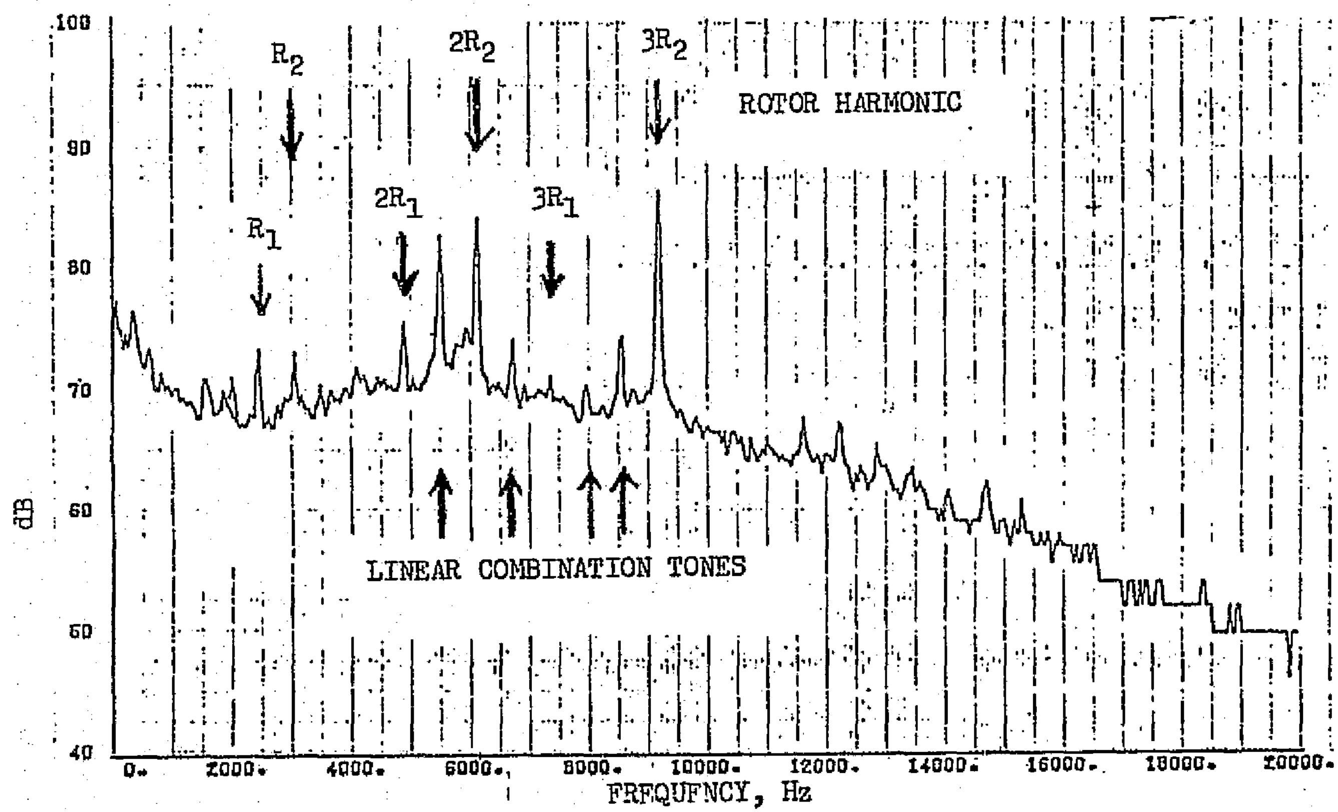
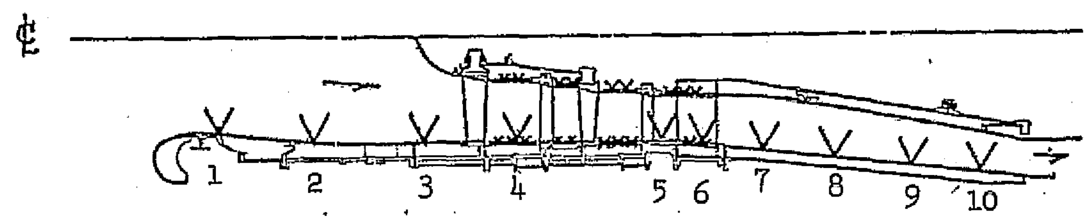
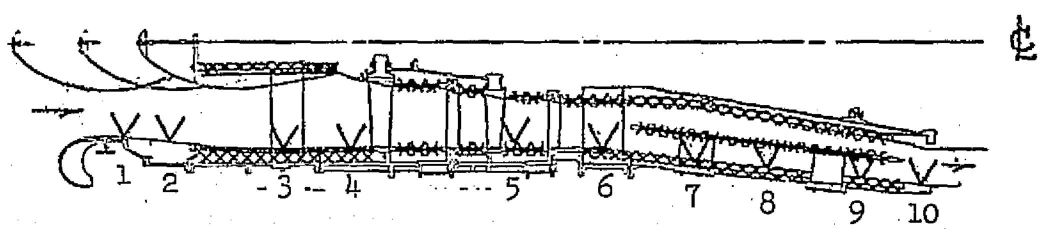


Figure 31 Illustration of Linear Combination Tones, Baseline Q2S Fan - 63 Percent of Design Speed, Observed Speed 5260 rpm, Microphone Angle 105°



BASELINE CONFIGURATION A

NOTE: V INDICATES MICROPHONE LOCATIONS



SONIC INLET, FULLY TREATED CONFIGURATION B

Figure 32 Internal Flush-Mounted Wall-Microphone Locations

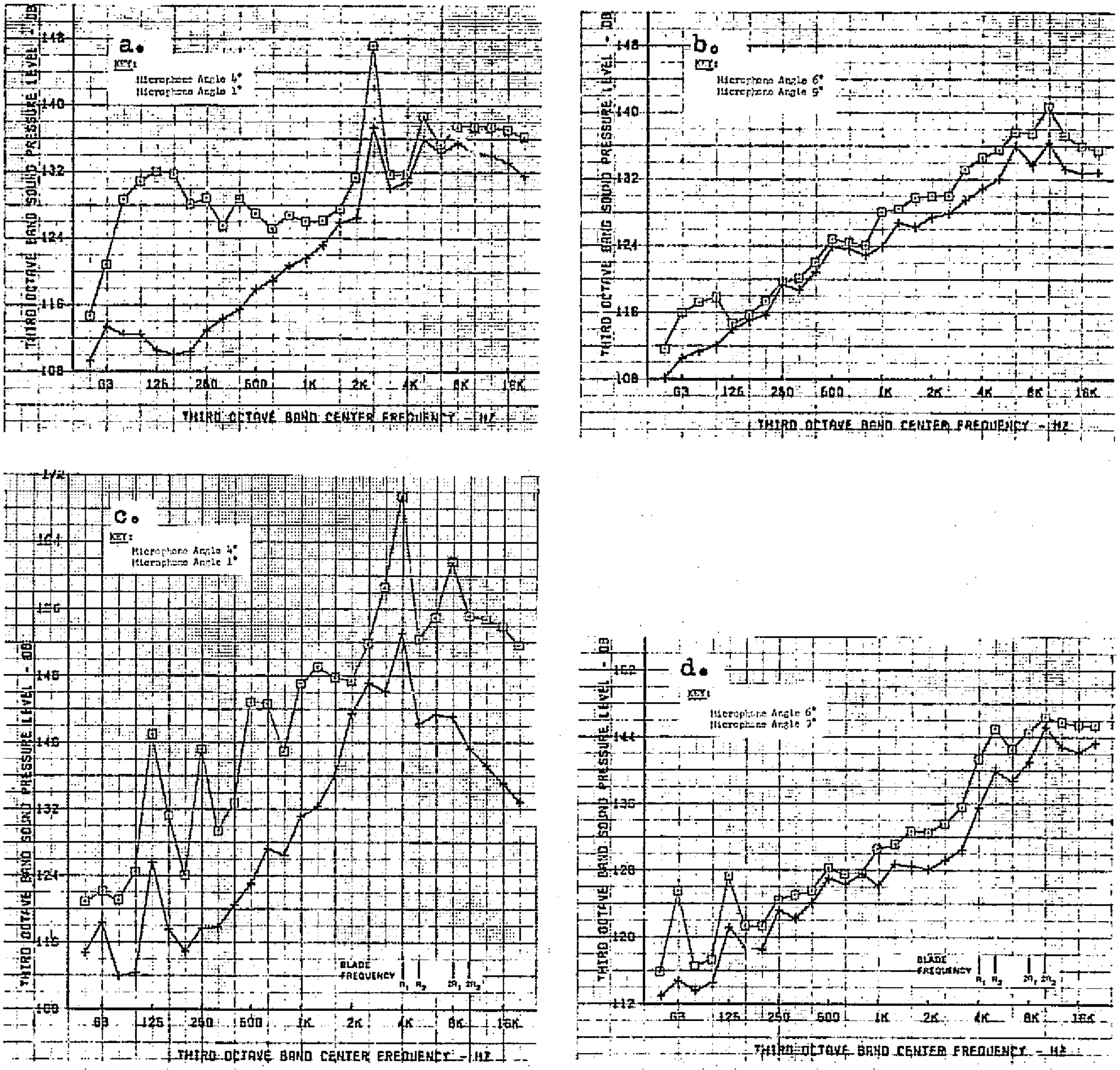


Figure 33 Baseline Q2S Fan Internal Microphone Spectra

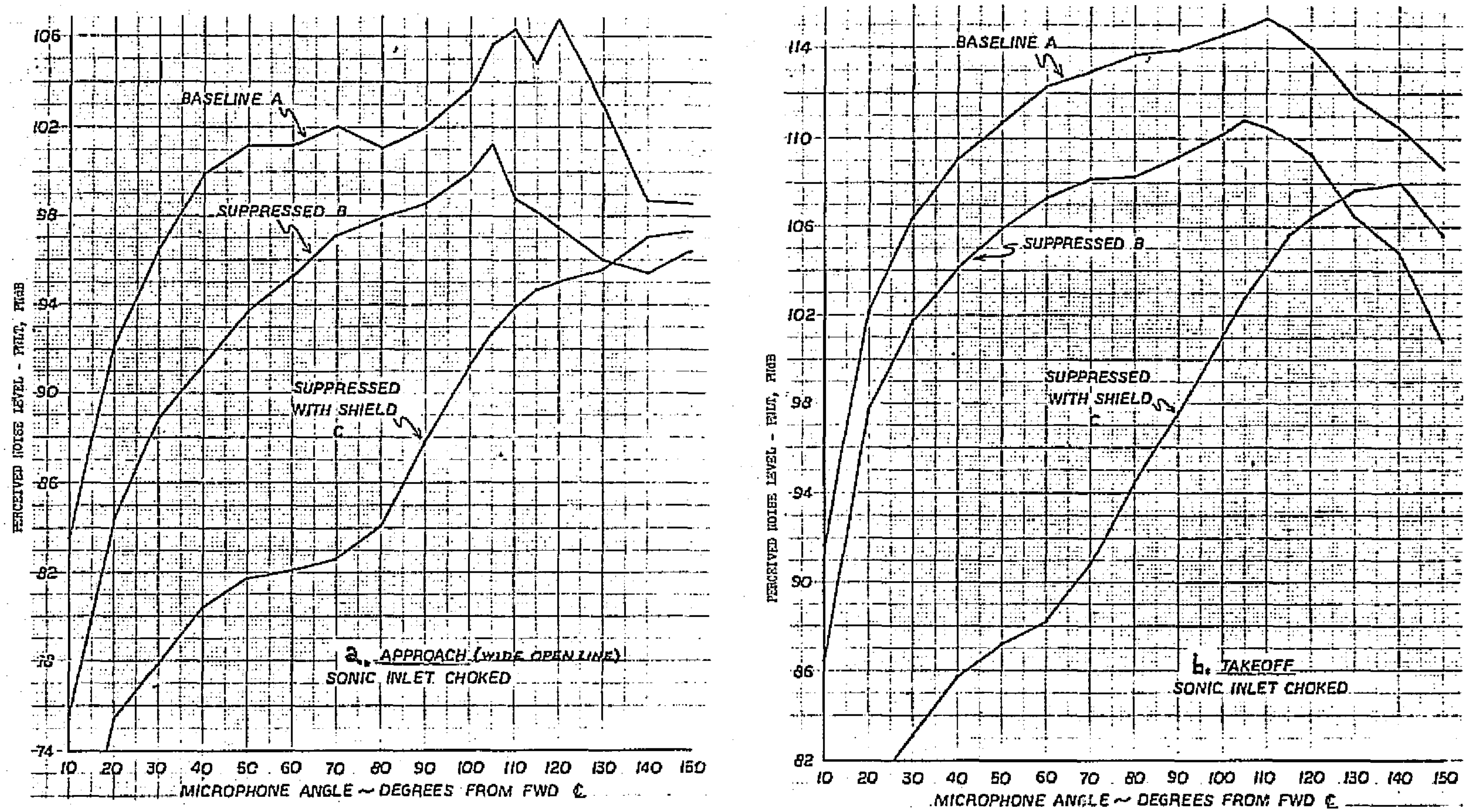


Figure 34 Baseline and Suppressed Configurations PNLT Directivity, 61 Meters [200 Feet] Sideline Noise

