Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

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SVHSER 6183

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FAN AND PUMP NOISE CONTROL

by

JOHN MISODA AND BERNARD MAGLIOZZI

PREPARED UNDER CONTRACT NO. NAS 9-12457

DRL LINE ITEM NUMBER 4

by

HAMILTON STANDARD

DIVISION OF UNITED AIRCRAFT CORPORATION

WINDSOR LOCKS, CONNECTICUT

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

JOHNSON SPACE CENTER

HOUSTON, TEXAS 77058

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ABSTRACT

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This report describes the development of improved, low noise level fan and pump concepts for Space Shuttle. In addition, a set of noise design criteria for small fans and pumps was derived. The concepts and criteria were created by obtaining Apollo hardware test data to correlate and modify existing noise estimating procedures. A set of Space Shuttle selection criteria was used to determine preliminary fan and pump concepts. These concepts were tested and modified to obtain noise sources and characteristics which yield the design criteria and quiet, efficient Space Shuttle fan and pump concepts.

FOREWORD

This report was prepared by the Hamilton Standard Division of United Aircraft Corporation for the National Aeronautics and Space Administration's Johnson Space Center in accordance with contract NAS 9-12457, and covers work accomplished between March 17, 1972 and the date of issue. The work was conducted under a joint program between the Space Systems Department and the Acoustics and Noise Control Group of the Aircraft Systems Department, with the consulting services of Bolt Beranek and Newman, Inc.

The efforts of Bolt Beranek and Newman, Inc., Acoustic Consultants of Cambridge, Massachusetts are acknowledged for the part they played in preliminary work on data analysis and hardware noise estimates. In particular, the efforts of Dr. H. Heller, Dr. A. George, Dr. F. Kern, and Dr. S. Widnall are recognized. Their efforts are noted in the first five works in the bibliography.

The effort of Dr. D. B. Hanson, Hamilton Standard Acoustics and Noise Control Group, for consultation of fan noise sources and on the theoretical aspects of the Hamilton Standard axial flow fan performance and noise calculation computer program are acknowledged.

Appreciation is expressed to Technical Monitors, Messrs. R. Drexel and J. C. Brady of the NASA Johnson Space Center, for their advice and guidance.

This program was conducted under the direction of Mr. F. H. Greenwood, Program Manager, by the authors Mr. B. Magliozzi, Acoustics and Noise Control Group, Aircraft Systems Department and Mr. J. Misoda, Advanced Engineering Group, Space Systems Department, Hamilton Standard.

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SUMMARY

This report describes the test data results and the analytical noise estimating methods used in developing noise design criteria for spacecraft fans and pumps. From these design criteria and preliminary testing, fan and pump concepts were defined for Space Shuttle.

The Design Criteria offer a means of designing fans and pumps of a certain required performance to a minimum noise level. These criteria advance the existing technology in fan and pump noise control and provide guidelines, constraints and trends for small fan and pump designs. The axial fan concept achieved from these Design Criteria is a low noise, efficient fan which updates the state of the art of quiet spacecraft fan design. The centrifugal pump design, likewise, has these attributes.

Small fan and pump noise sources were first investigated by testing Apollo Command Service Module (CSM) and Lunar Module (LM) Environmental Control System (ECS) hardware. Various fan data indicated the existence of tones at the blade passing frequency and the propagation of the various harmonics of these tones. The tone noise due to rotor and stator interaction also was high. The fan motor noise usually was masked by the aerodynamic noise except in one axial flow fan where the bearings and/or the unbalance controlled the noise at high frequencies. Motor noise in the Apollo CSM pump dominated the noise of the centrifugal pump while in the Apollo LM pump sliding vanes controlled the noise level. Thus, improved motors will be required on future pumps and may be required also on future fans to achieve low noise levels.

The test data obtained from the Apollo LM and CSM ECS hardware testing was incorporated into the existing noise estimating methods. The pump noise levels were scaled from larger motor data with additional noise sources to account for the type of pump rotor. Incorporation of the Apollo data into existing noise estimating methods yielded a new Hamilton Standard Empirical Fan Noise Estimating Procedure which predicts small spacecraft size fan noise with reasonable accuracy. More accurate estimations of axial flow fan noise can be made with Hamilton Standard's axial flow fan performance and noise calculation computer program. This program was utilized to correlate both the LM cabin fan and the PLV fan with a good degree of accuracy.

The preliminary fan and pump concepts for Space Shuttle were selected on the basis of a NASA and Hamilton Standard coordinated selection criteria of weight, volume, power, noise and potential noise. The noise was estimated by the previously noted procedures. The weight, volume and power were estimated for flight designs.

The preliminary concept hardware for verification testing was selected from the equipment suppliers' data and then tested to obtain noise characteristics. Subsequently, modifications were made to the hardware and the units

then were retested to establish the new noise levels. This gave data useful for further correlation of the estimating methods and to establish trends and guidelines for quiet and efficient fan and pump design criteria.

These design criteria combined with the test data from the Apollo hardware and from the verification hardware provided the necessary technical information for the selection of the final Space Shuttle fan and pump concepts. The Space Shuttle cabin fan design point is a flow of 400 cfm of air at a pressure rise of 2.5 inches of water. The flow enters a large-screen-covered bellmouth located somewhat upstream of a three-bladed rotor with NACA series 16 airfoil sections. The fan hub is 2.75 inches in diameter and the fan tip diameter is 5.5 inches. Spacing between the rotor and stator is 4 inches, or 1.5 rotor mean chord lengths. Eleven stators with NASA 400 series airfoil sections are used. Both the fan rotor and motor rotor are balanced. The fan runs at 11,200 rpm, weighs 5.4 pounds and is 8 inches in diameter by 13 inches in length. The calculated power consumption is 221 watts. The estimated noise level is 76 dB NC with potential improvement to 70 dB NC.

The Space Shuttle Cabin Heat Transfer Loop pump flows 500 pounds per hour of water and produces a pressure rise of 20 psi. Flow enters the centrifugal rotor through a smooth, well-rounded inlet. The rotor has six backward curved vanes and a 1.30 inch tip diameter from which the fluid passes into an increasing area scroll. Here some of the fluid is bypassed for lubricating the hydrodynamic bearings and cooling the motor. Both the motor rotor and pump rotor are balanced. The pump runs at 11,200 rpm, weighs 2.5 pounds, and is 3.5 inches in diameter by 4.75 inches long. The unit has an estimated power consumption of 110 watts and a noise level of 40 dB NC at three feet.

INTRODUCTION

Noise generation by environmental control system components is unavoidable. Aerodynamic noise generation in the form of periodic pressure pulsations, for example, necessarily accompanies processes which add energy to or remove energy from a gas. Noise generated aerodynamically is particularly troublesome because the mechanisms of generation are not completely understood, and because external acoustic treatment, such as mufflers, in the path between source and receiver is often costly in performance and weight.

In Mercury, Gemini, and Apollo the noise level of ECS components caused an annoying cabin environment for the occupants. The MOL vehicle utilized mufflers for fans and valves at some weight penalty to achieve an acceptable noise level. With the advent of Space Shuttle and its longer duration space missions,the acoustic environment becomes more and more important. In addition to providing a background noise level suitable for communications, noise control also will have to aim at eliminating psychological disturbances and annoyances. As such, Space Shuttle has stringent noise requirements and measures will have to be taken to reduce noise generation at the source in order to minimize external treatment. To be effective, such measures must be considered during the design stage of a component.

NASA JSC sponsored this study of Fan and Pump Noise Control because very little noise data exists. Determining the noise sources in small fans and pumps was an introduction to the objective of determining small fan and pump design criteria and quiet, efficient fan and pump concepts for the Space Shuttle.

The study was divided into five sections. The first was an evaluation of all Apollo ECS fans and pumps. This was performed by first estimating the noise levels generated by the hardware and then actually testing the hardware. Second, the results of this evaluation were refined further to establish a useful noise estimating method for deriving preliminary Space Shuttle fan and pump concepts. Third, these preliminary concepts were tested utilizing commercially available hardware. During this testing, modifications were made to reduce noise and to establish further noise sources. Fourth, all of the testing, analyzing, and estimating methods then were incorporated into a set of design criteria for small fans and pumps. Finally, using these design criteria, fan and pump concepts for the Space Shuttle were defined.

This report describes the work accomplished in each section. The report is organized chronologically and leads basically to the developed design criteria and the Space Shuttle fan and pump concepts.

CONCLUSIONS

On the basis of the results from this program, the following conclusions have been reached:

- The motors and bearings of quiet fans and pumps used in future spacecraft may produce significant noise, unless the motor bearings are carefully designed. Ball bearings are the noisiest type and may dominate the noise of quiet pumps and contribute to the noise of quiet fans. Sleeve type bearings appear acceptably quiet for both fans and pumps.

- Of the three types of fans tested in this study the squirrel cage centrifugal was quietest by a small margin. The axial fan was next, with the radial blade centrifugal being the noisiest.

- At present state-of-the-art squirrel cage fans are significantly heavier and less efficient than are axial fans, the axial fans having the advantage of extensive development for use in submarines and aircraft. Because the gain in noise improvement for the squirrel cage fan tested was relatively small, and since this program was limited to present state-of-the-art, the axial fan was selected for Shuttle requirements.

- Of the types of pumps considered in this study, the backward curved centrifugal pump is quietest, if the inlet pressure and geometry are controlled to prevent cavitation. In this type of unit, the motor becomes the dominant noise source and must be carefully designed to avoid electromagnetic and bearing noise. Other pumps which make use of sliding vanes, meshing lobes, vibrating diaphragms and so forth, have noise levels well above those of the centrifugal pump and their motor bearings do not dominate the noise level.

- None of the fans and pumps tested in this program could achieve the design objectives of 30 dB NC at three feet. The centrifugal pump was closest at 40 dB NC. The measured axial fan noise was at 76 dB NC. However, a quiet axial flow fan was estimated at 70 dB NC.

- An axial flow fan optimized for noise, weight, volume and aerodynamic performance to meet the Space Shuttle requirements of 400 cfm and 2.5 inches of water static pressure rise will have a 5.5 inch rotor tip diameter and run at 11,200 rpm. The fan should have three rotor blades, 11 stator vanes, and a blade to vane gap of 1.5 blade chords.

- A centrifugal pump optimized for noise, weight, volume and hydraulic performance to meet the Space Shuttle requirements of 480 pounds per hour and 20 psi total to total pressure rise should have a 1.30 inch diameter rotor with six backward curved vanes and run at 11,200 rpm. For minimum noise sleeve type bearings should be used, however, life requirements may dictate the use of ball bearings. The 3.5 inches diameter by 4.75 inch long pump should have a potted motor stator well-balanced rotating assembly, and utilize the flowing fluid for motor cooling.

- The Hamilton Standard axial flow fan performance and noise calculation program shows good correlation between measured and estimated aerodynamic noise sources for these small ventilation fans.

- None of the fan noise estimating methods investigated in this study were directly useable. Of the many methods, the Allen, ASHRAE, and Buffalo-Forge methods appeared the most promising. The Buffalo-Forge method was modified by a speed correction to arrive at the Empirical Fan Noise Estimating Procedure. This method is a good tool for quickly obtaining a reasonable noise estimate and obtaining noise trends with design and operating parameters.

RECOMMENDATIONS

On the basis of the work conducted under this program the following recommendations are made if further development of axial fans is undertaken.

- The Hamilton Standard Axial Flow Fan Noise and Performance Calculation Computer Program should be used to refine the axial flow fan design for the Space Shuttle application. Additional variation of parameters such as blade twist distribution and blade camber distribution should be included. The goal should be to achieve the required Shuttle fan performance with noise generation characteristics requiring no further sound suppression, and without significant weight and power penalty. The results of this study should be incorporated in the Shuttle cabin fan concept.

- A breadboard fan should be fabricated in accordance with the final Shuttle cabin fan concept. It should have removable blades and stators to allow fan configurations having various geometries to be tested. The geometrical modifications should include serrated leading edges, porous surfaces or portions of porous surfaces.

- A performance and noise level test program should be conducted on the breadboard Shuttle cabin fan. Several inlet configurations including long inlet ducts and inlet flow straightening devices, and various rotor to stator spacing should be tested. The test program should correlate the predicted noise and performance values with the values obtained from testing, to verify and if necessary improve the quantitative predictive capability.

NOMENCLATURE

A_B = Blade Area ~ ft^2

B = number of rotor blades

BFI = Blade Frequency Increment

BLC = Boundary Layer Control

Btu = British thermal unit

C = Chord length ~ ft

cfm = flow ~ cubic feet per minute

C_L = Chord length ~ ft

c_o = speed of sound in atmosphere ~ fps

CSM = Command Service Module

D = tip diameter ~ inches

D_B = ball diameter ~ inches

dB = decibel

E = Energy flux (Btu/sec x ft^2)

EC/LS = Environmental Control/Life Support

F_o = force ~ pounds

fps = feet per second

f_{ratio} = frequency ratio

ft = feet

HP = Fan Input horsepower

hr = hour

H_T = Total enthalpy at the temperature T of the gas leaving the compressor ~ Btu/hr

NOMENCLATURE (Continued)

Hz = Hertz

ID = inner diameter ~ inches

IGV = Inlet Guide Vanes

in = inch

K = Constant Integer ($-\infty$ to $+\infty$ range)

k = ω/c_o = ft^{-1}

lb = pound

LM = Lunar Module

M = harmonic number

m = mass of body ~ slugs; also meter

mm = millimeter

N = rotation speed ~ rpm; also Newton

Ns = specific speed ~ rpm

n = number of balls

NC = noise criteria

OD = outer diameter ~ inches

P = Pressure ~ psia (total pressure = static + dynamic)

PAM = pulse amplitude modulation

PLV = Postlanding Ventilating

PNdB = Perceived Noise ~ dB

PPM = pulse position modulation

psi = pounds per square inch

psia = pounds per square inch absolute

PWL = sound power level ~ dB

NOMENCLATURE (Continued)

Q = displaced volume of the body being excited ~ ft^3

Q^1 = accession or entrained volume of the fluid being excited ~ ft^3

Q_d = fan discharge flow ~ cfm

R = distance from noise source ~ ft

rpm = revolutions per minute

rps = revolutions per second

S = rotor annulus area ~ ft^2

sec = second

SPL = sound pressure level

T = total temperature ~ degrees Rankine

t = airfoil blade maximum thickness ~ ft

V = number of stator vanes

$V_{0.7}$ = Blade velocity at a diameter equal to 0.7 times the tip diameter ~ fps

VAC = voltage alternating current

VDC = voltage direct current

V_t = rotor tip velocity ~ fps

V_w = wall velocity ~ fps

$\dot{w}$ = mass flow per unit time ~ lb/sec

α = Blade Angle ~ degrees

α_{CH} = Blade Chord Angle ~ degrees

ΔP = change in pressure ~ inches water

NOMENCLATURE (Concluded)

δ = hub - tip ratio

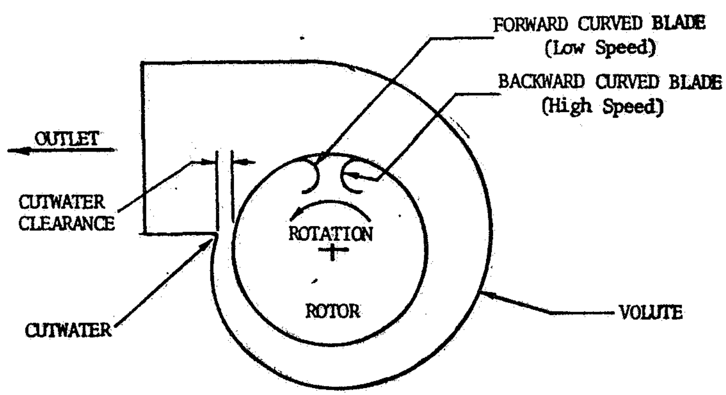
θ = Blade Twist Angle ~ degrees

π = Constant = 3.14159

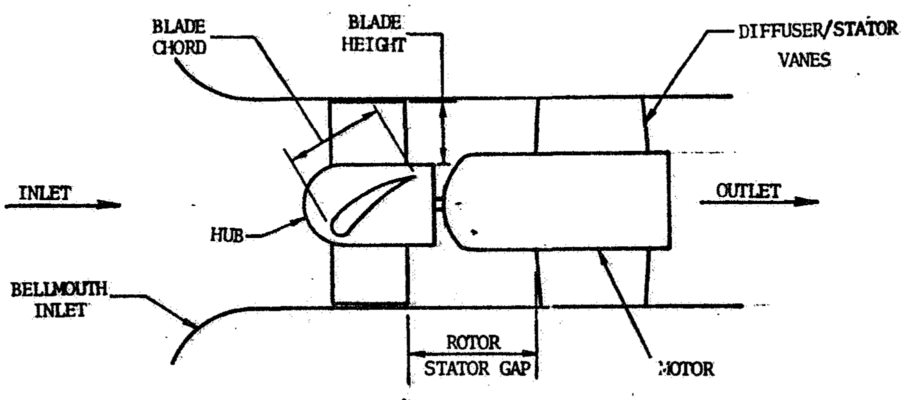
ρ_0 = density of environmental atmosphere ~ slugs/ft^3

ω = rotational speed ~ radians/sec

CENTRIFUGAL TYPE FAN OR PUMP



AXIAL TYPE FAN



FAN AND PUMP NOMENCLATURE

APOLLO FAN, COMPRESSOR, AND PUMP NOISE EVALUATION

The first phase of the Fan and Pump Noise Control Program consisted of acoustic noise tests, conducted on two water-glycol pumps, three axial fans, and two air compressors to serve as a basis for evaluating the noise sources in small pumps, ventilating fans, and compressors. The data from these tests, properly analyzed, were to be used to identify the types and origins of the various noise sources in these devices and to verify the capability of noise prediction methods. Thus, measurements of pump case radiated noise levels and fan and compressor inlet and exhaust noise levels were made in the acoustic far-field to determine the acoustic power generated by these items.

All data was analyzed by 1/3 octave bands. Narrow-band frequency analyses were made for selected conditions to aid in interpreting the noise components.

Measurements also were made of the noise from an isolated pump motor and an isolated fan motor to assess the mechanical and electro-mechanical noise sources of the driving motors.

TEST DESCRIPTION

The test program was conducted in accordance with the detailed Plan of Test for Test No. 1, contained in Appendix C.

Test Item Description

Two water-glycol pumps, three fans and two air compressors were tested in this program. The pumps consisted of the LM ECS glycol pump and the CSM ECS glycol pump. The three fans tested were the LM cabin fan, the CSM cabin fan, and the CSM PLV fan. Lastly, the two Apollo program air compressors tested were the LM and CSM suit compressors.

The LM ECS glycol pump is of the sliding vane type driven by a brushless, 28 VDC motor, whereas the CSM ECS glycol pump is a radial blade centrifugal pump driven by a 400 Hz, three-phase motor.

All three fans are of the axial flow type. The CSM cabin and PLV fans are low tip speed design, with four and three rotor blades, respectively. Both fans have five stator vanes. The LM suit compressor is a radial blade centrifugal unit and the CSM suit compressor has a radial rotor with a mixed flow stator resulting in an axial outlet.

Test Facility Description

All testing was done in Rig #14 of Hamilton Standard's Space Systems Department. This pressure chamber, of approximately 216 cubic feet of volume, has all surfaces treated with open-cell polyurethane foam to provide an essentially free-field environment over the frequency range of interest at the source-to-microphone distances used for the measurements. The chamber consists of two cylinders joined together with the dimensions shown in figure 1. The free volume of the larger diameter section is approximately 145 cubic feet and 71 cubic feet for the smaller section.

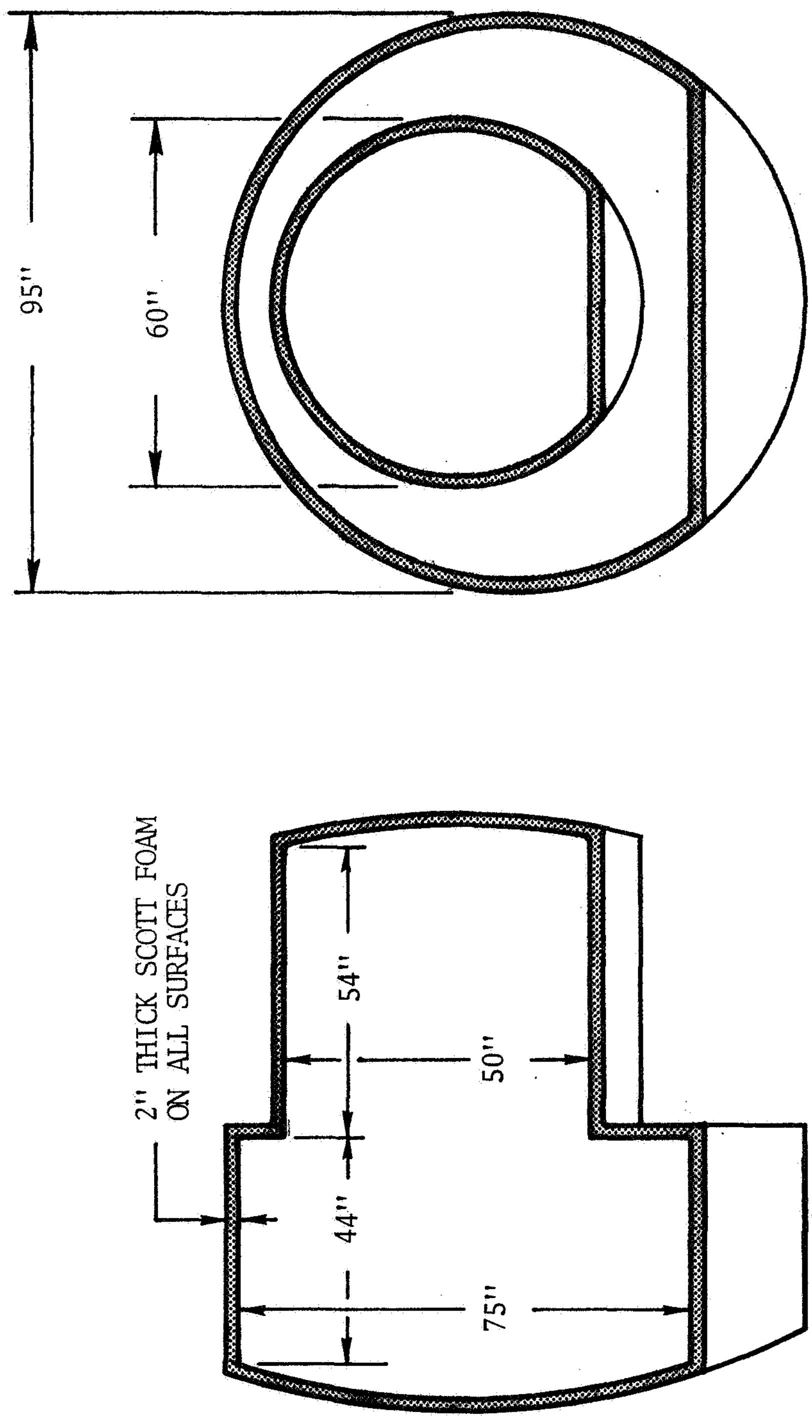
Since the case radiated pump noise was of prime interest, the whole volume of the chamber was used in testing the pumps. However, it was desired to isolate the inlet and exhaust noise components in the fans and compressors. Thus, the chamber was modified by the installation of an acoustically insulated plywood partition to divide the chamber into two sections as shown in figure 4. The partition also served as the fan system pressure regulator. The fans were installed in the partition such that the inlets were in one section and the exhaust in the other.

Background noise in the chamber was at an acceptable low level for all testing. For the very quiet pumps the chamber background noise did predominate below 500 Hz. However, as can be seen in figure 40 the absolute level was below NC-30 and was therefore not significant.

Test Description

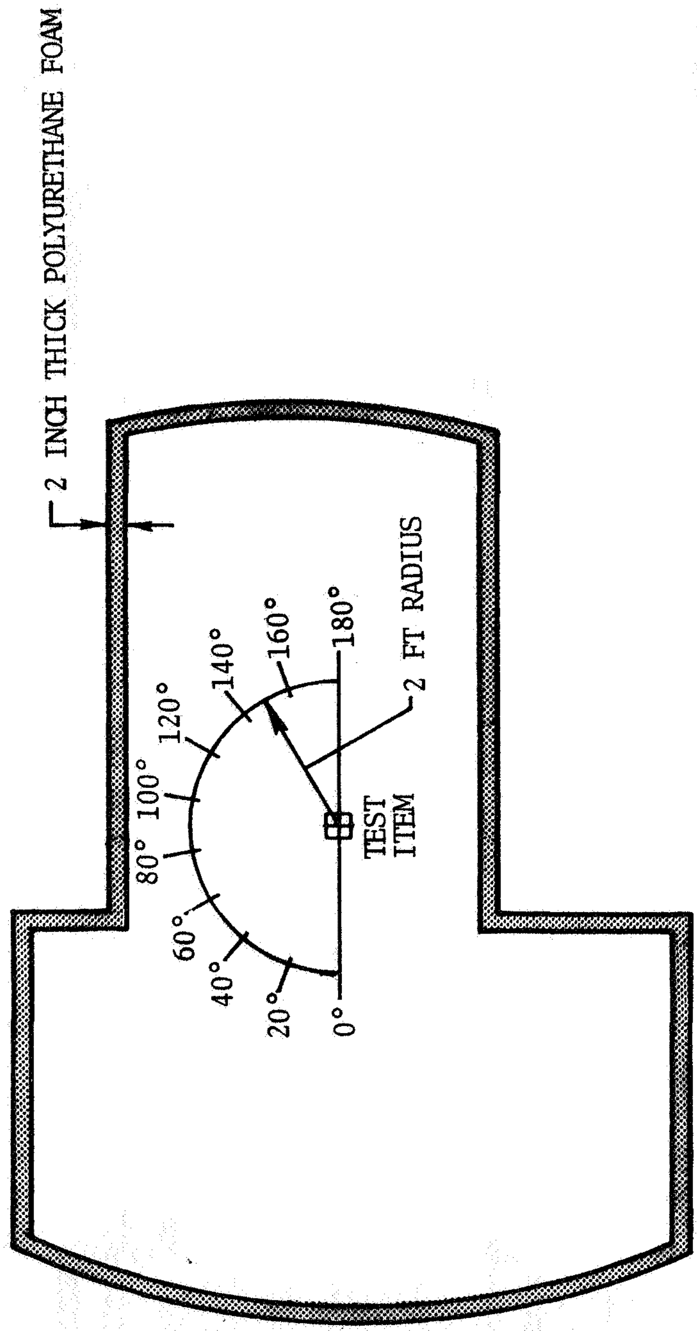
The pumps were tested at ambient pressure. For these tests, the pumps were each suspended at the approximate center of the chamber by Bungee cord. Acoustic noise measurements were made over a 180 degree arc, from 0 to 180 degrees, at 20 degree intervals, at a two foot radius. The locations of the pumps and microphones are shown in figure 2. The pump operating conditions are summarized in Table I.

The LM cabin fan and suit compressor were tested at 5 psia, while the PLV fan was tested at 14.7 psia. The CSM cabin fan and suit compressor were each tested at 5 and 14.7 psia. Each fan and compressor was installed in the plywood divider separating the two halves of the chamber using vibration isolators. In the case of the PLV fan, the LM cabin fan, and the CSM cabin fan, the pressure drop from one side of the chamber to the other was matched to the fan design condition. In the case of the two compressors, where high pressure rise was required at low flow in the compressor circulation loop, woven fiber metal was used to adjust the pressure drop. Due to the low flow velocities and uniformity of the material, no distorting of inflow was present at the fan inlets.