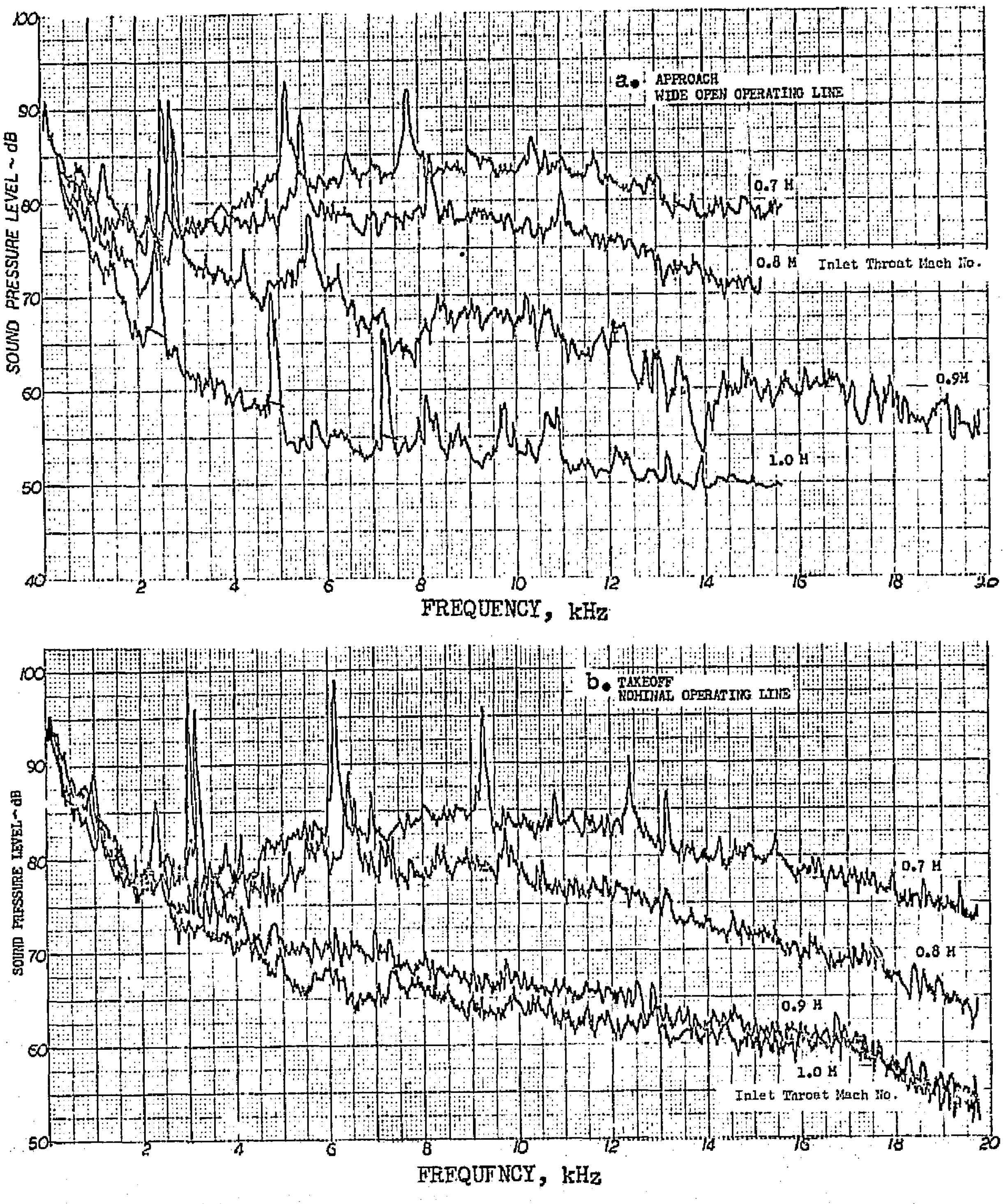


Figure 35 Sonic Inlet Q2S Fan Spectra, 50 Hz Bandwidth, Near Field Microphone

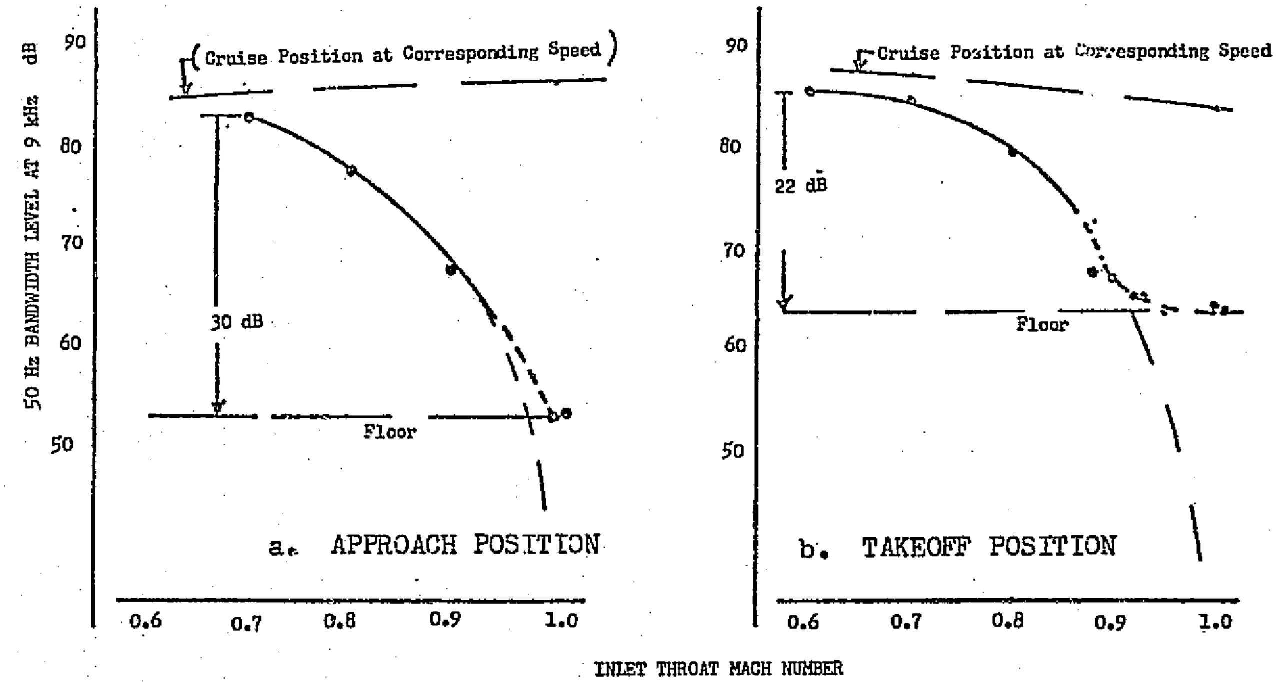


Figure 36 Sonic Inlet Q2S Fan Near Field Monitor Microphone Sample Reading-Variation With Inlet Throat Mach Number

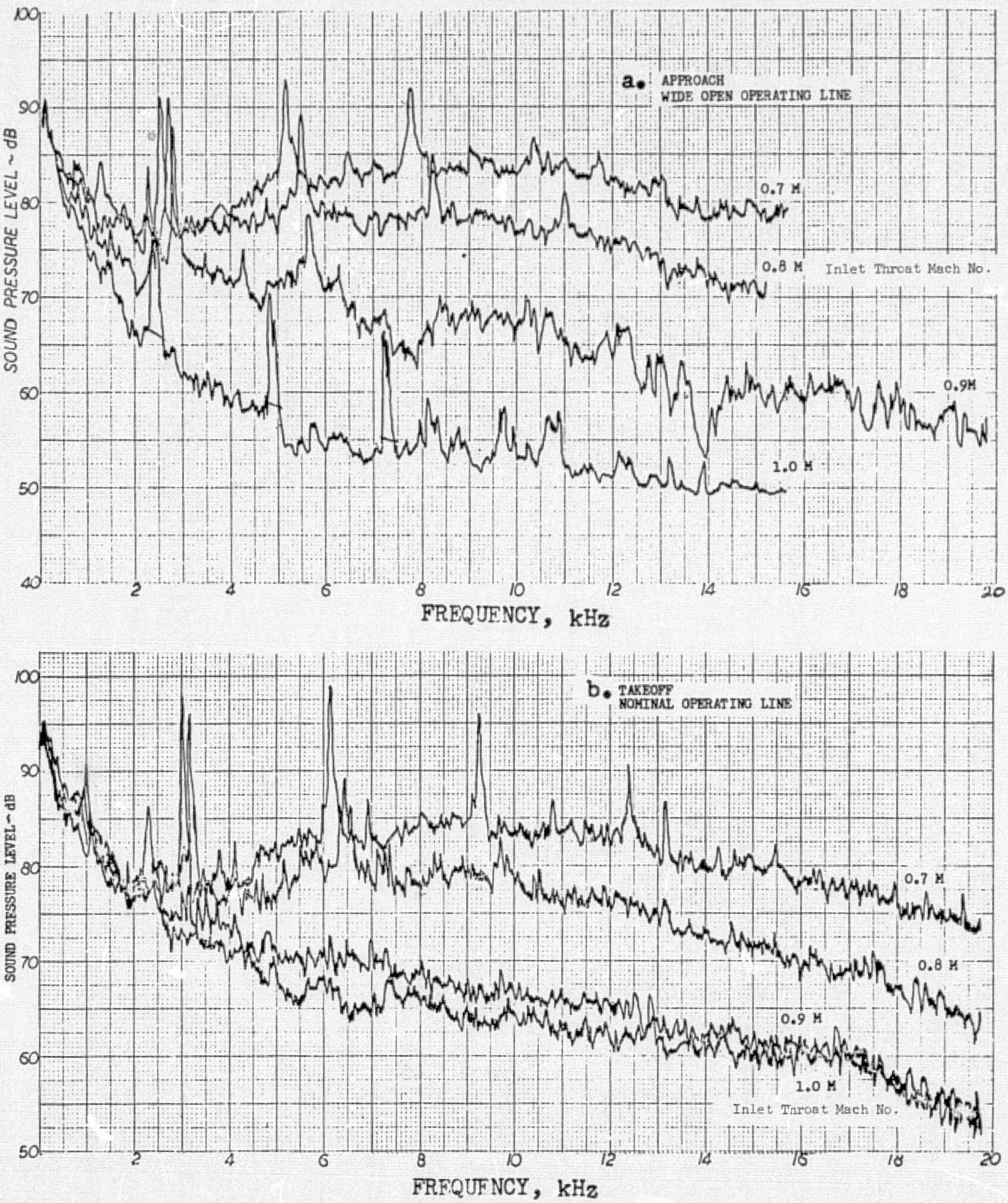


Figure 35 Sonic Inlet Q2S Fan Spectra, 50 Hz Bandwidth, Near Field Microphone

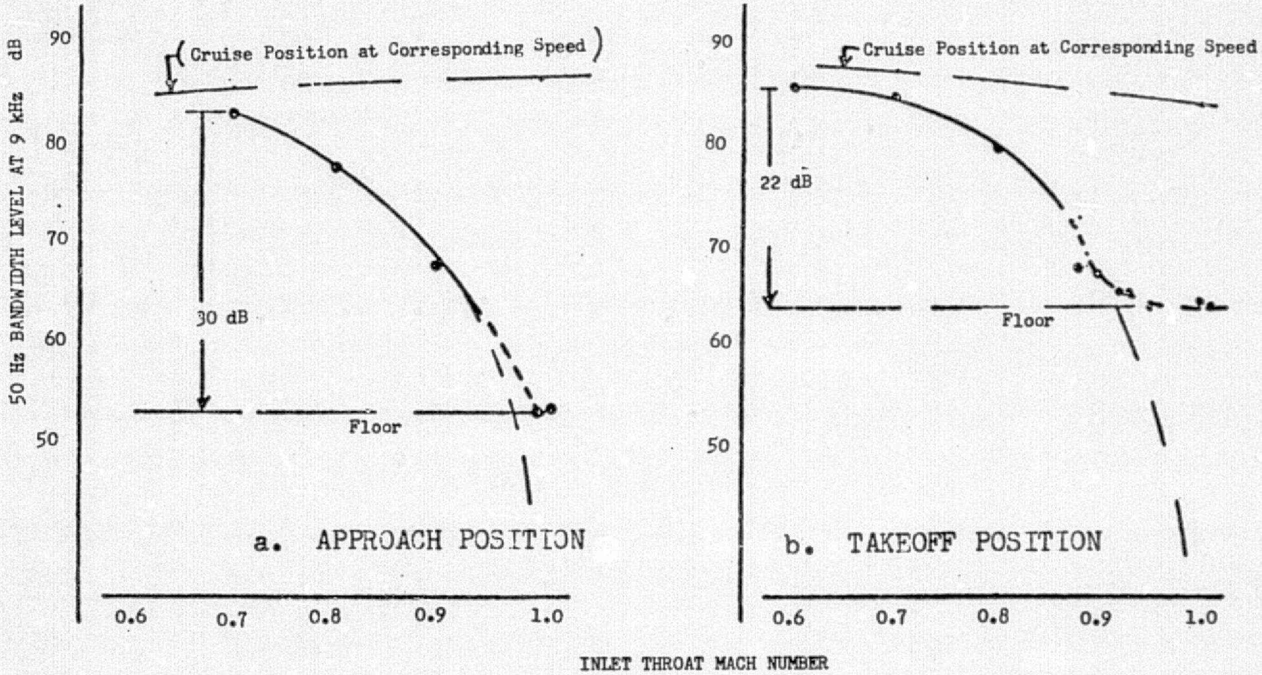


Figure 36 Sonic Inlet Q2S Fan Near Field Monitor Microphone Sample Reading-Variation With Inlet Throat Mach Number