APPROXIMATE INTERIOR DIMENSIONS OF RIG 14

FIGURE 1



MICROPHONE LOCATIONS FOR PUMP NOISE MEASUREMENTS

FIGURE 2

TABLE I

PUMP PERFORMANCE TEST DATA SUMMARY

PARAMETER	LM PUMP		CSM PUMP	
	Design	Actual	Design	Actual
Fluid	Glycol-Water	Glycol-Water	Glycol-Water	Glycol-Water
P_{in} (psia)	14.7	13.6	14.7	13.6
Flow (lb/hr)	222	222	200	200
ΔP (psi	50	29.7	36	29.5
Power (watts)	25	19.6	52	63.7
Speed (rpm)	5500	-	22,000	-
Power Source	28 VDC	28 VDC	115VAC, 400 Hz 3 Phase	115VAC, 400 Hz 3 Phase
Average SPL at 3 ft and 14.7 psia ~ dB(A)	-	52	-	50

To ensure uniform inflow to all the fans and compressors, generous bellmouths similar to the one shown in figure 3 were used on the inlets. Two tests were run on each item. The first test had pressure probes in the inlet bellmouths to determine the flow by measuring static and dynamic pressures at the item inlets. These pressure probes then were removed and the test repeated while the noise measurements were made.

The fan test conditions which were run are summarized in Table II. The noise was measured at six locations, from 7.5 to 82.5 degrees in 15 degree increments, along an arc two feet in radius, for the inlet and outlet configuration, as shown in figures 4 and 5. The signals from the microphones were recorded on magnetic tape for later evaluation.

Later in the analysis, it was suspected that the motor noise was contributing to the measured noise levels of the pumps and the PLV fan. Therefore, abbreviated tests were conducted on the LM pump motor and the PLV fan motor in which full octave bands were measured, then integrated into octave band sound power levels for comparison with the total item noise levels.

DATA REDUCTION

All the data was reduced by 1/3 octave bands. A sample plot is shown in figure 6. The data from the microphones then was integrated to give inlet and exhaust 1/3 octave band sound power levels for the fans and compressors and case radiated 1/3 octave band sound power levels for the pumps. Also, the 1/3 octave band sound power levels were summed into full octave band sound power levels. The tabulated 1/3 octave band sound pressure levels, 1/3 octave band sound power levels, and octave band sound power levels are included in Appendix B.

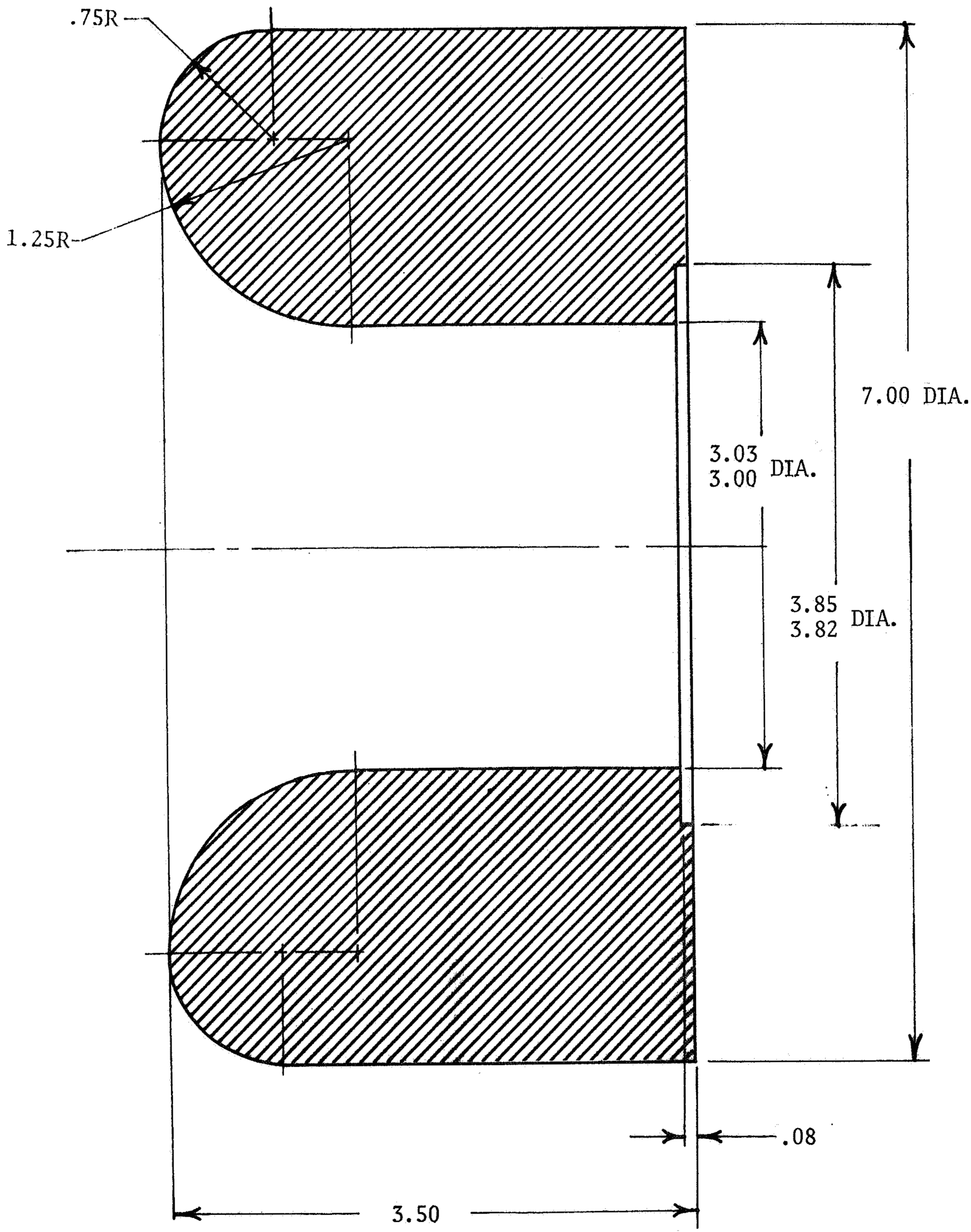
Narrow band frequency spectra of pump noise were determined for one representative microphone location (120 degrees) to identify the noise components. These were determined also for the fan and compressor inlets and exhaust noise signals, at 52.5 degrees for the inlet and 67.5 degrees for the exhaust. (1)

DISCUSSION OF TEST RESULTS

Pump Noise

Figure 7 shows the 1/3 octave band power levels of the case radiated noise of the LM and CSM pumps. Although there are minor differences in their respective spectra, the noise signatures of the two units are remarkably

(1) Note that 67.5 degrees on the exhaust corresponds to an angle of 112.5 degrees relative to the inlet axis. This is seen readily in figure 4.



TYPICAL FAN INLET BELLMOUTH

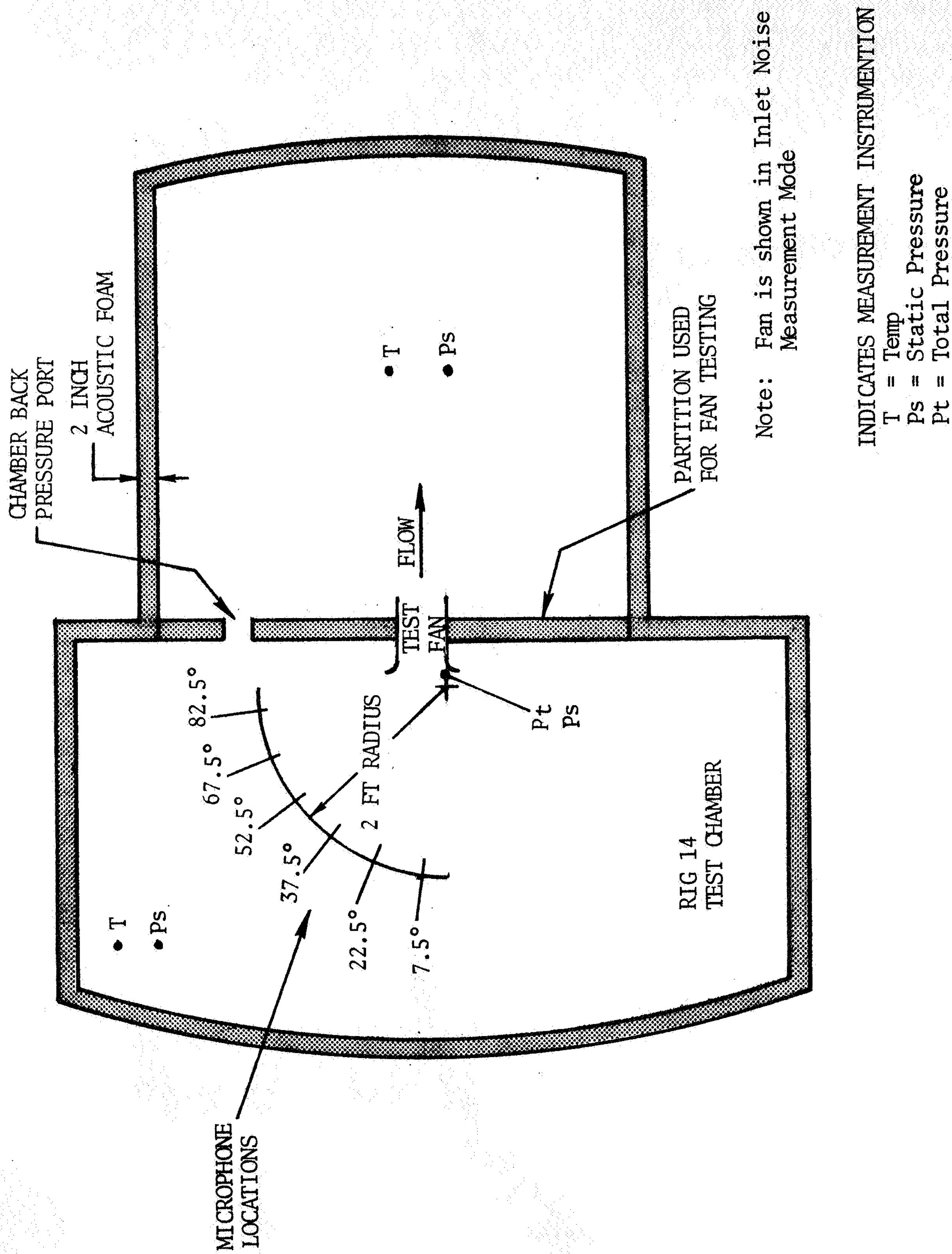
FIGURE 3

TABLE II

FAN PERFORMANCE AND COMPRESSOR TEST DATA SUMMARY

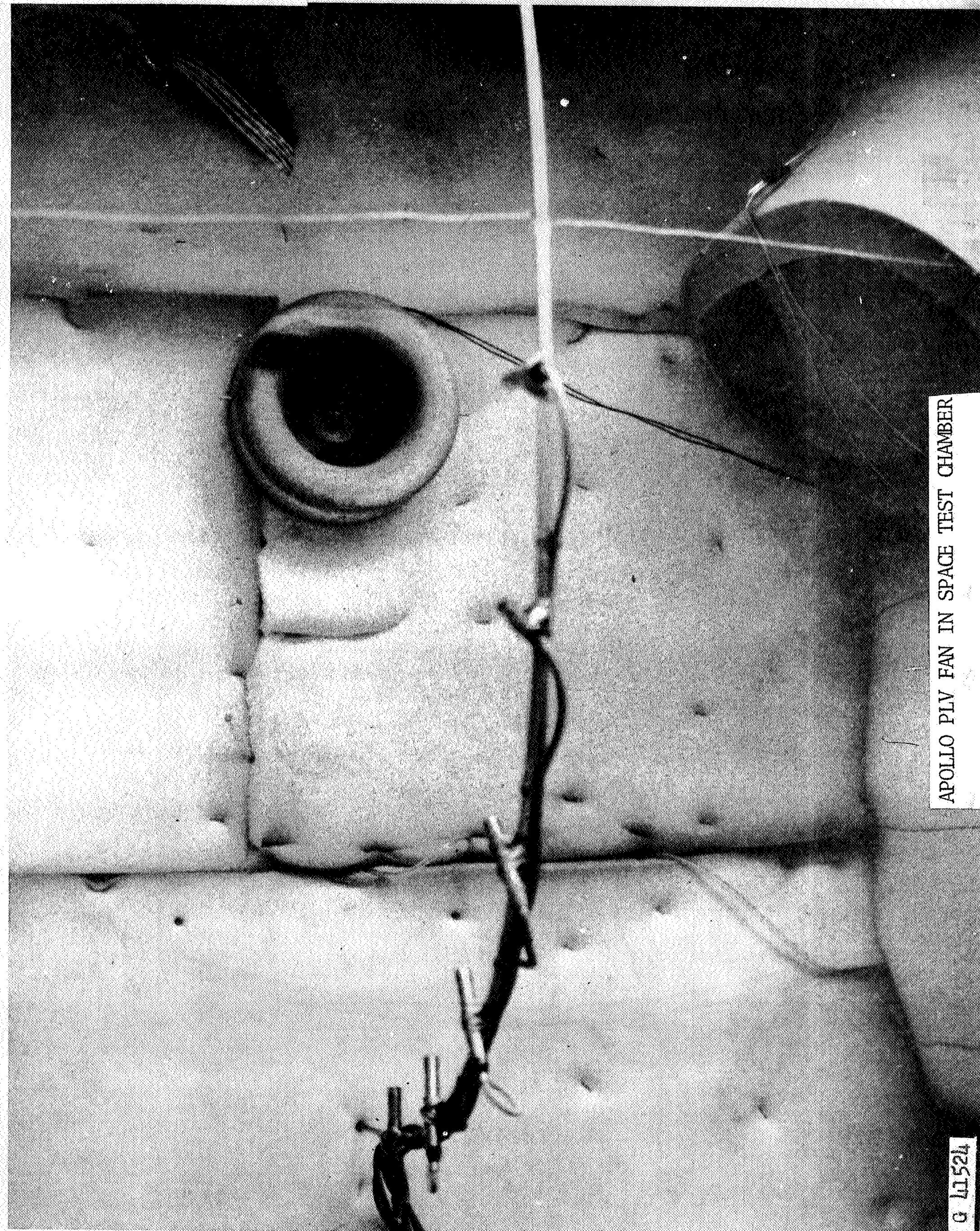
PARAMETER	LM CABIN FAN		CSM CABIN FAN		PLV FAN	
	Design	Actual	Design	Actual	Design	Actual
Flow (cfm)	183	122	86	77	150	150
ΔP (inches H_2O)	0.4	0.4	0.4	0.15	0.4	0.4
P_{in} (psia)	5.0	5.0	5.0	5.0	14.7	14.7
Power (watts)	30	28	20	20	17	18.2
Speed (rpm)	13,000	12,600	11,000	10,500	5,500	4,100
Tip Speed (fps)	213	206	144	138	120	90
Power Source	28 VDC	28 VDC	115VAC, 400 Hz 3 Phase	115VAC, 400 Hz 3 Phase	28 VDC	28 VDC
Average SPL at 3 ft and 14.7 psia ~ dB(A)	-	75	-	55	-	53

PARAMETER	LM SUIT COMPRESSOR			CSM SUIT COMPRESSOR		
	Design	Actual		Design	Actual	
		Inlet Test	Exhaust Test		Inlet Test	Exhaust Test
Flow (cfm)	27	-	-	35	27	27
ΔP (inches H_2O)	15.0	13.6	14.6	10.0	10.5	10.4
P_{in} (psia)	5.0	5.0	5.0	5.0	5.0	5.0
Power (watts)	160	98	147	85	138	138
Speed (rpm)	25,000	26,250	24,000	22,000	-	-
Tip Speed (fps)	410	430	392	350	-	-
Power Source	28 VDC	28 VDC	28 VDC	115VAC, 400 Hz 3 phase	115VAC, 400 Hz 3 Phase	115VAC,400 Hz 3 Phase
Average SPL at 3 ft and 14.7 psia ~ dB(A)	-	76	76	-	68	73



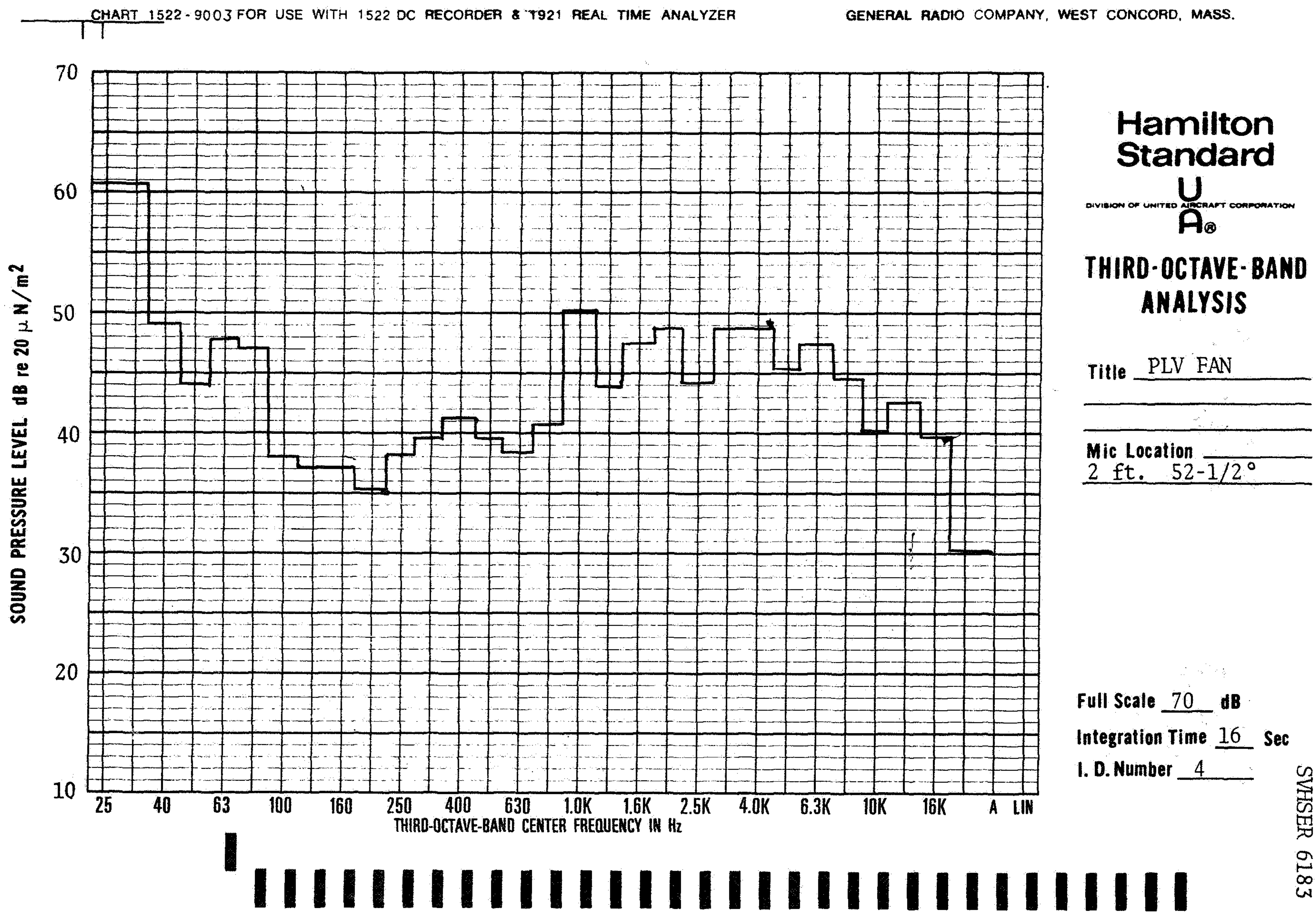
FAN NOISE TEST SETUP

FIGURE 4



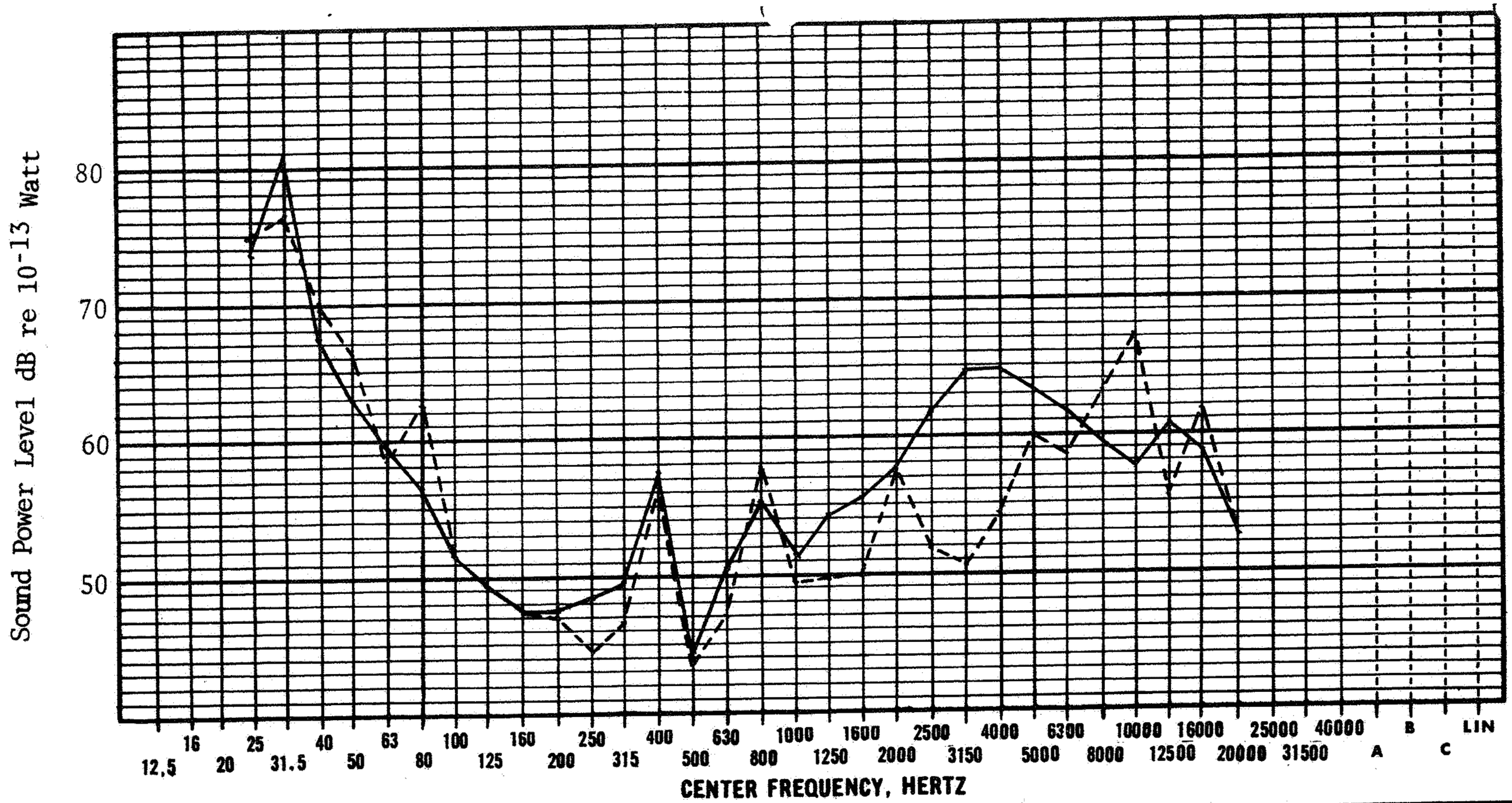
APOLLO PLV FAN IN SPACE TEST CHAMBER

FIGURE 5



SAMPLE 1/3 OCTAVE BAND ANALYSIS

FIGURE 6



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE CASE RADIATED PUMP NOISE

Test Date ______ **Run No.** ______

Mic Location ______ **Reel No.** ______

Analysed By ______ **Identification No.** ______

Analysis Method ______ **Sheet** ____ **of** ____

Comments, Sketches, Etc.

——— LM PUMP

– – – CSM PUMP

FIGURE 7

similar, even though the LM pump is of the sliding vane type operating at 5,500 rpm and the CSM pump is the centrifugal type operating at 22,000 rpm. To better define the noise components, a 5 Hz bandwidth frequency analysis was done for the noise signal from each pump at 120 degrees azimuth. These analyses are shown in figures 8 and 9. Several tones are immediately identifiable. In the case of the LM pump, there are four vanes, and with a shaft speed of 5,500 rpm this produces a vane passage frequency of 367 Hz. This tone can be seen in figure 8, along with several harmonics. In figure 9, a tone in the vicinity of 367 Hz may be seen also in the CSM pump noise spectrum. This corresponds to the rotational speed and thus is expected to be due to imbalance. Several harmonics of this tone can be distinguished. The remaining tones are more difficult to identify, but from subjective listening tests of the CSM pump motor, it was concluded that the total pump noise is due primarily to the noise of the motor. This observation is consistent with the spectrum shown in figure 9, which shows noise components associated primarily with motor imbalance and bearing noise.

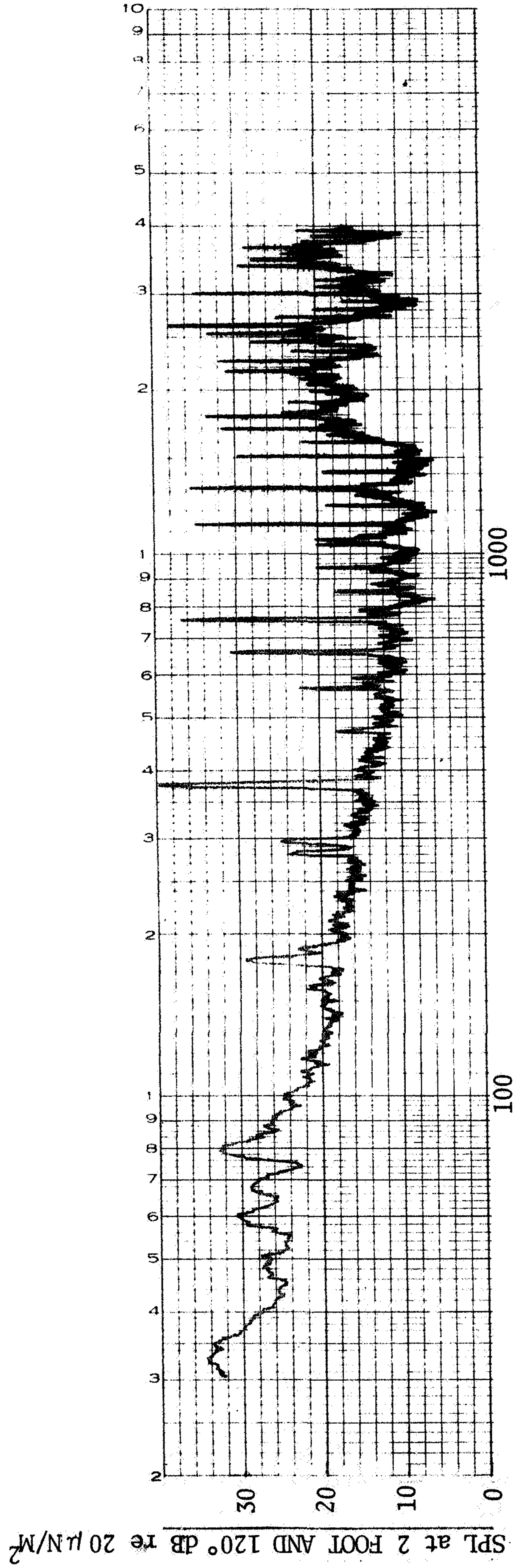
The LM pump noise frequency spectrum shows somewhat fewer tones than does the CSM pump noise, and these, or at least the dominant ones, appear to be related to the pump rather than the motor. To verify the motor noise contribution to the total LM pump noise, a test was run to measure the pump noise with the impeller disconnected. Figure 10 shows the comparison between the LM pump noise and the LM pump motor-alone noise. It is seen that the motor-alone noise levels are significantly lower than the total pump noise levels and therefore do not contribute to the total pump noise.

It appears that the CSM pump noise levels are due primarily to motor noise, whereas the LM pump noise levels are due to the sliding vane assembly. Therefore, it is anticipated that the motor will be a major noise source in the small quiet pumps which will be used on future spacecraft, especially since small size and light weight dictate the use of relatively high speed units.