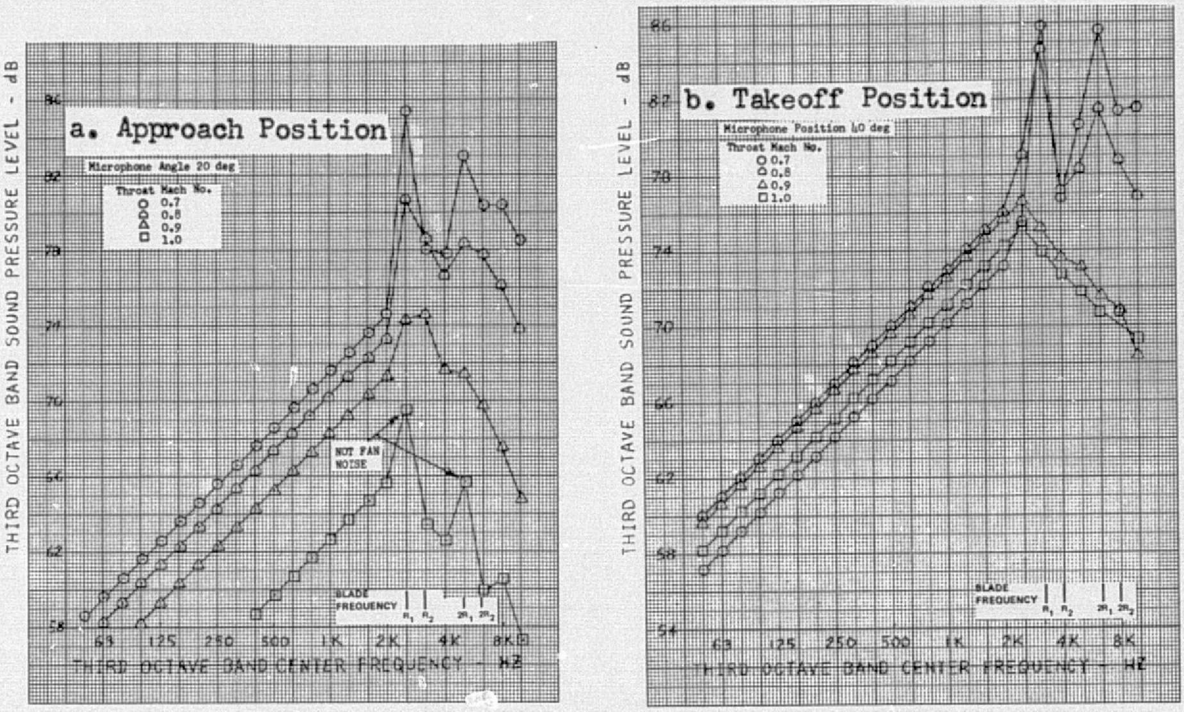


Figure 37   Sonic Inlet Q2S Fan Third Octave Band SPL Spectra, Radius = 45.7 Meters [150 Feet]

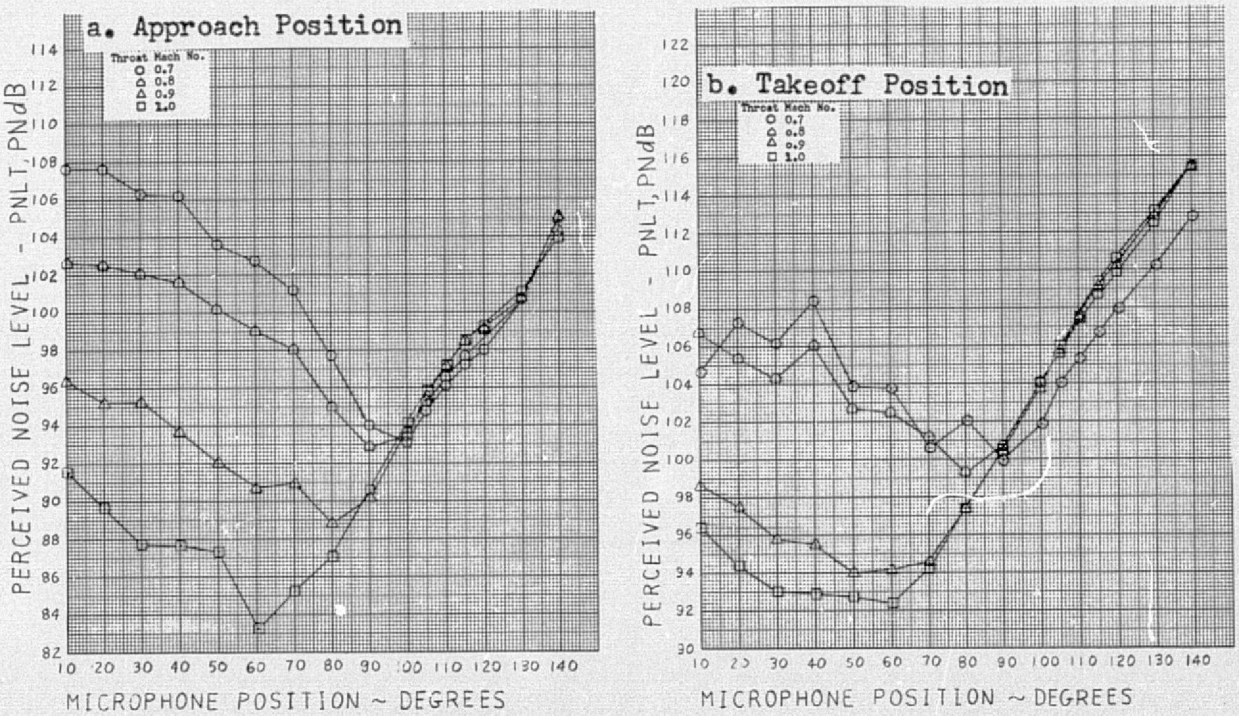


Figure 38   Sonic Inlet Q2S Fan PNLT Directivity, Radius = 45.7 Meters [150 Feet]

C·2

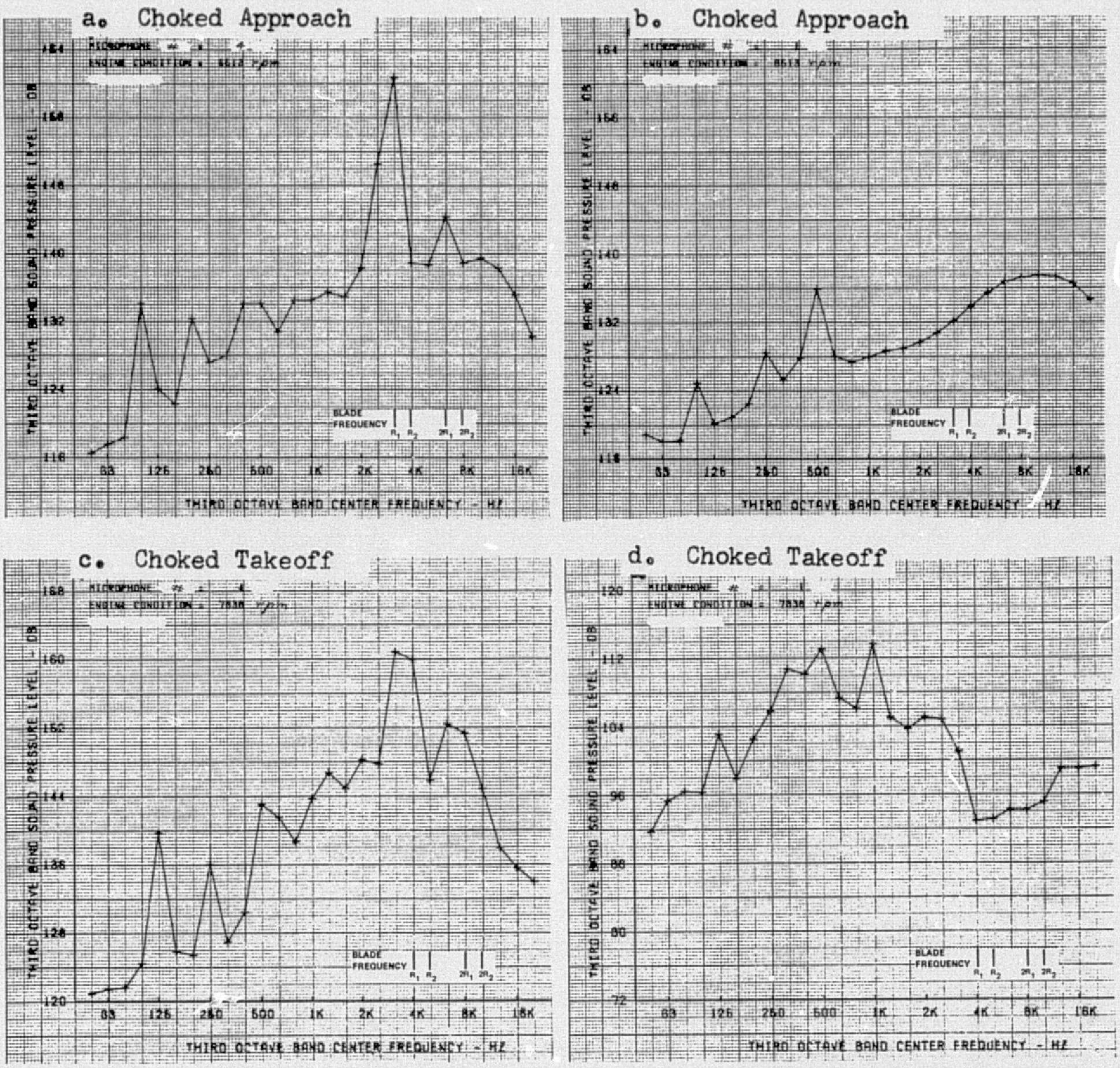


Figure 39 Inlet Flush Mounted Wall Microphones, 1/3-Octave Band Spectra, Q2S Fan Suppressed Configuration B

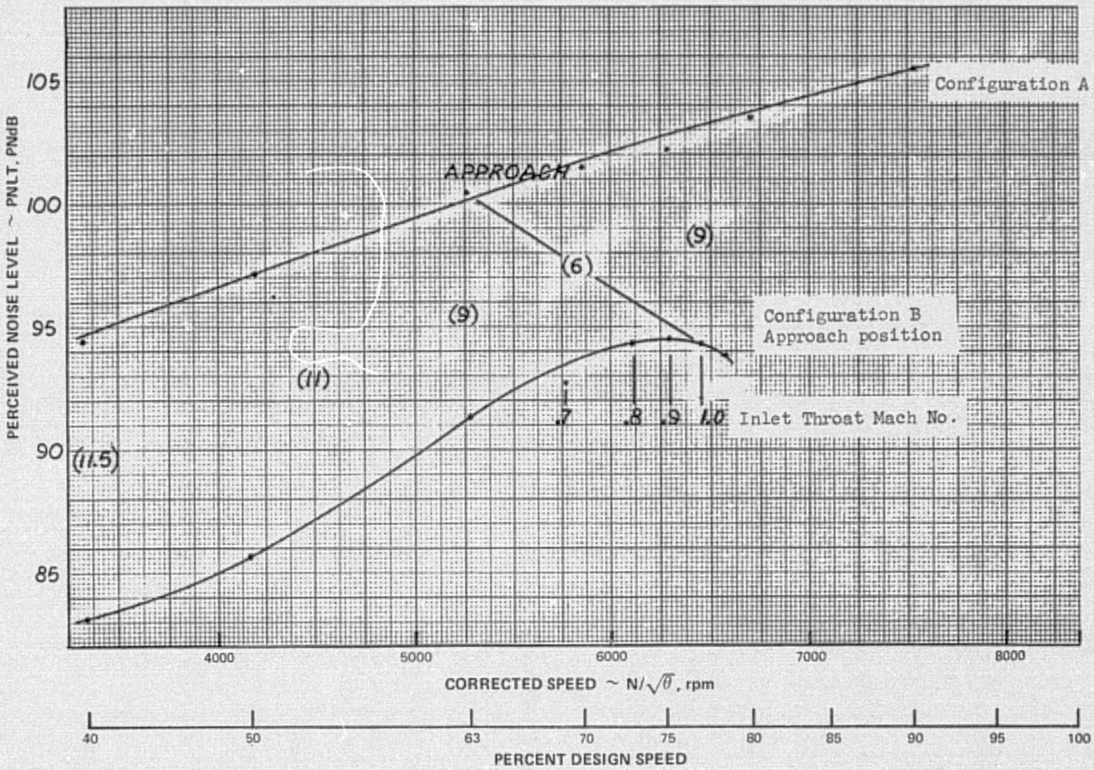


Figure 40 Peak Aft Noise Versus Fan Speed For Baseline and Suppressed Approach Configurations - 112.8 Meters [370 Feet] Sideline Noise