Axial Fan Noise

Figures 11 through 14 show the inlet and exhaust 1/3 octave band sound power levels for the LM cabin fan at 5 psia, the PLV fan at 14.7 psia, the CSM cabin fan at 5 psia, and the CSM cabin fan at 14.7 psia, respectively.

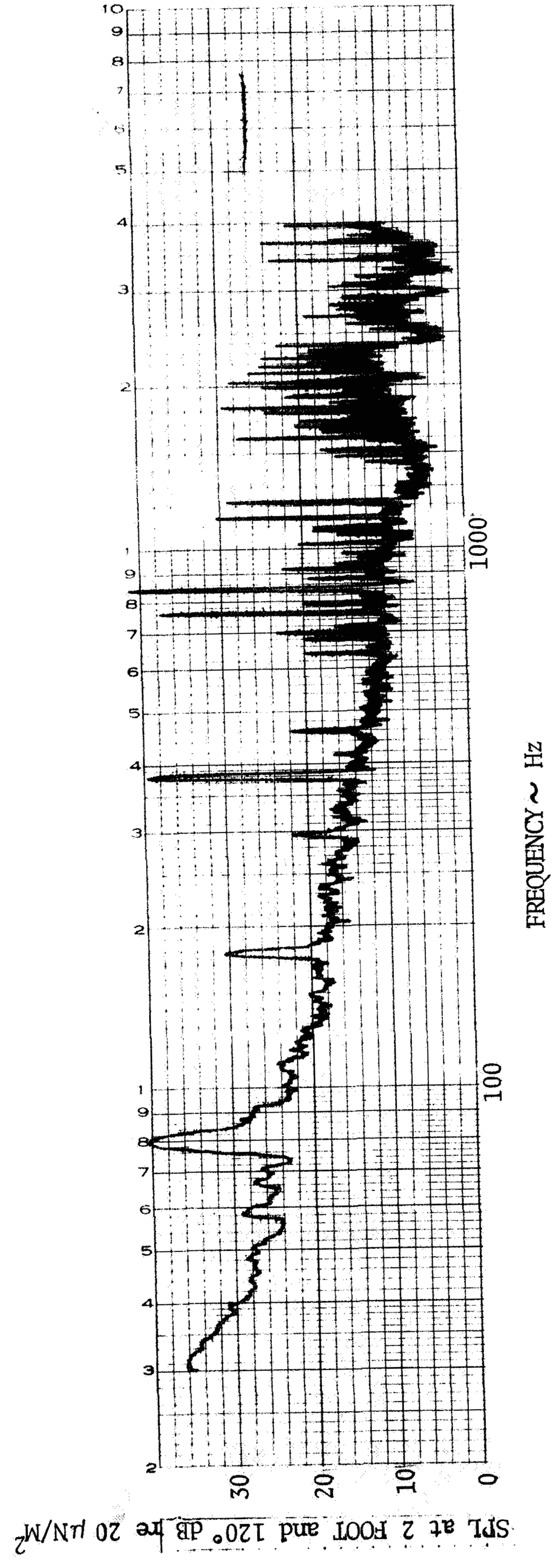
The LM cabin fan sound power levels, shown in figure 11, exhibit several tones. The blade passing fundamental, calculated to be in the vicinity of 2300 Hz, is quite apparent. Also, the second and third harmonics can be distinguished. These tones appear to originate at the stator, since they are much stronger in the exhaust noise than in the inlet noise. Figures 15 and 16 show narrow band frequency plots for the LM cabin fan inlet and exhaust noises, respectively. The fundamentals, second harmonic and fourth harmonic are apparent in the inlet noise, whereas a stronger full complement of tones may be seen in the exhaust noise. The remainder of the signals appears to be a broad band noise peaking in the vicinity of 7000 Hz.



NOTE: This data was recorded through "B" weighting network

LM PUMP NOISE
B.W. = 5 Hz

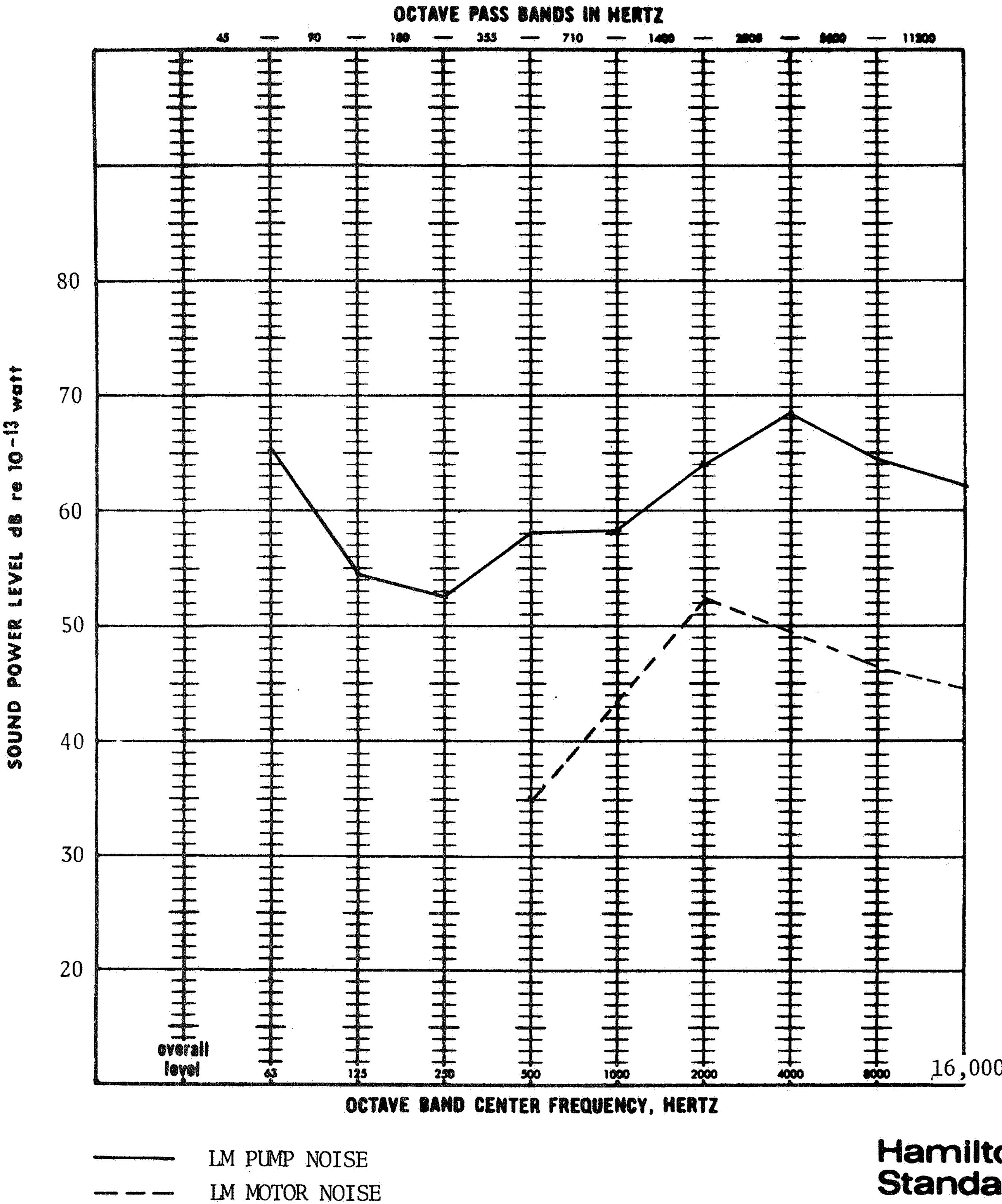
FIGURE 8



NOTE: This data was recorded through "B" weighting network

CSM PUMP NOISE
B.W. = 5 Hz

FIGURE 9



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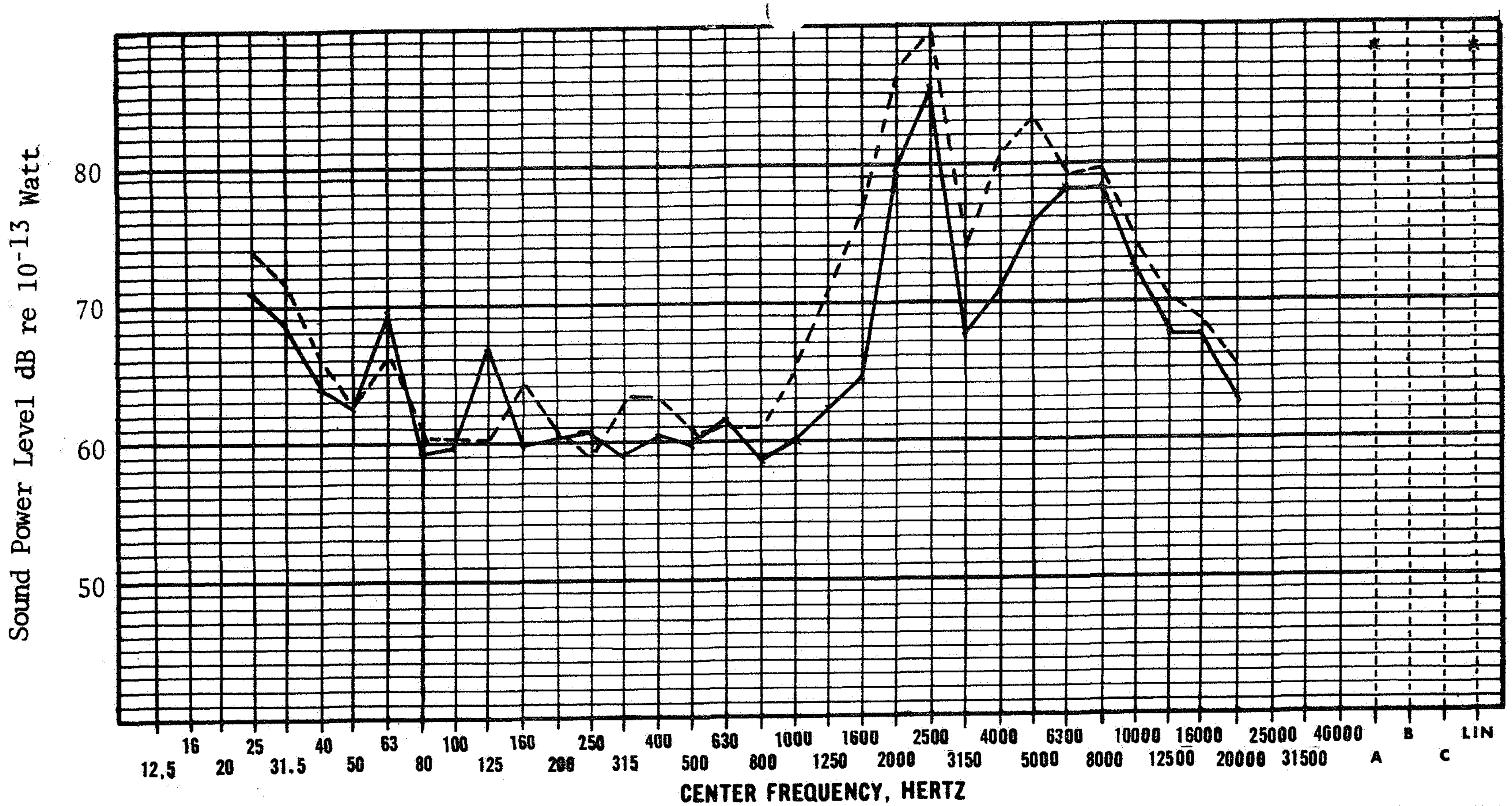
OCTAVE BAND ANALYSIS

COMPARISON OF LM PUMP NOISE AND
LM MOTOR NOISE

FIGURE 10

HSF 1970 8/69



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE LM CABIN FAN AT 5 psia

Test Date ______ Run No. ______

Mic Location ______ Reel No. ______

Analysed By ______ Identification No. ______

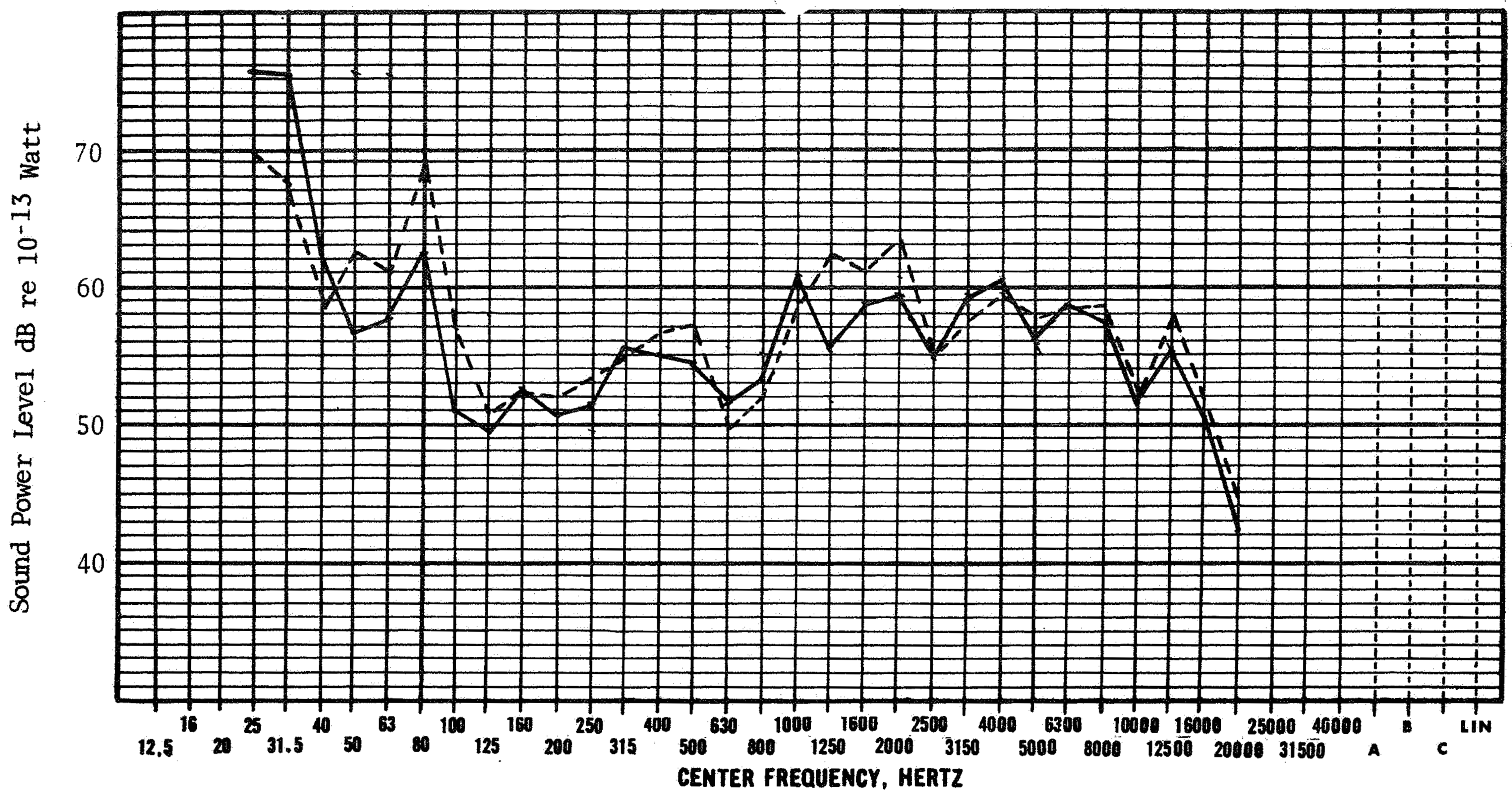
Analysis Method ______ Sheet ____ of ____

Comments, Sketches, Etc.

——— INLET NOISE

– – – EXHAUST NOISE

FIGURE 11



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE PLV FAN AT 14.7 psia

Test Date ____ **Run No.** ____

Mic Location ____ **Reel No.** ____

Analysed By ____ **Identification No.** ____

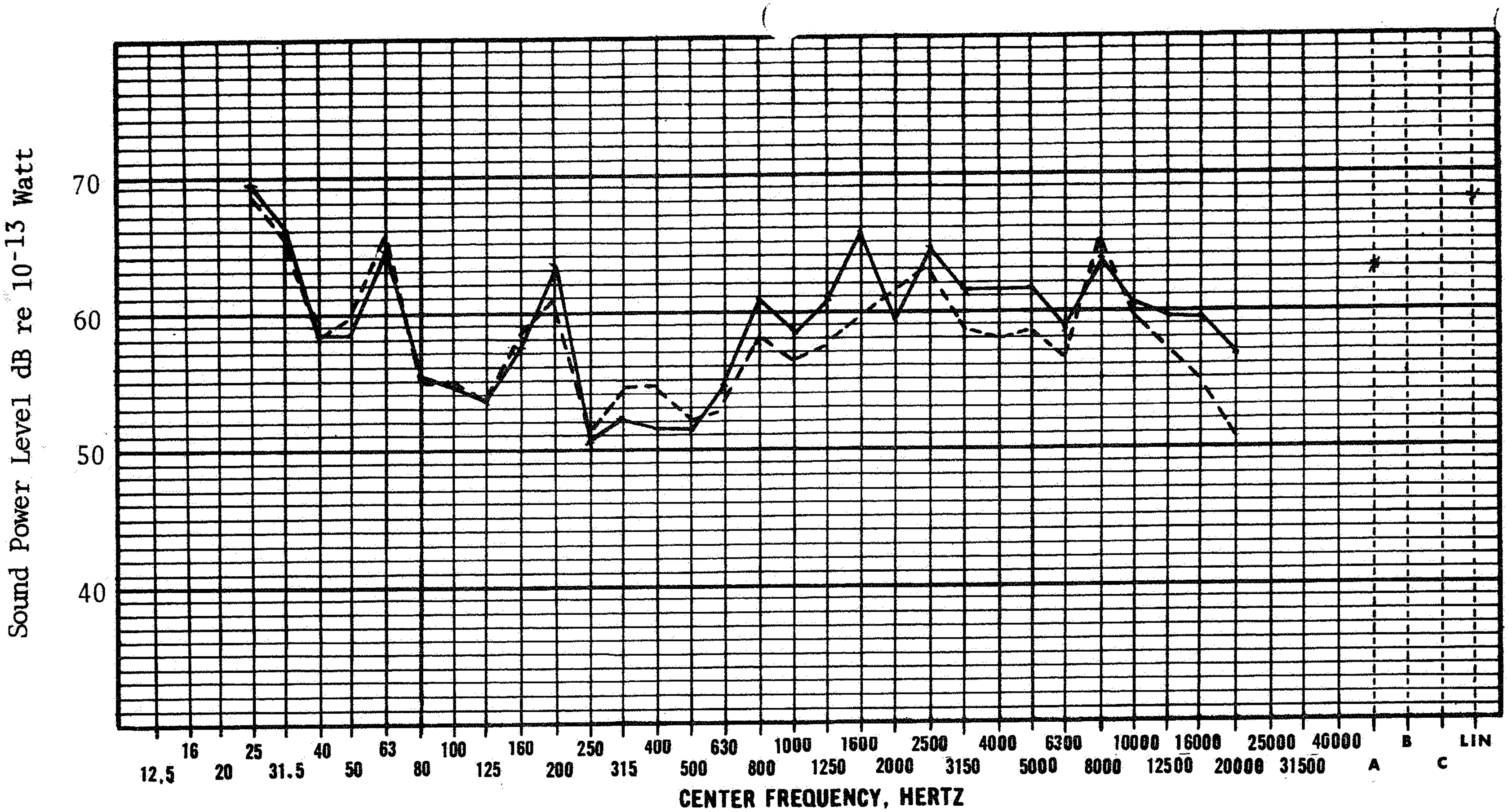
Analysis Method ____ **Sheet** ____ **of** ____

Comments, Sketches, Etc.

——— INLET NOISE

– – – EXHAUST NOISE

FIGURE 12



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE CSM CABIN FAN AT 5 psia

Test Date ______ **Run No.** ______

Mic Location ______ **Reel No.** ______

Analysed By ______ **Identification No.** ______

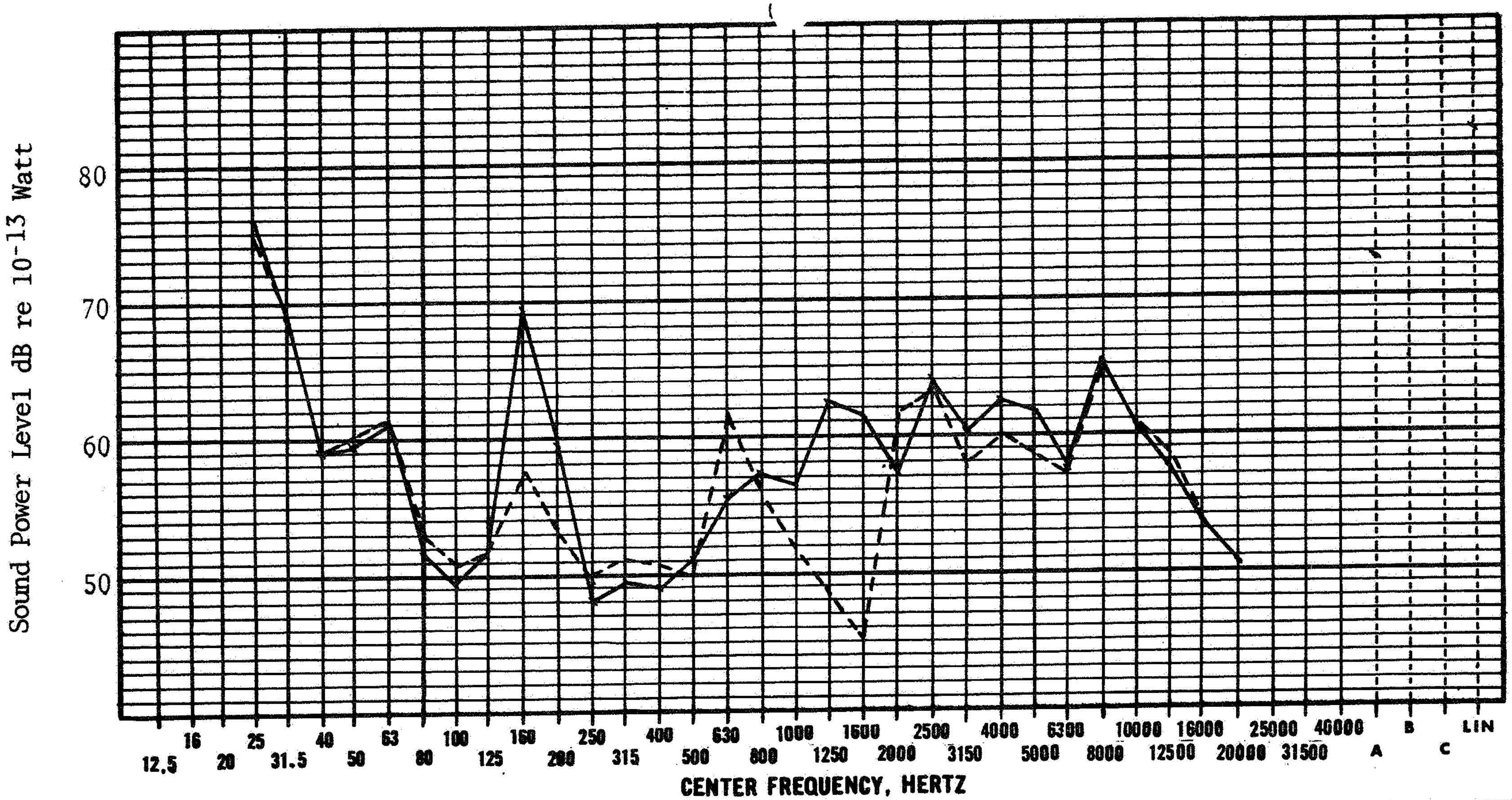
Analysis Method ______ **Sheet** ____ **of** ____

Comments, Sketches, Etc.

——— INLET NOISE

– – – EXHAUST NOISE

FIGURE 13



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE CSM CABIN FAN AT 14.7 psia

Test Date ______ **Run No.** ______

Mic Location ______ **Reel No.** ______

Analysed By ______ **Identification No.** ______

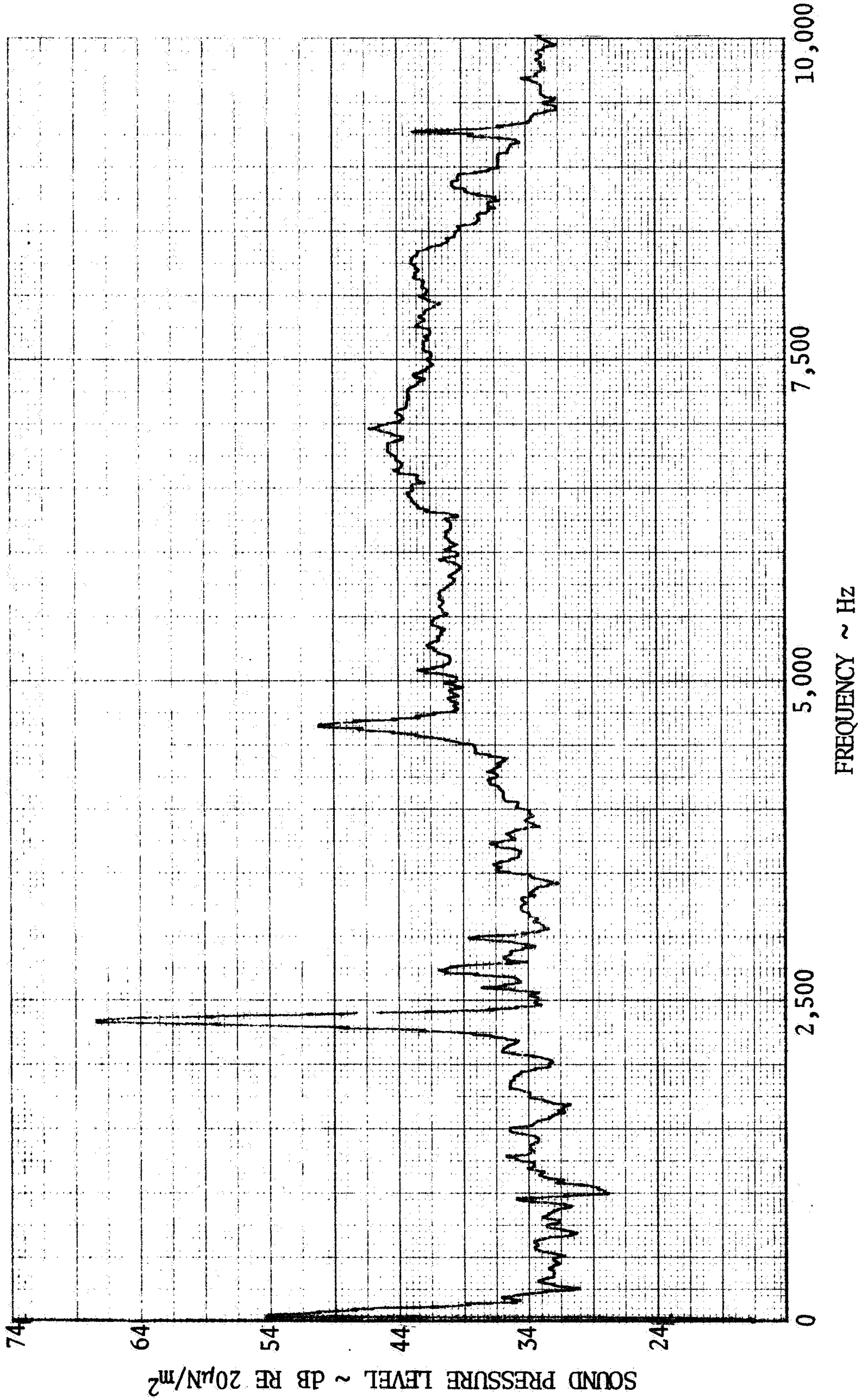
Analysis Method ______ **Sheet** ____ **of** ____

Comments, Sketches, Etc.