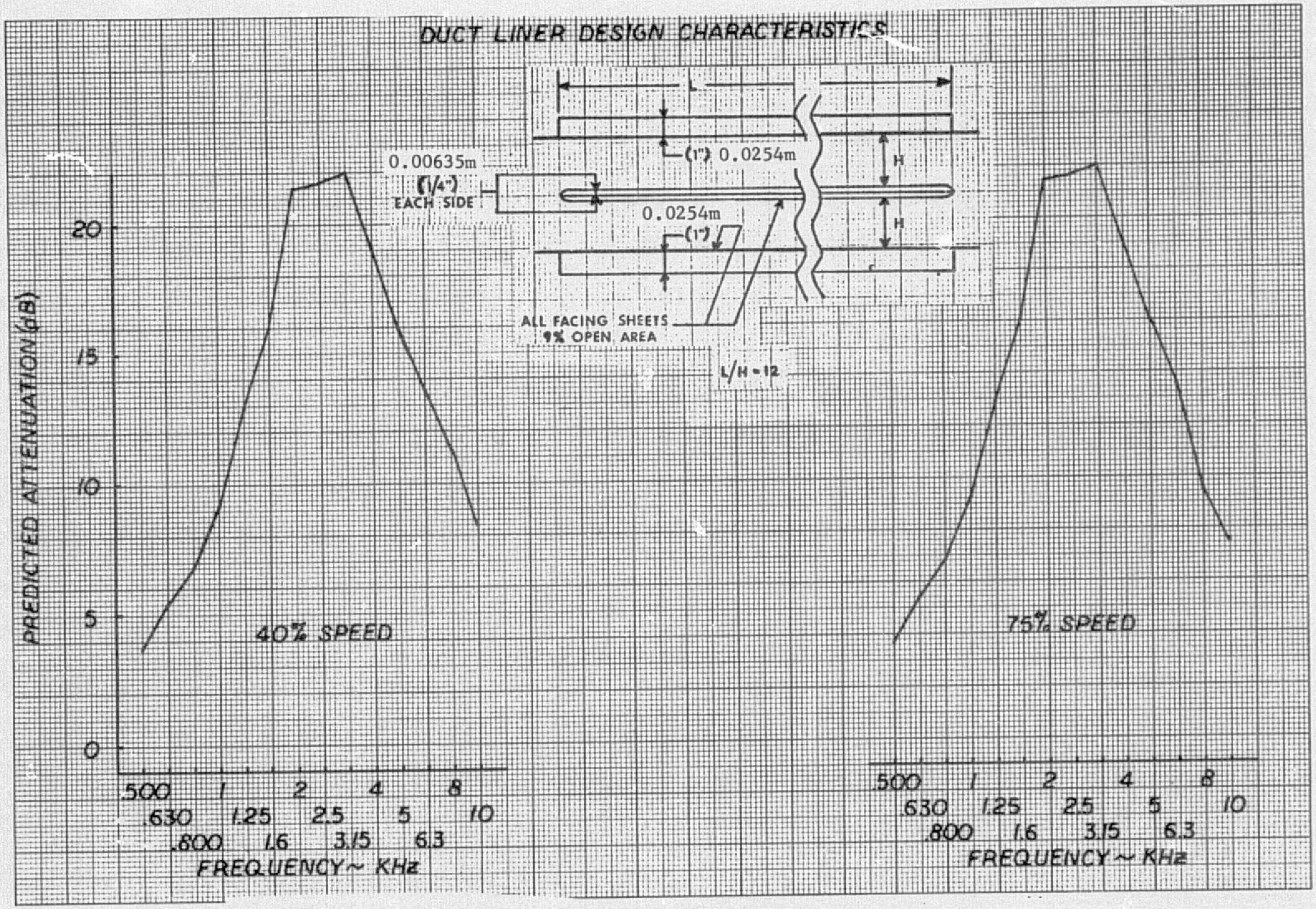


Figure 41 Q2S Fan Duct Liner - Calculated Acoustic Characteristics

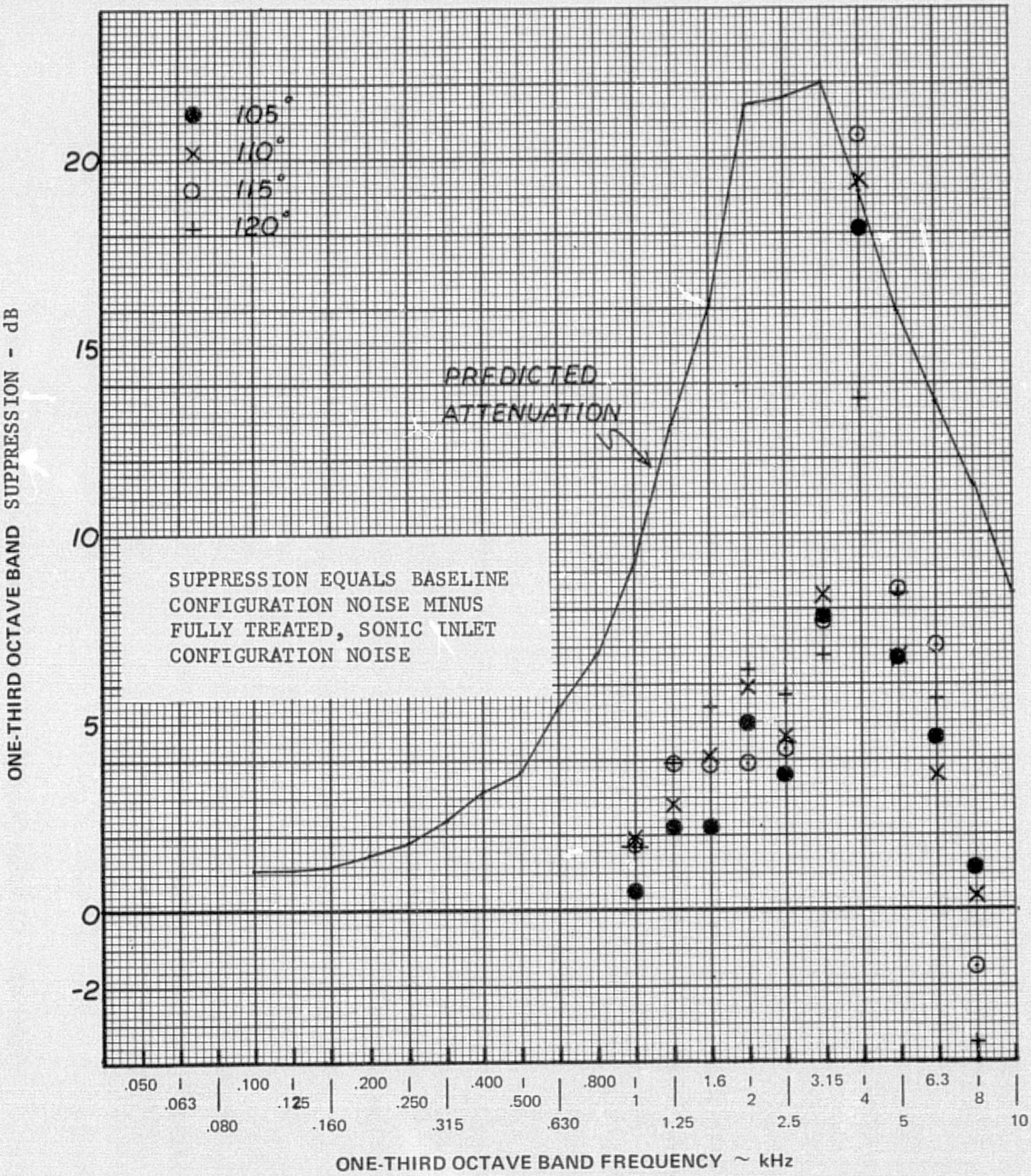


Figure 42 Liner Attenuation at 40 Percent of Design Speed

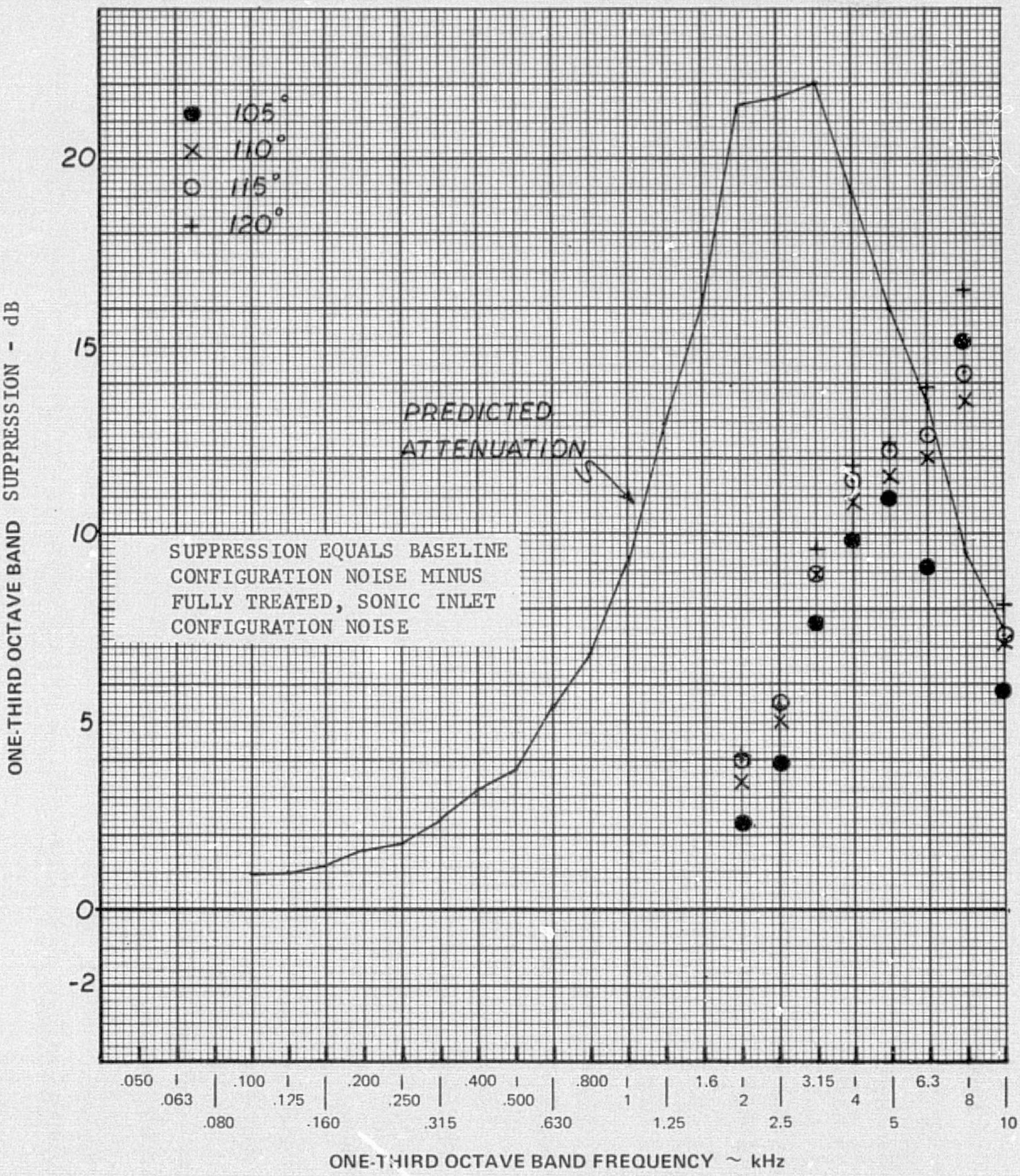


Figure 43 Liner Attenuation at 75 Percent of Design Speed

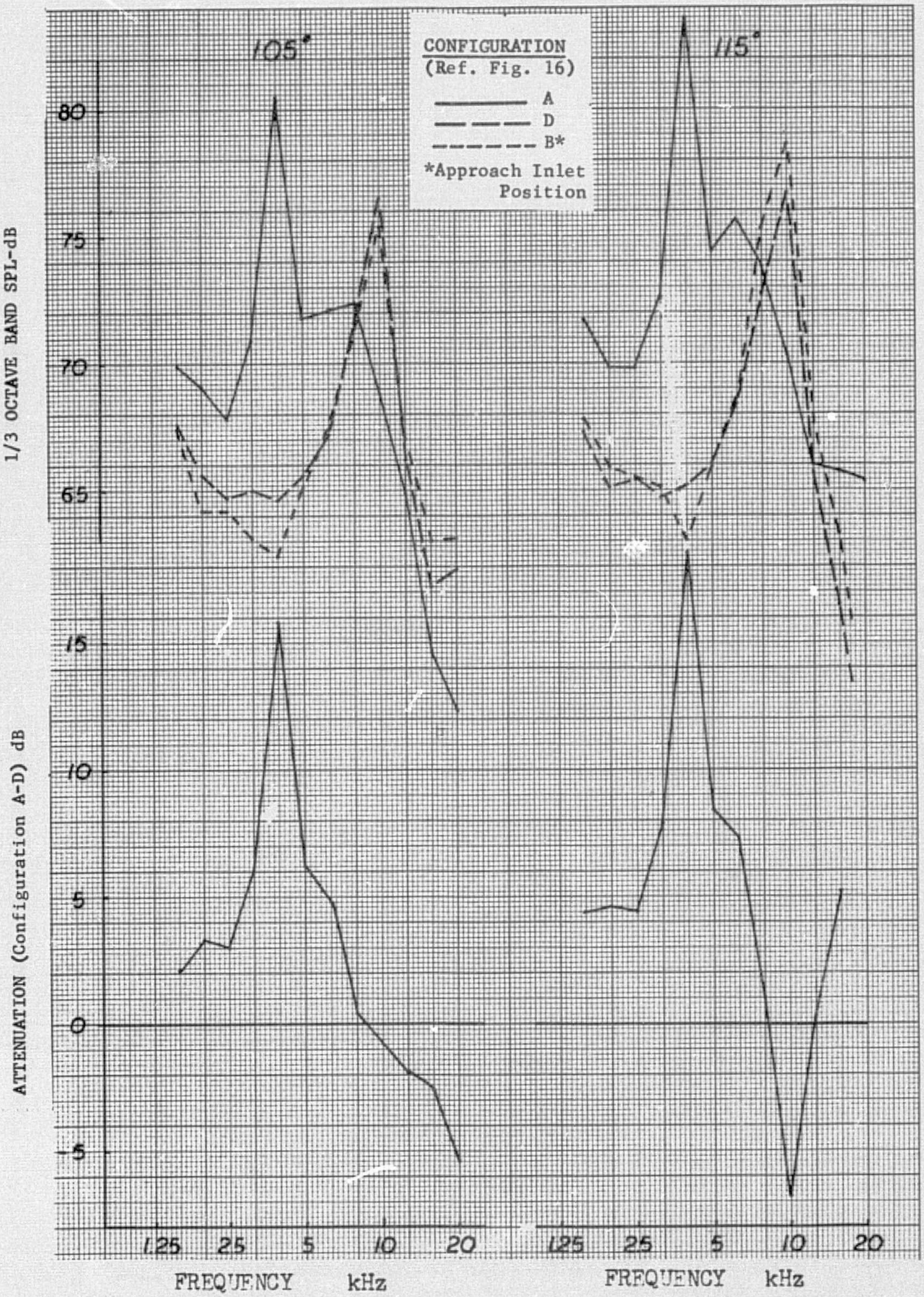


Figure 44 Q2S Fan Spectra and Attenuation at 40 Percent of Design Speed at 45.7 Meters [150 Feet] Radius