——— INLET NOISE

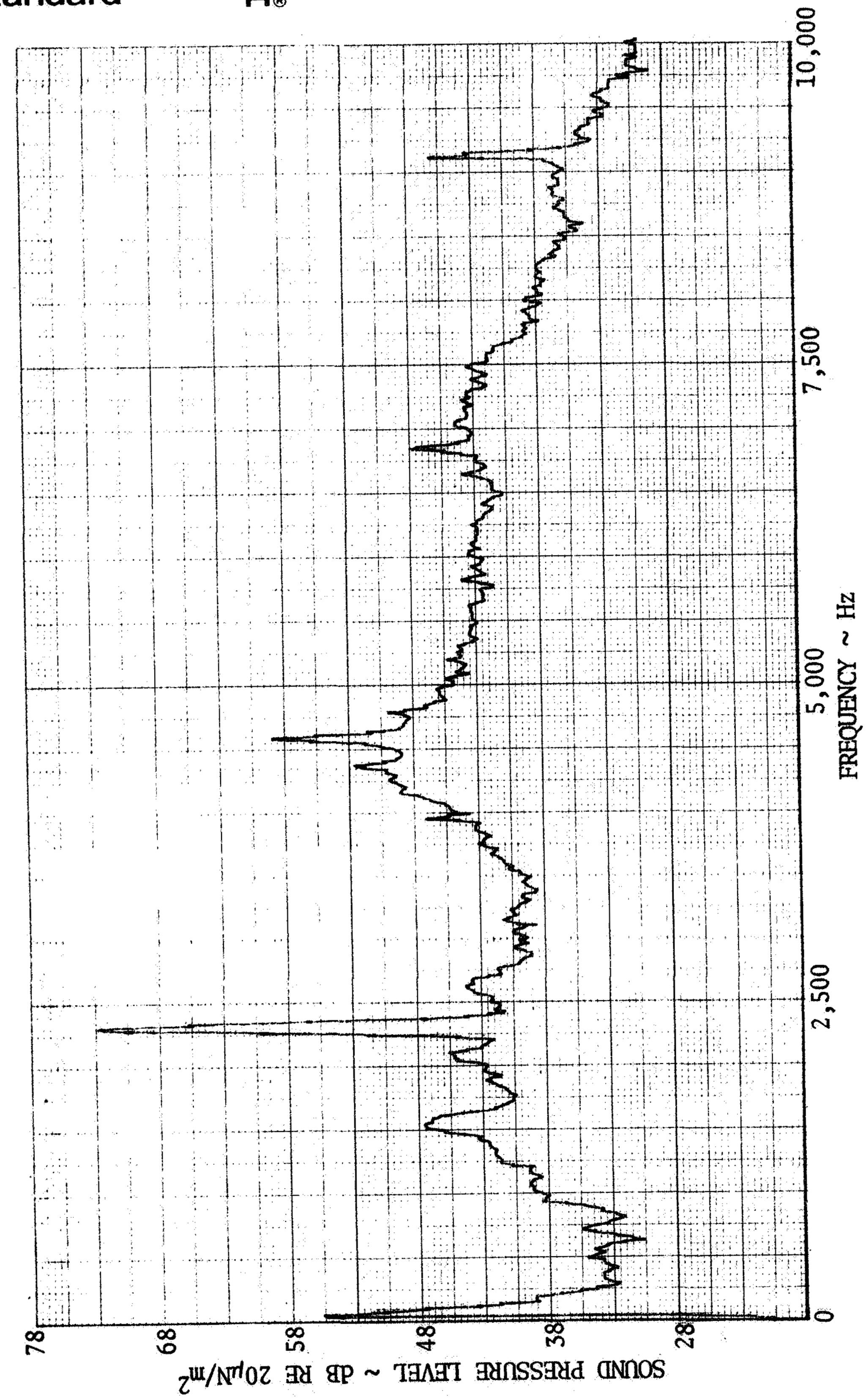
– – – EXHAUST NOISE

FIGURE 14



LM CABIN FAN INLET NOISE

FIGURE 15



LM CABIN FAN EXHAUST NOISE

FIGURE 16

The PLV fan noise, in figure 12, does not show any significant tones. Narrow band plots, figures 17 and 18, show tones on the inlet at approximately 1050 Hz and at approximately 7250 Hz. The tone at 1050 Hz corresponds to the fifth harmonic of blade passing frequency. The component at 7250 Hz cannot be identified with any aerodynamic noise source. The PLV exhaust noise appears to have more tones, most of which do not appear related to blade passing frequency.

The CSM cabin fan noise, shown in figure 13 for the data at 5 psia and in figure 14 for the data at 14.7 psia, does not exhibit strong tones either. Narrow band plots for this fan operating at 14.7 psia, shown in figures 19 and 20, do not show anything significant, except perhaps for a multiplicity of tones in the higher frequencies above 7500 Hz. It may be seen also that apart from some minor differences in the levels of some bands, the sound power spectrum for this fan operating at 5 psia is the same as the spectrum for the fan operating at 14.7 psia.

Although these three fans are low tip speed axial units, it is seen that only the LM fan shows tones at the blade passing frequency. This is because the first few harmonics of the PLV and CSM cabin fans are below acoustic cut-off, and thus they do not propagate.

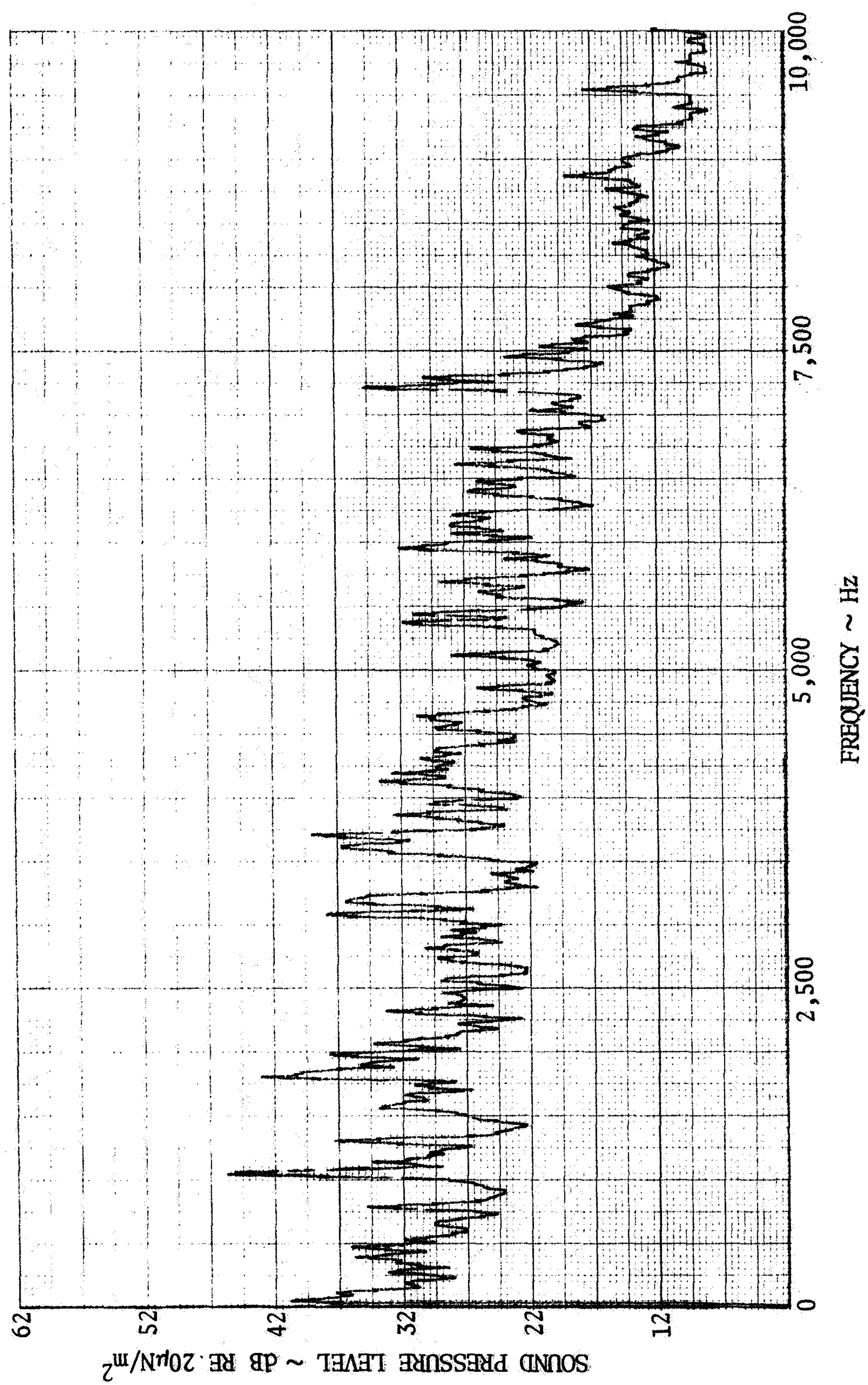
The cut-off phenomenon occurs as follows. The wall velocities, V_W of the rotor/stator interaction modes are given by

$$V_W = \frac{MBV_t}{(MB + KV)}$$

where M is the harmonic number, V_t is the rotor tip velocity, B is the number of rotor blades, V is the number of stator vanes, and K is an integer which takes values from $-\infty$ to $+\infty$. If the wall velocities of all the interaction modes for a given harmonic are subsonic, they cannot propagate efficiently along the fan duct and are said to be below cut-off.

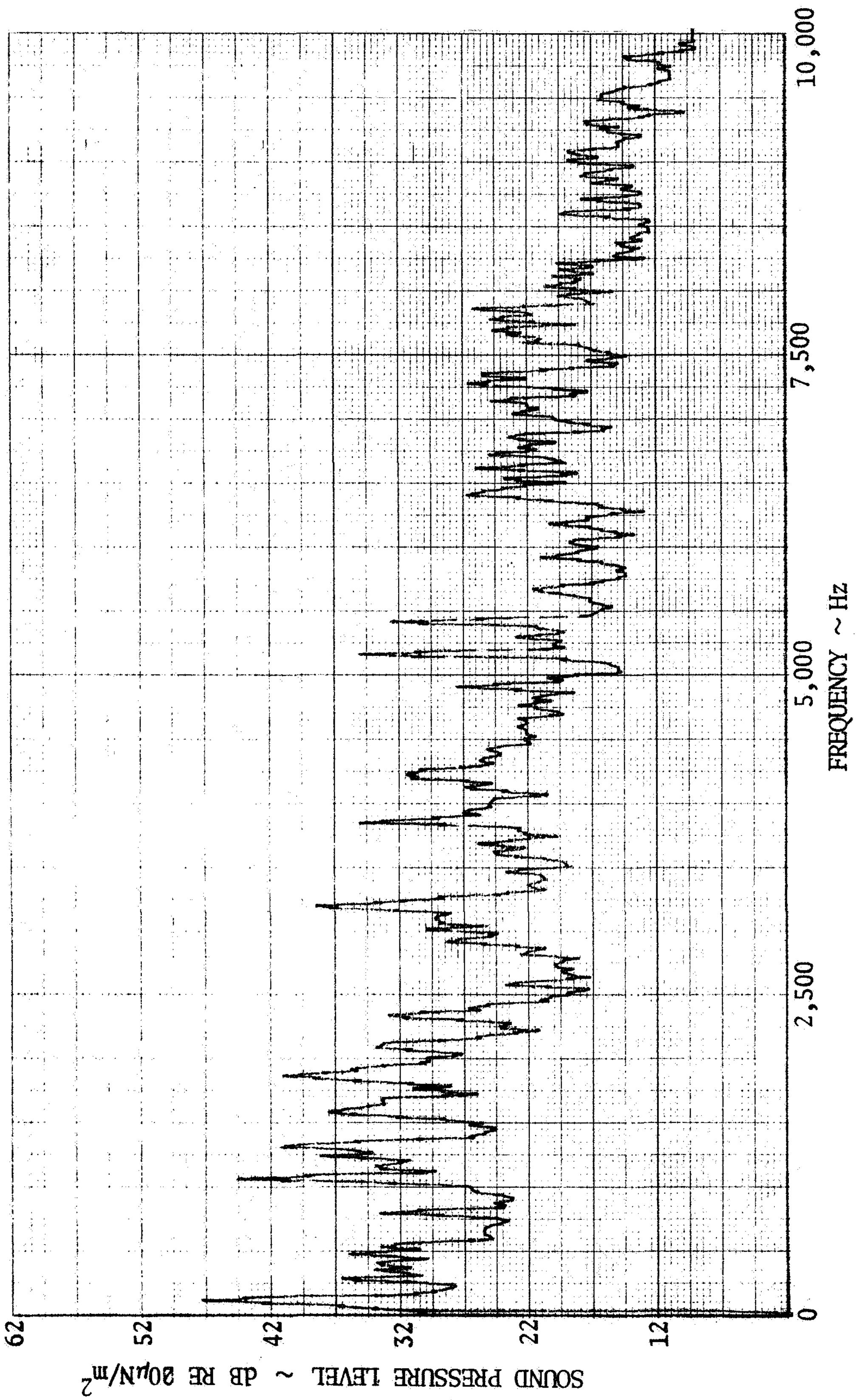
The PLV fan has a tip speed of approximately 90 fps, three rotor blades and five vanes. It thus is seen by applying the above formula that the first four harmonics are cut off. Recalling the PLV fan noise spectra shown in figures 17 and 18, the lowest tone frequency was seen to be at approximately 1050 Hz, corresponding to the 5th harmonic(i.e. 5 x 70 rps x 3 blades). Similarly, for the CSM cabin fan, with tip speed of 144 fps, four rotor blades and five stator vanes, the first three harmonics are cut off and would not be expected to propagate.

The LM fan, however, with a higher tip speed and with eleven rotor blades, has none of its harmonics cut off.