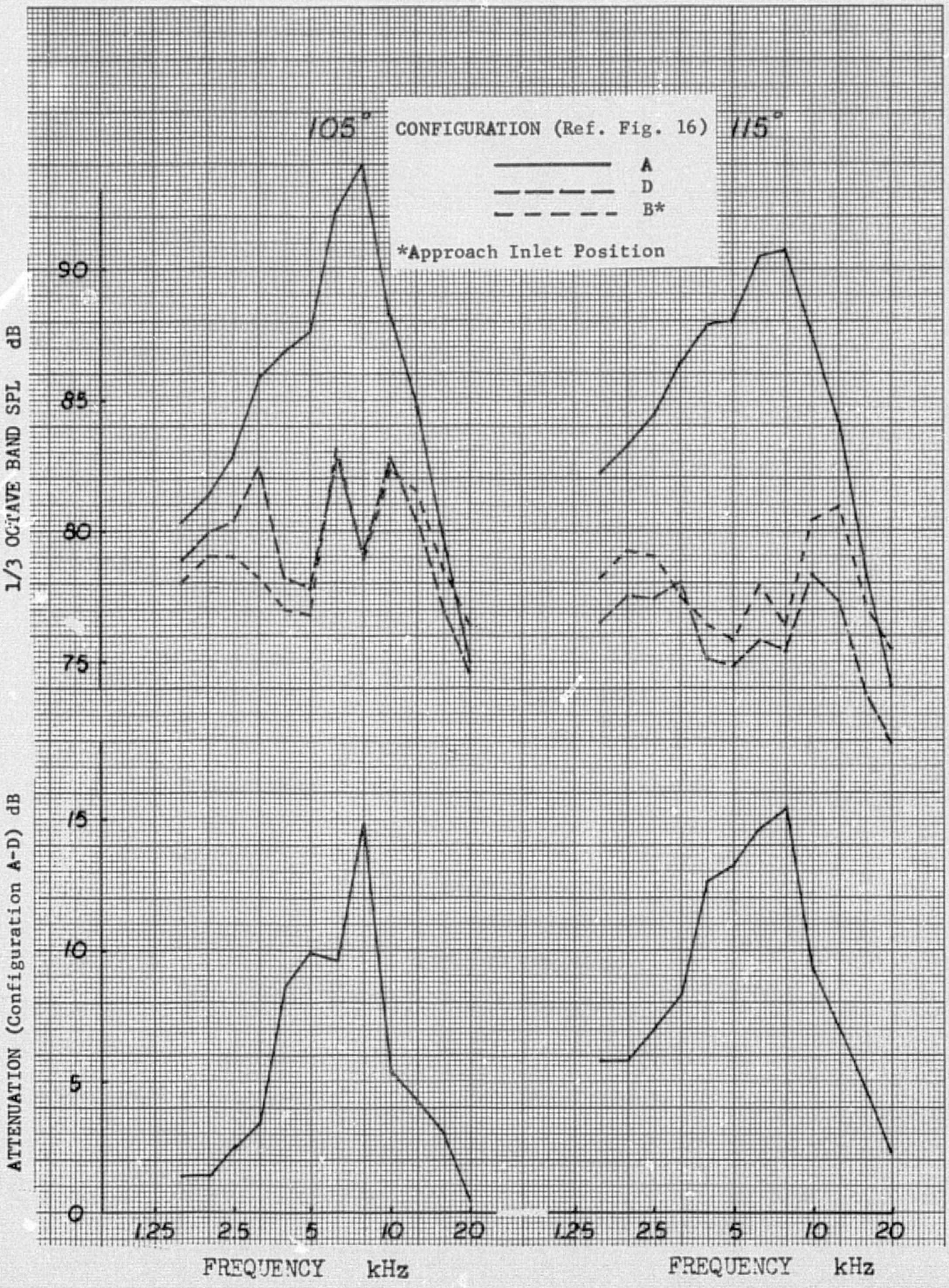


Figure 45 Q2S Fan Spectra and Attenuation at 75 Percent of Design Speed at 45.7 Meters [150 Feet] Radius

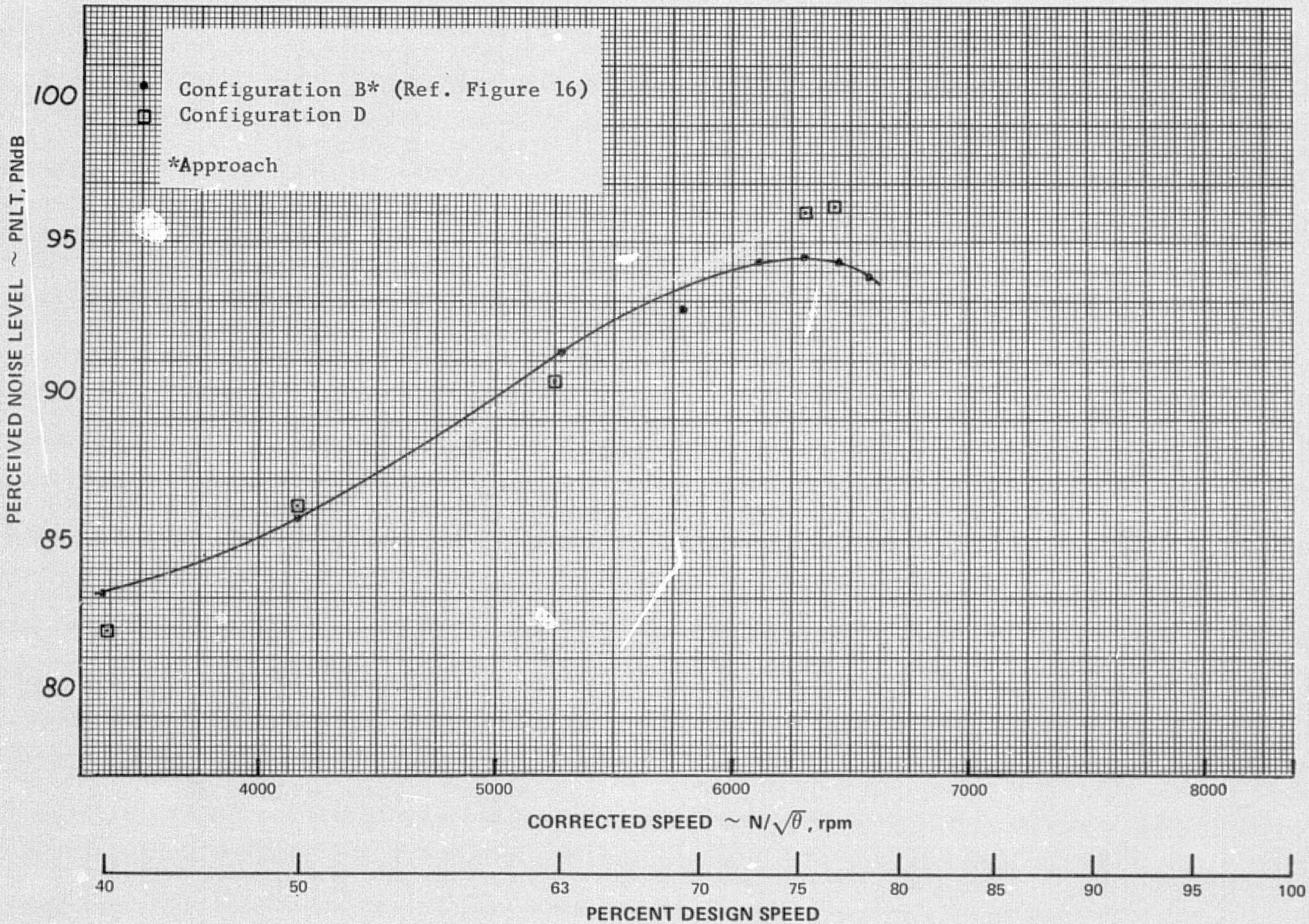


Figure 46 Illustration of Null Effect of Sonic Inlet on Aft Noise - 113 Meters [370 Feet] Sideline Noise

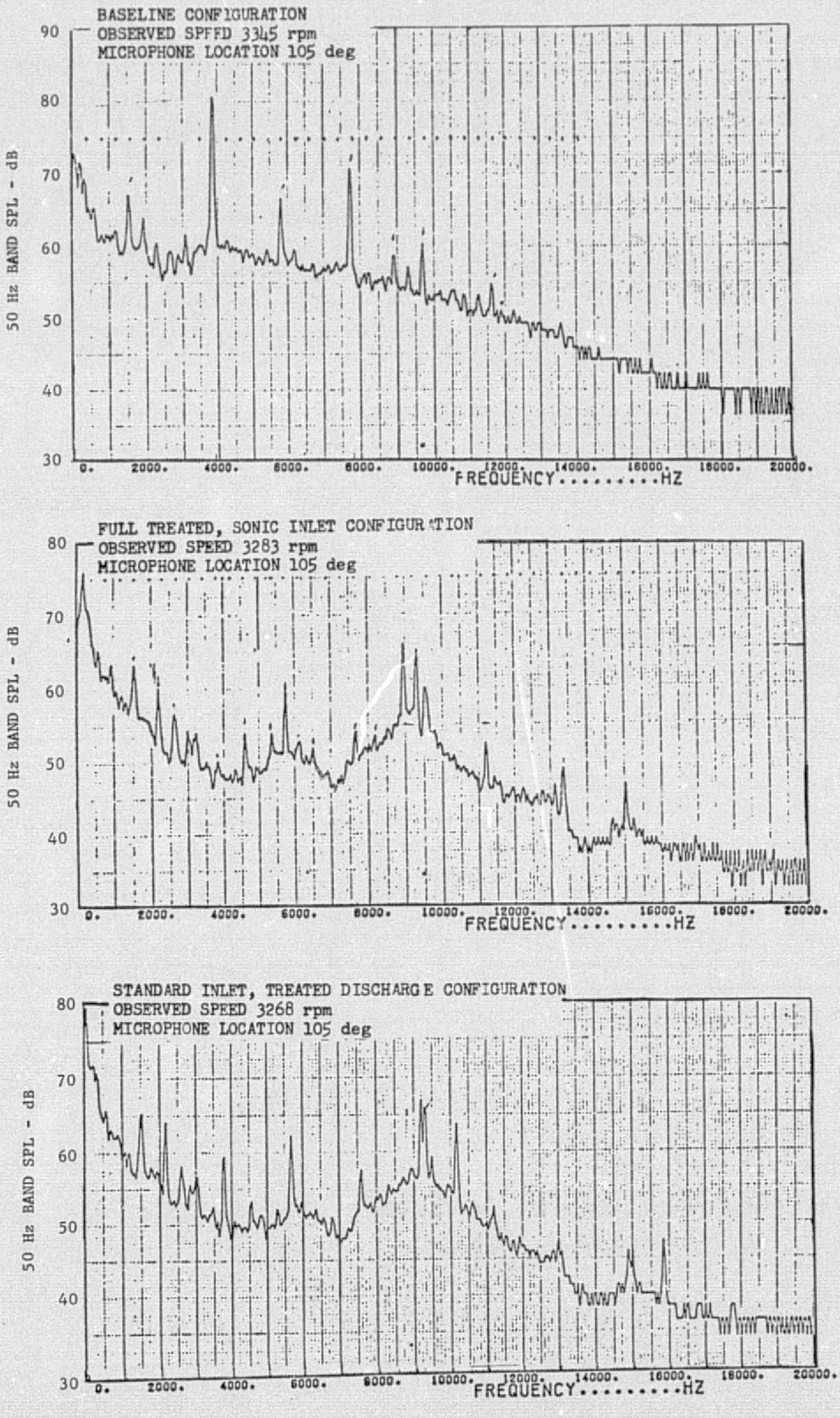


Figure 47 Comparison of Spectra of Configurations A, B (Approach), and D at 40 Percent of Design Speed

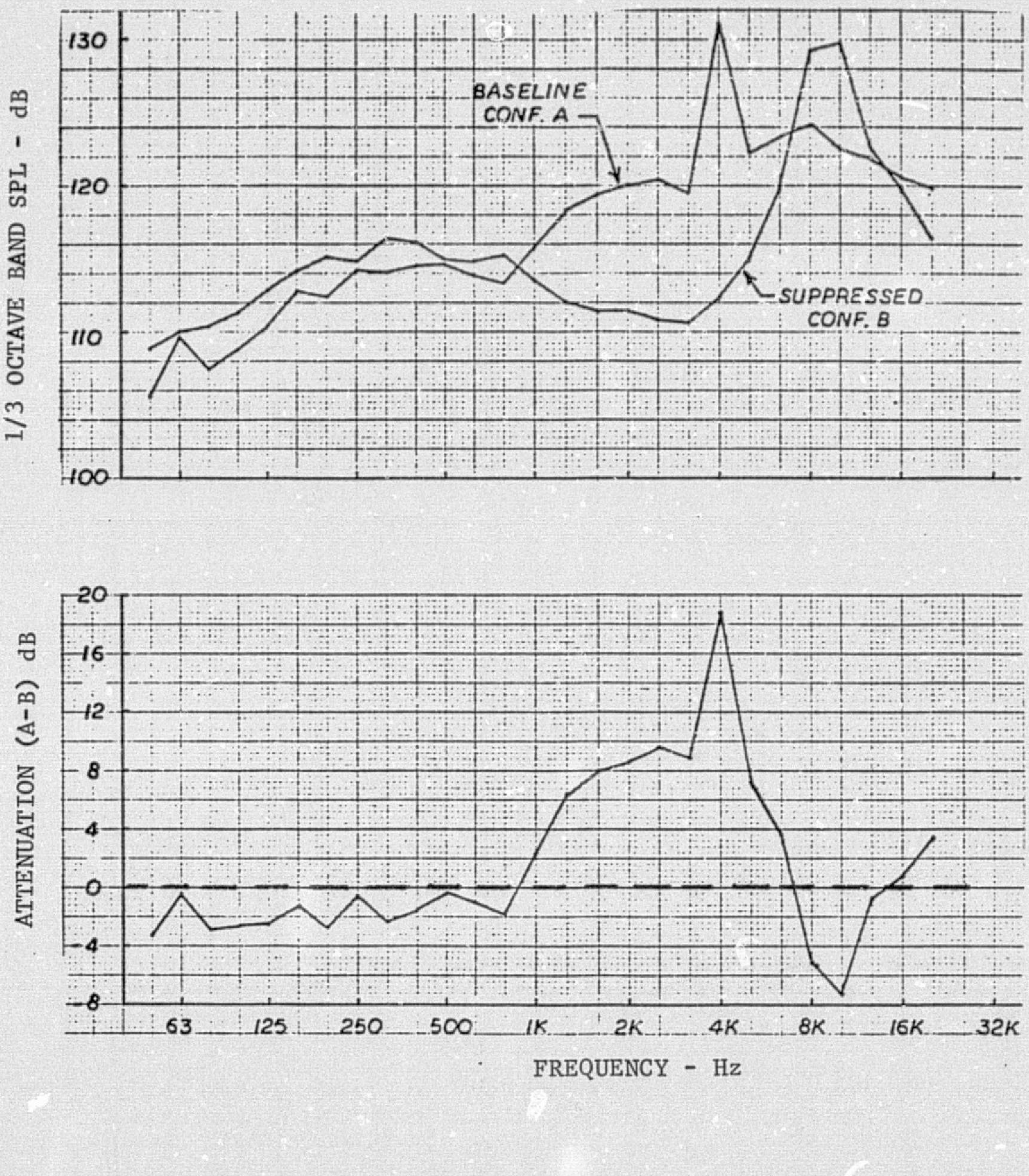


Figure 48 Spectra and Attenuation, Rear Flush Mounted Microphone at No. 9 Location - 40 Percent of Design Speed

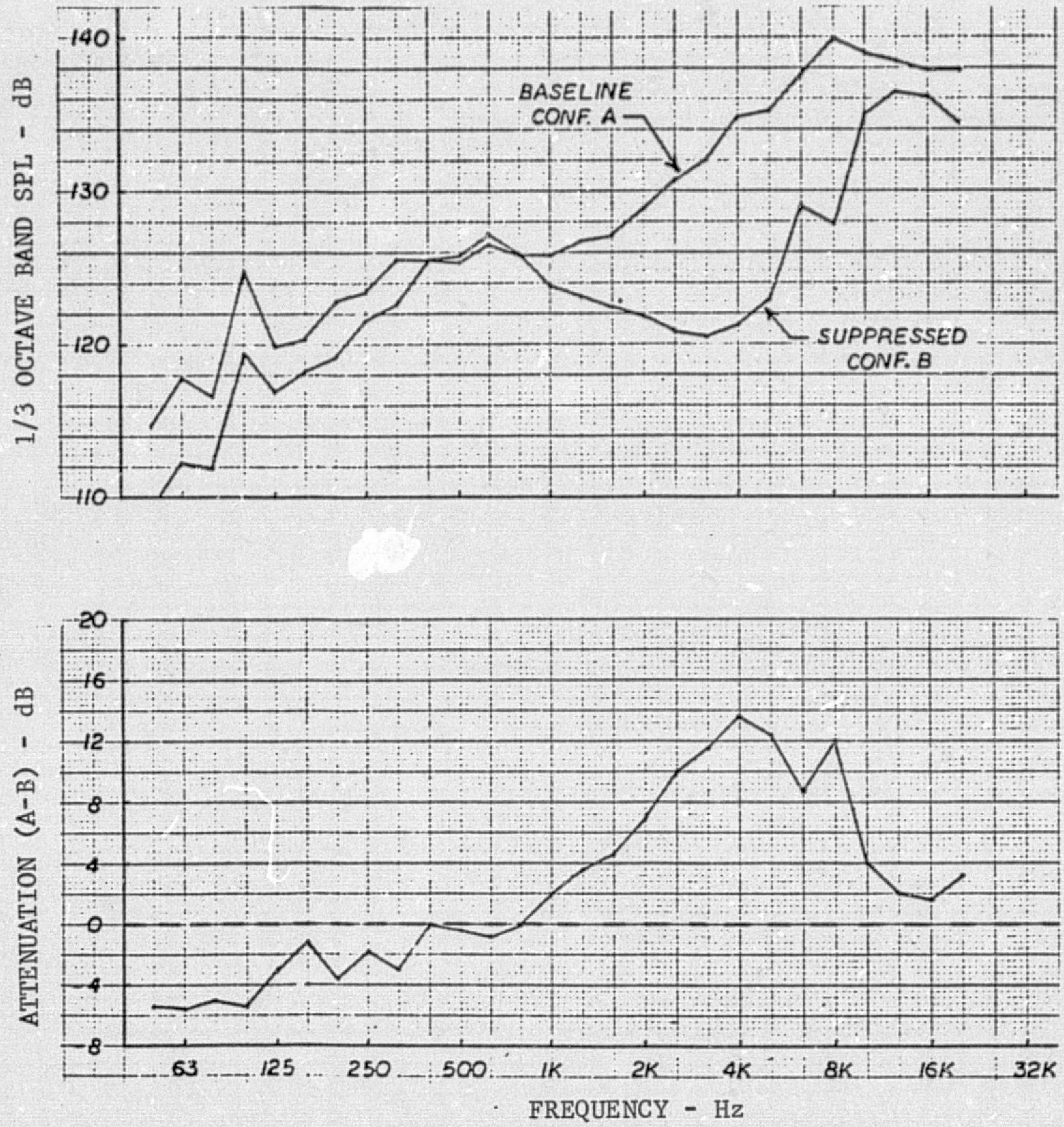
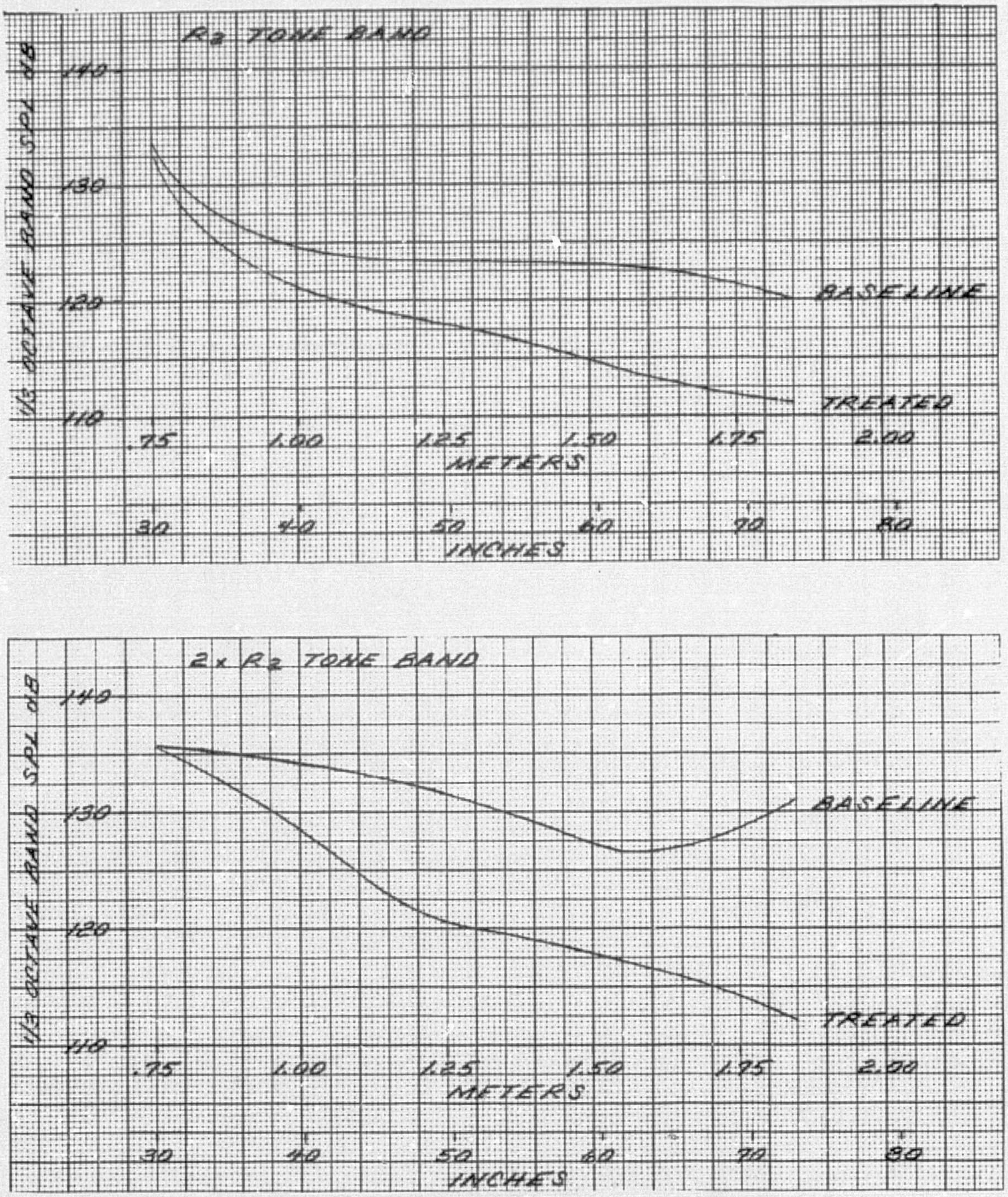


Figure 49 Spectra and Attenuation, Rear Flush Mounted Microphone at No. 9 Location - 75 Percent of Design Speed



AXIAL DISTANCE - DISCHARGE DUCT

Figure 50 Variation of Rotor Tone Band Levels in Discharge Duct - 40 Percent of Design Speed

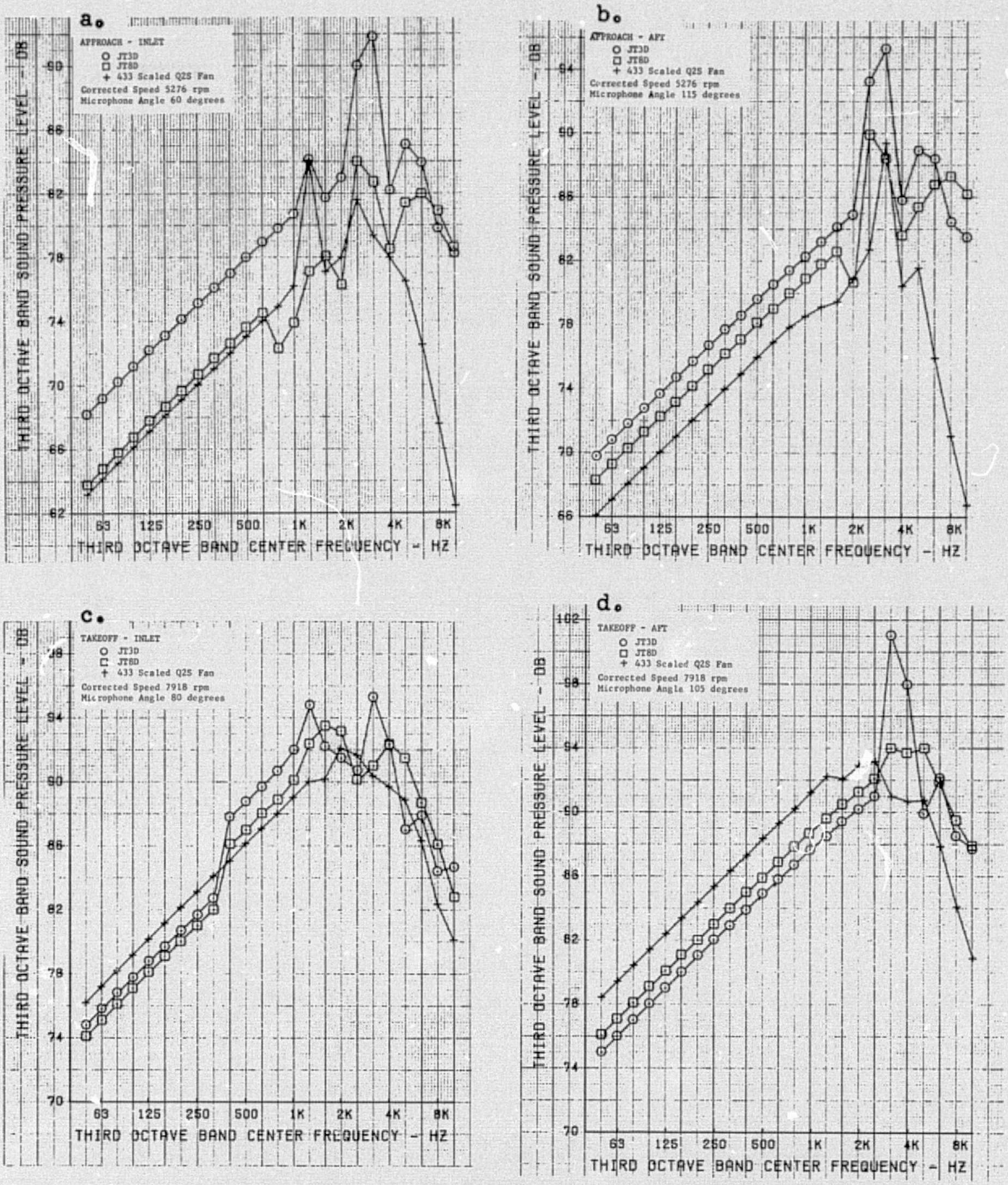
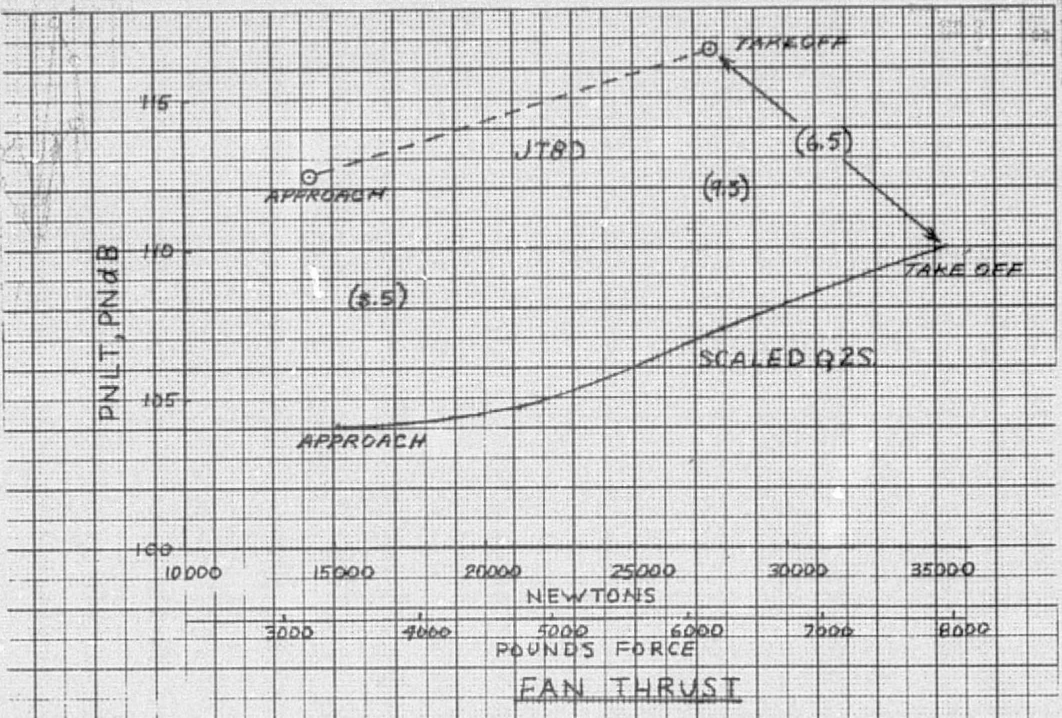


Figure 51 Full-Scale Engine Fan Spectra, 113 Meters [370 Feet] Sideline Noise



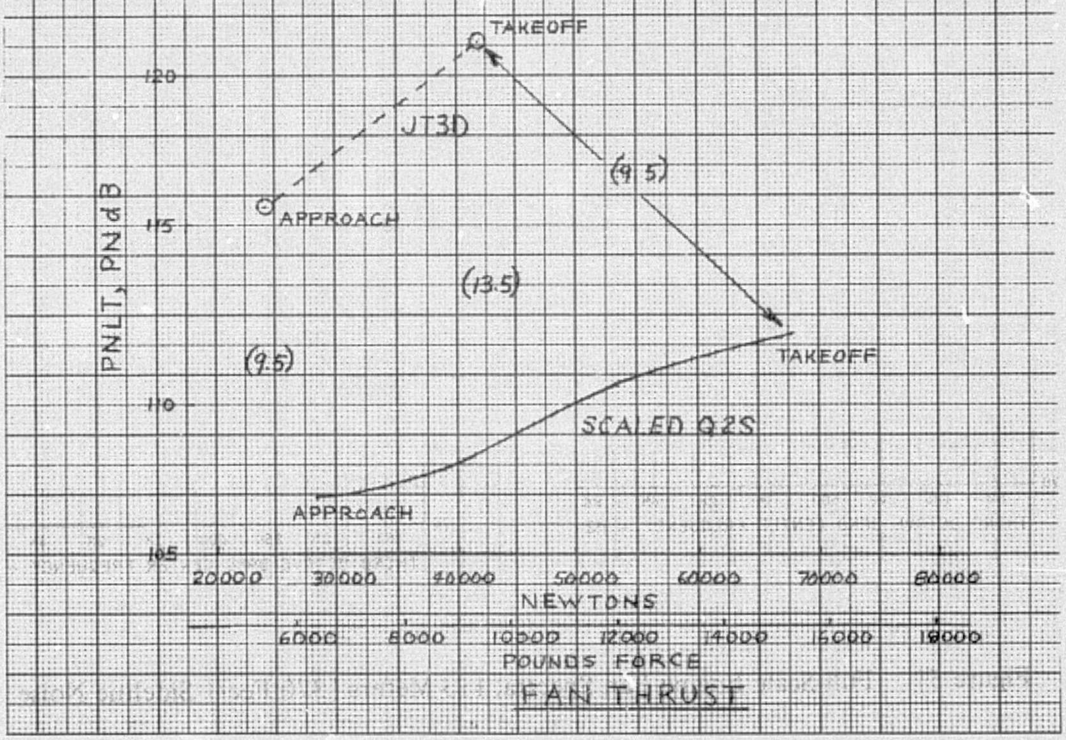


Figure 52 Scaled Baseline Comparisons - Aft Noise - 112.8 Meters [370 Feet] Sideline Noise

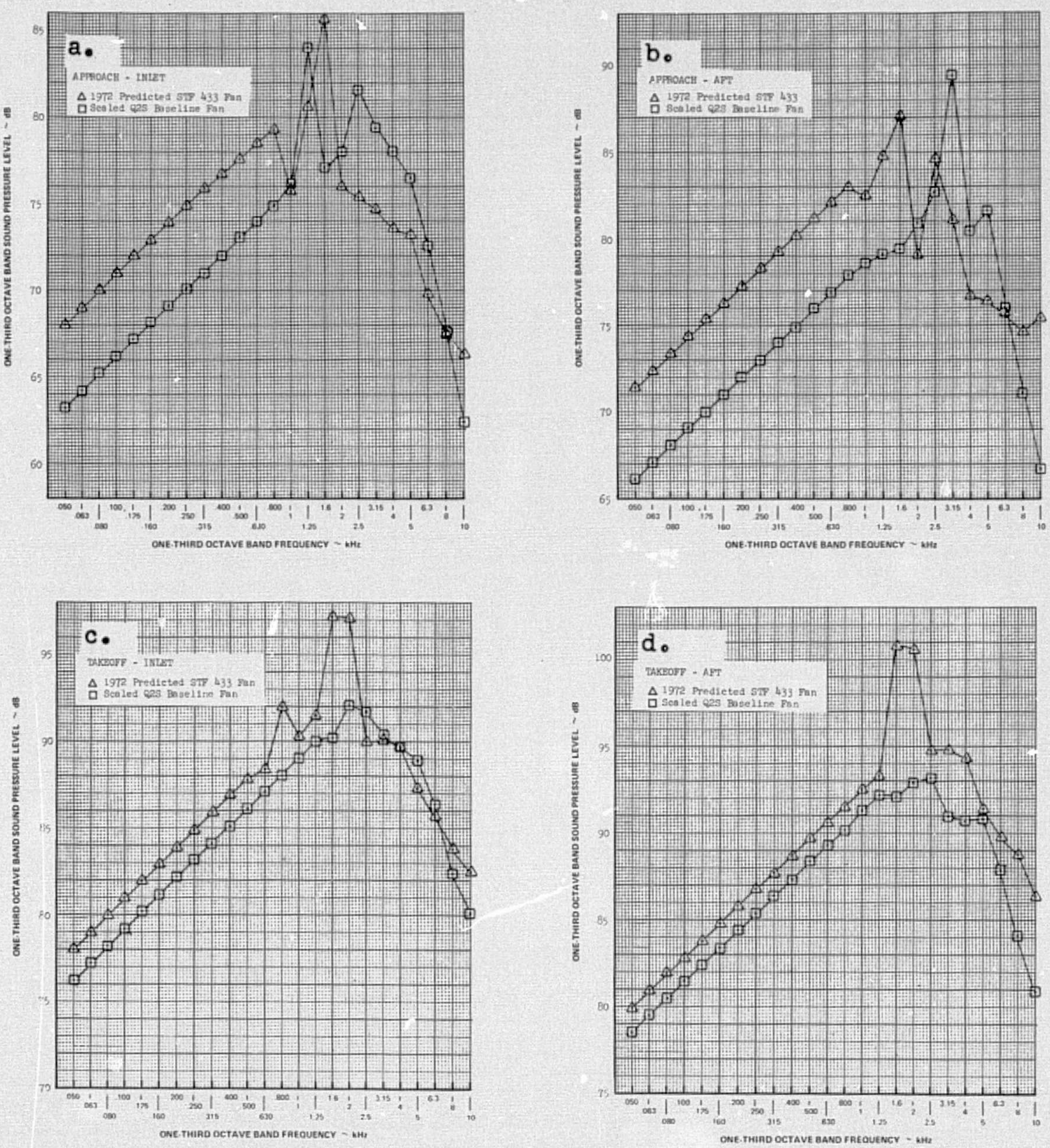


Figure 53 Comparison of Scaled Q2S Fan Baseline Spectra With 1972 Predicted STF 433 Fan

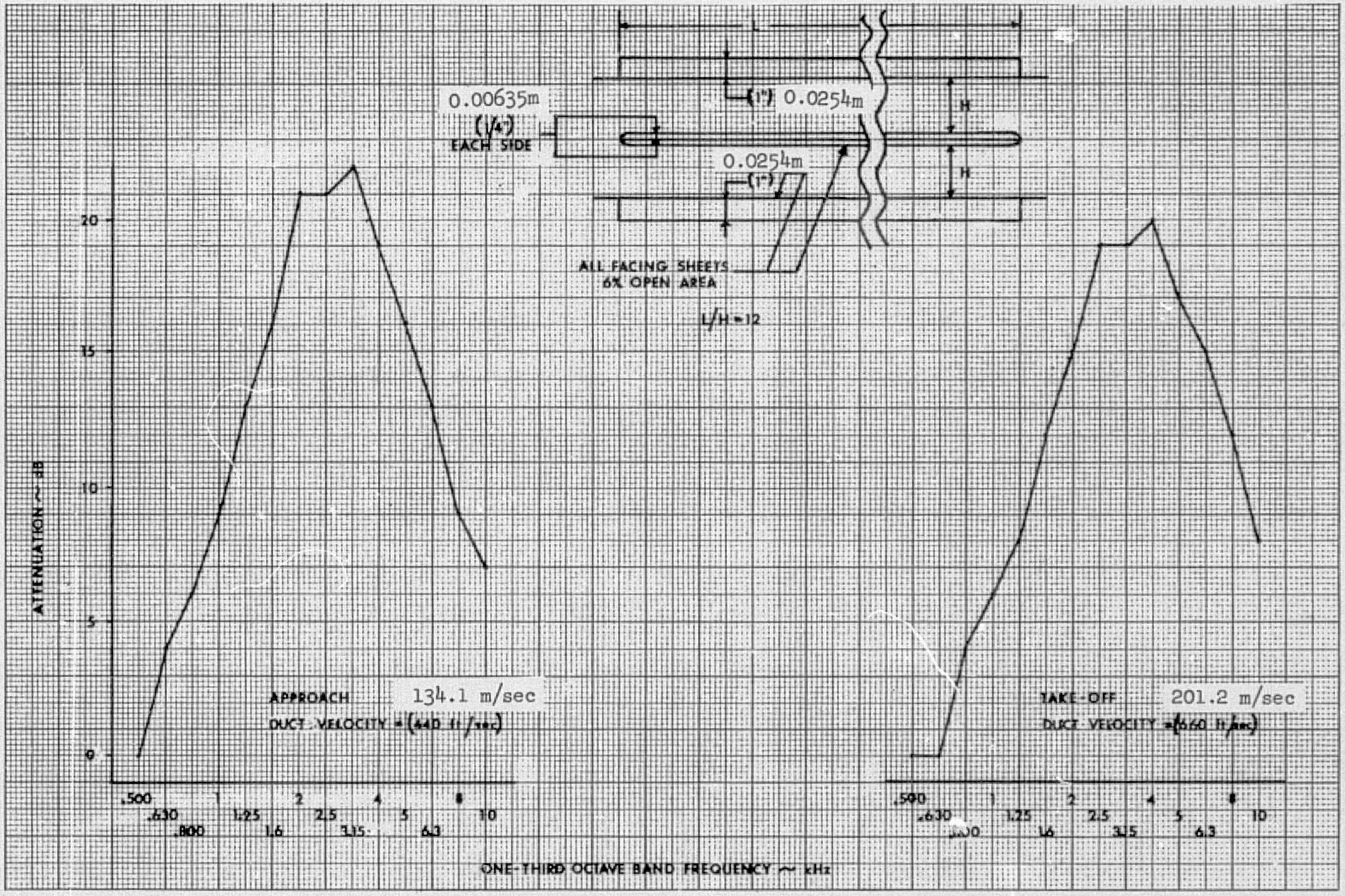


Figure 54 STF 433 Liner Design Characteristics

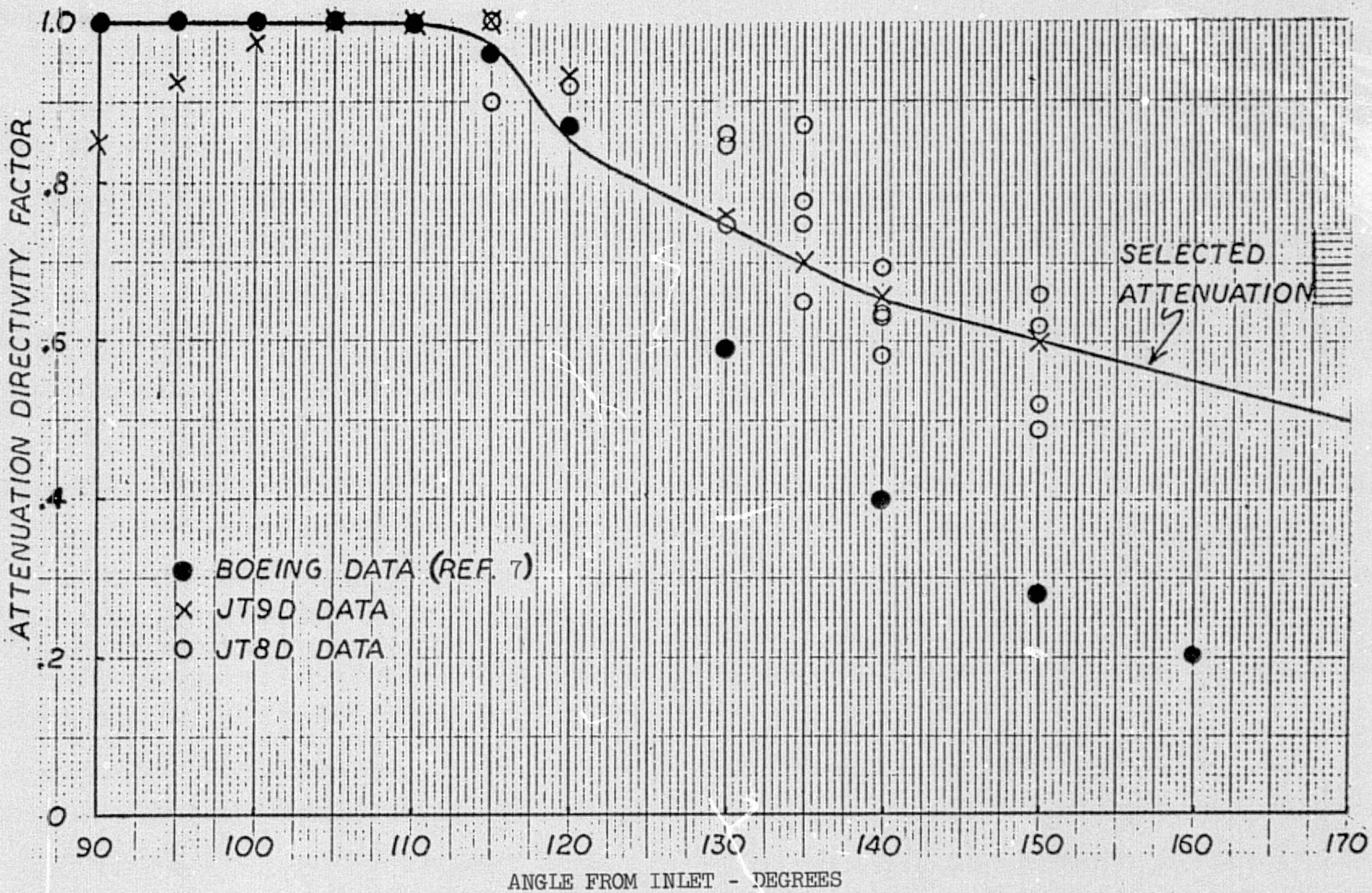


Figure 55 Lining Attenuation Directivity

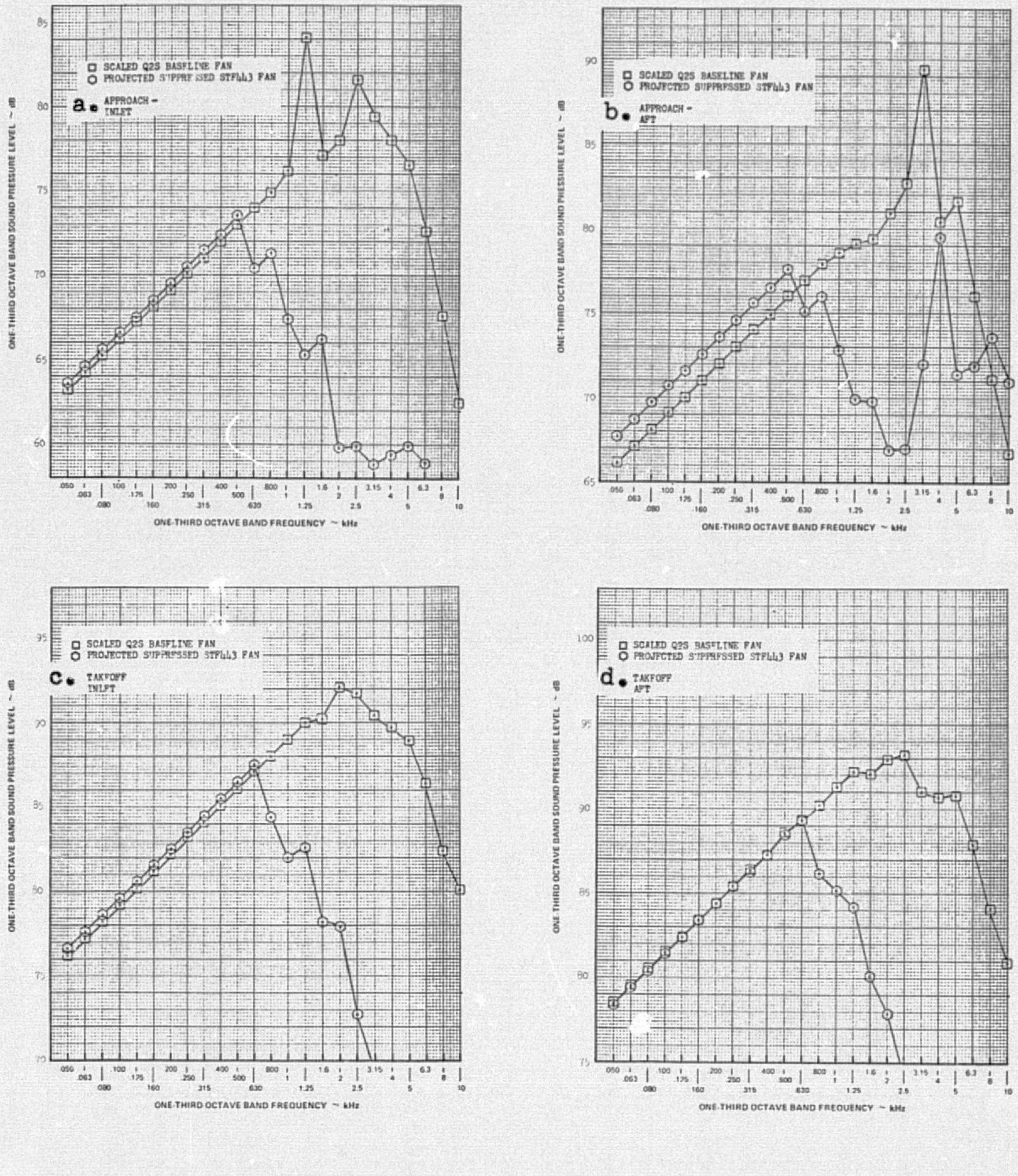


Figure 56   Projected Suppressed STF 433 and Scaled Q2S Fan Baseline Spectra

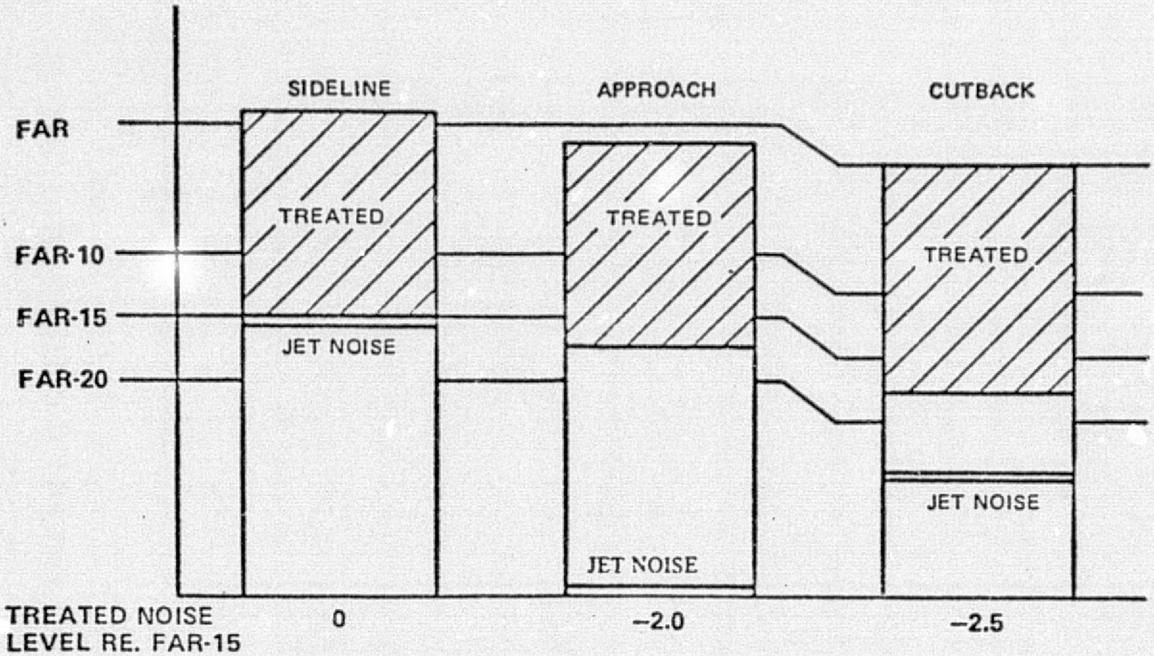


Figure 57 1972 Predicted ATT Noise Levels (Ref. 1)

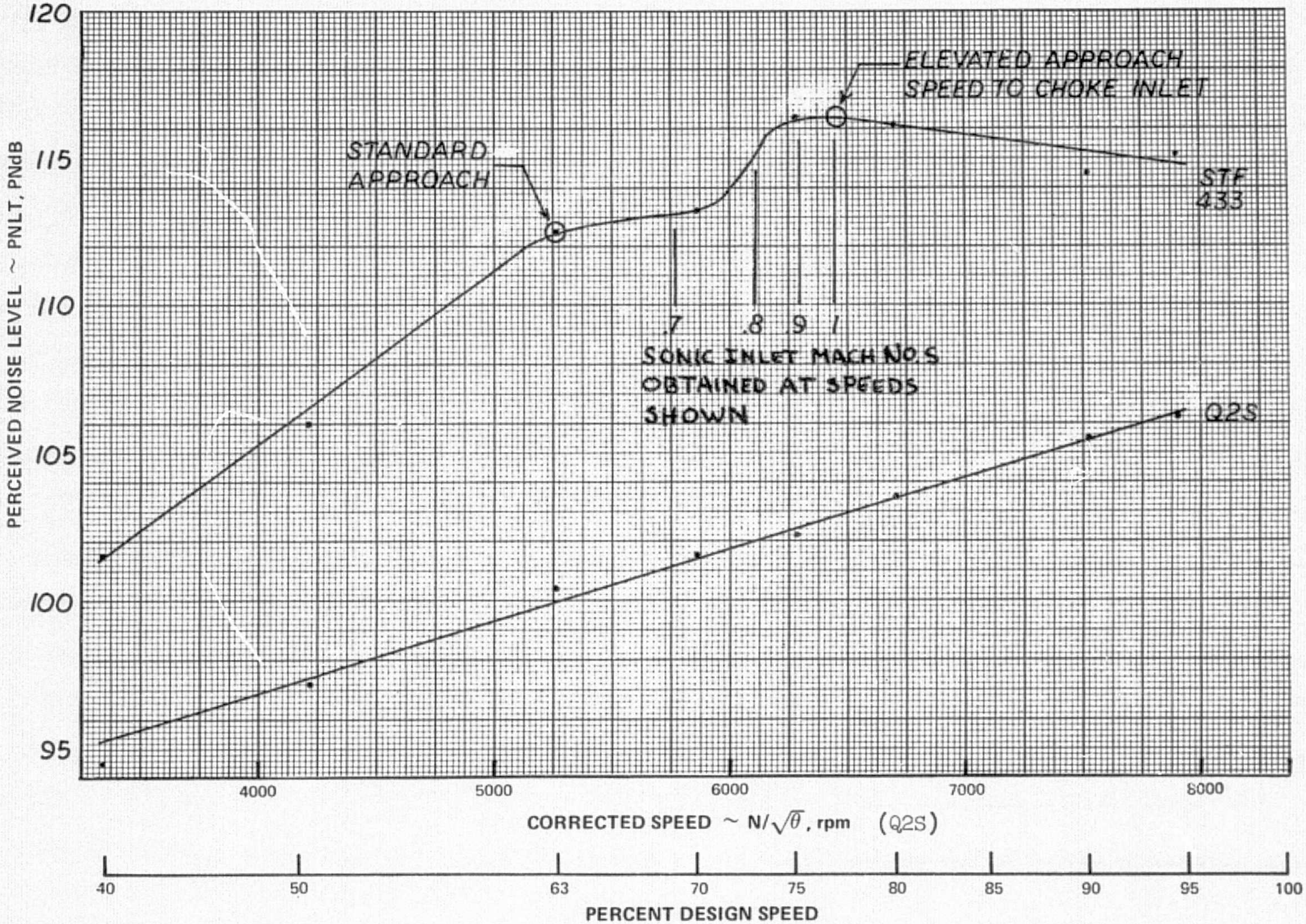


Figure 58 Q2S Fan and Q2S Fan Scaled to STF 433 Size, Peak Aft PNLT - 112.8 Meters [370 Feet] Sideline Noise