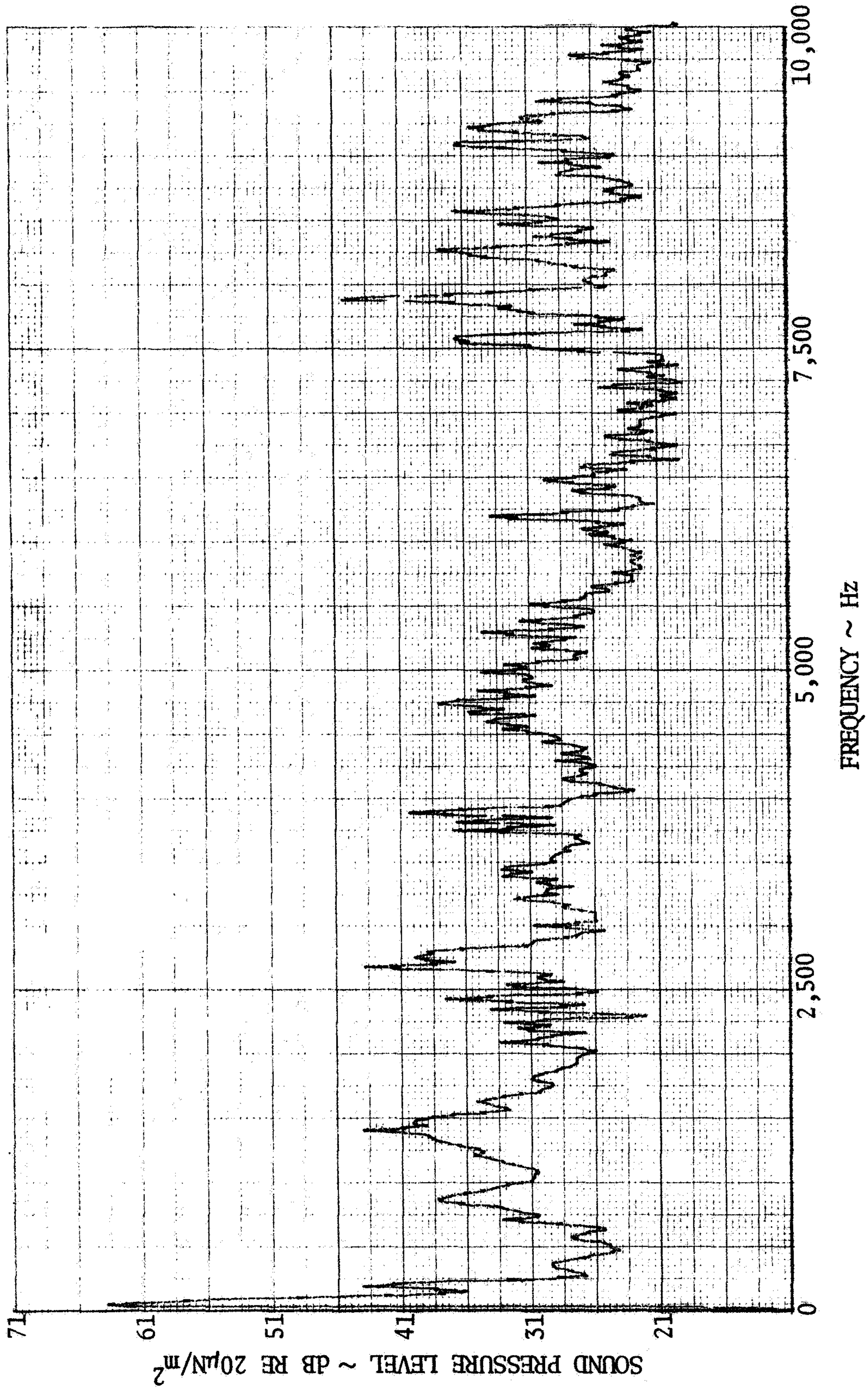
PLV FAN INLET NOISE

FIGURE 17



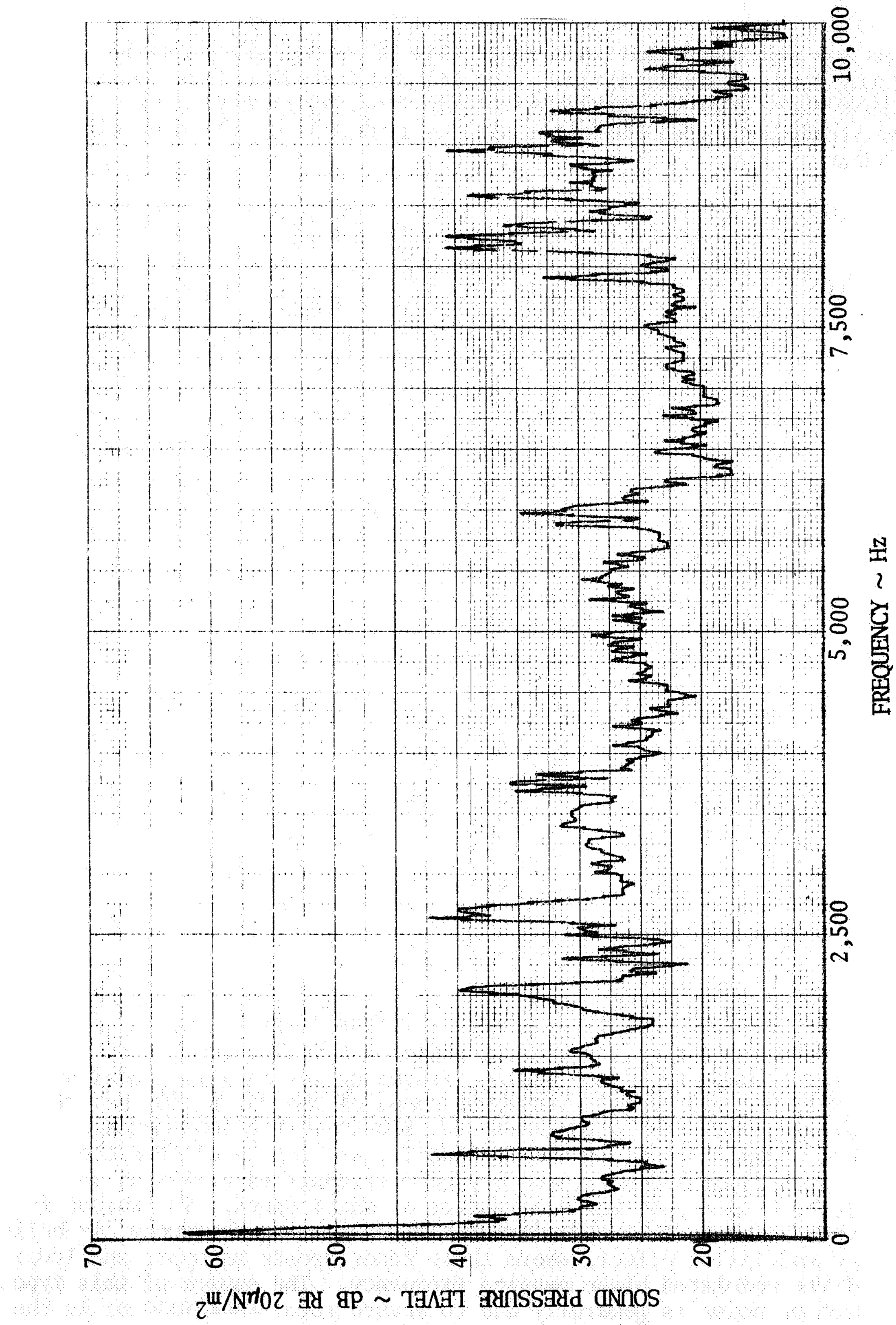
PLV FAN EXHAUST NOISE

FIGURE 18



CSM CABIN FAN INLET NOISE

FIGURE 19



CSM CABIN FAN EXHAUST NOISE

FIGURE 20

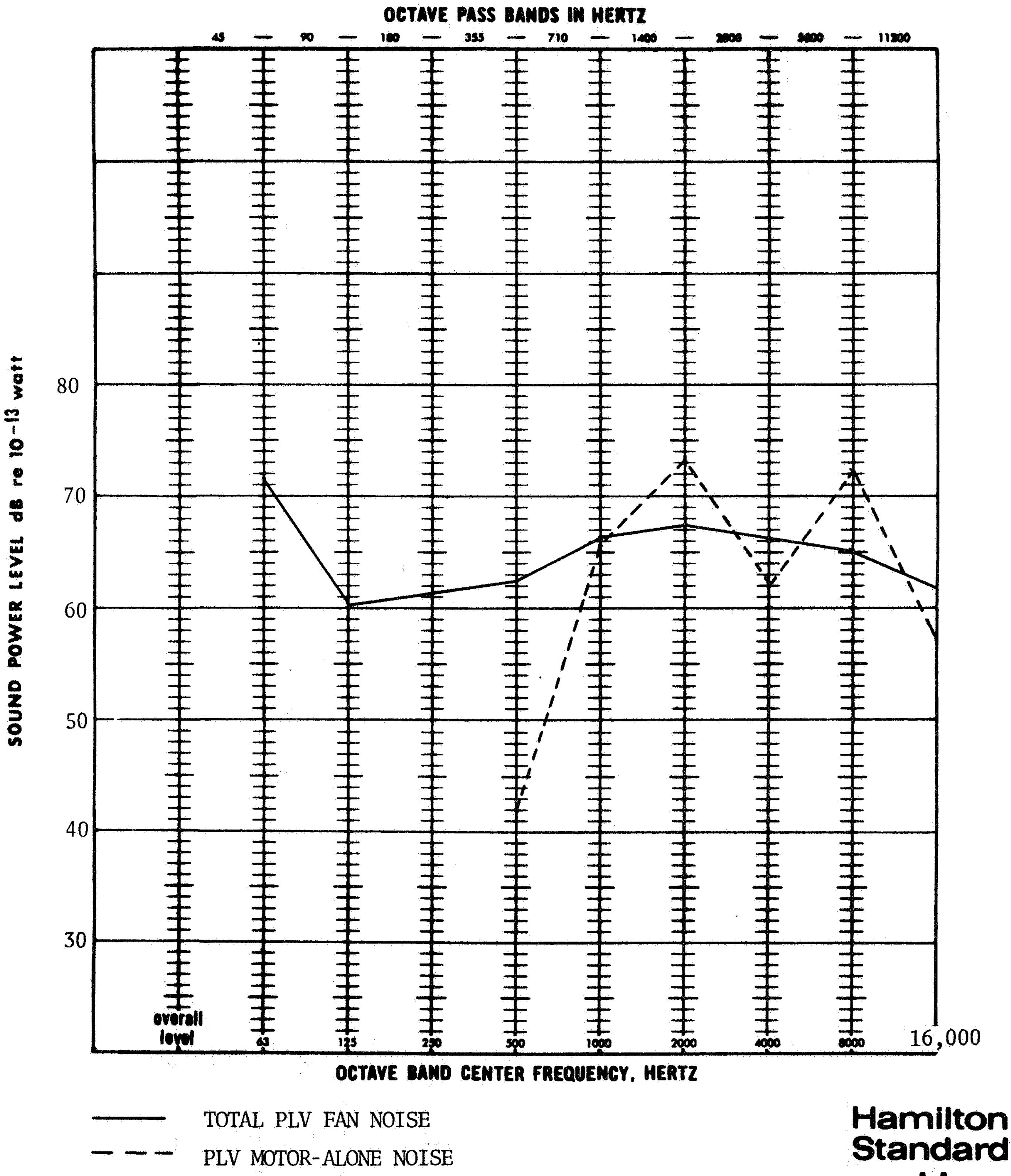
It thus was concluded that on a subjective basis the LM fan would exhibit strong tonal characteristics. The PLV and CSM cabin fans, however, would not have these characteristics since the lower frequency tones are cut off and the remaining higher harmonics are low enough in level to be masked by the broadband noise.

As was mentioned earlier, there appear to be several high frequency tones in the PLV and CSM cabin fan data which do not seem to be related to aerodynamic noise sources. Thus other sources of noise were considered. Since it was found that motor noise was a significant contributor in the CSM pump noise spectrum, the motor noise from the PLV fan was investigated as the high frequency noise contributor. In this investigation, the fan motor was operated alone at the same rotational speed as was measured during the noise data acquisition of the entire fan. Octave band measurements were made around the motor and integrated to give sound power levels. Figure 21 shows the "motor-alone" noise levels compared to those of the fan assembly. It is seen that the motor exhibits significant noise levels in the frequency bands above 500 Hz. Since the motor noise exceeds the total fan assembly noise, it can be concluded that noise levels are not identical during loaded and unloaded operation. However, these levels are representative of the motor noise. It thus is concluded that the high frequency noise levels seen in the spectra from the PLV and CSM cabin fans are not aerodynamic in origin, but rather are due to mechanical sources, most likely the bearings.

Compressor Noise Levels

The LM suit compressor sound power levels are summarized in figure 22. Several tones are apparent. The blade passing frequency is calculated to be 5250 Hz. This corresponds to the apparent tone shown in the 5000 Hz band of the exhaust noise. However, no such tones are seen in the inlet noise. Figure 23 shows a narrow band plot of inlet noise. The blade passing frequency is seen to occur where it is expected. However, there is another strong component at approximately 3400 Hz which is not a pure tone, since it has a fairly broad bandwidth. The origin of this signal is not apparent.

The exhaust noise spectrum, shown in figure 24, indicates the presence of a strong tone at 4850 Hz. Due to slightly different loading conditions on the compressor, the test speed was 24,000 rpm instead of 26,250 rpm as for the inlet noise test. The fundamental blade passing frequency for this 12 bladed unit is thus 4800 Hz and the fundamental rotational speed of the fan is 400 Hz. As is seen in the figure, then, the strong tone of 4850 Hz is the fundamental. The two tones immediately adjacent to the fundamental are separated from the fundamental by 400 Hz. Several other tones may be distinguished at 400 Hz intervals, down to 400 Hz. These appear to be harmonics of shaft speed. The reason for the two strong tones adjacent to the fundamental blade passing frequency, is believed to be due to a modulation effect, where these tones appear as upper and lower side-bands of the modulated blade passing frequency. The source of this type of one-per-revolution noise is generally due to severe rotor imbalance or to the



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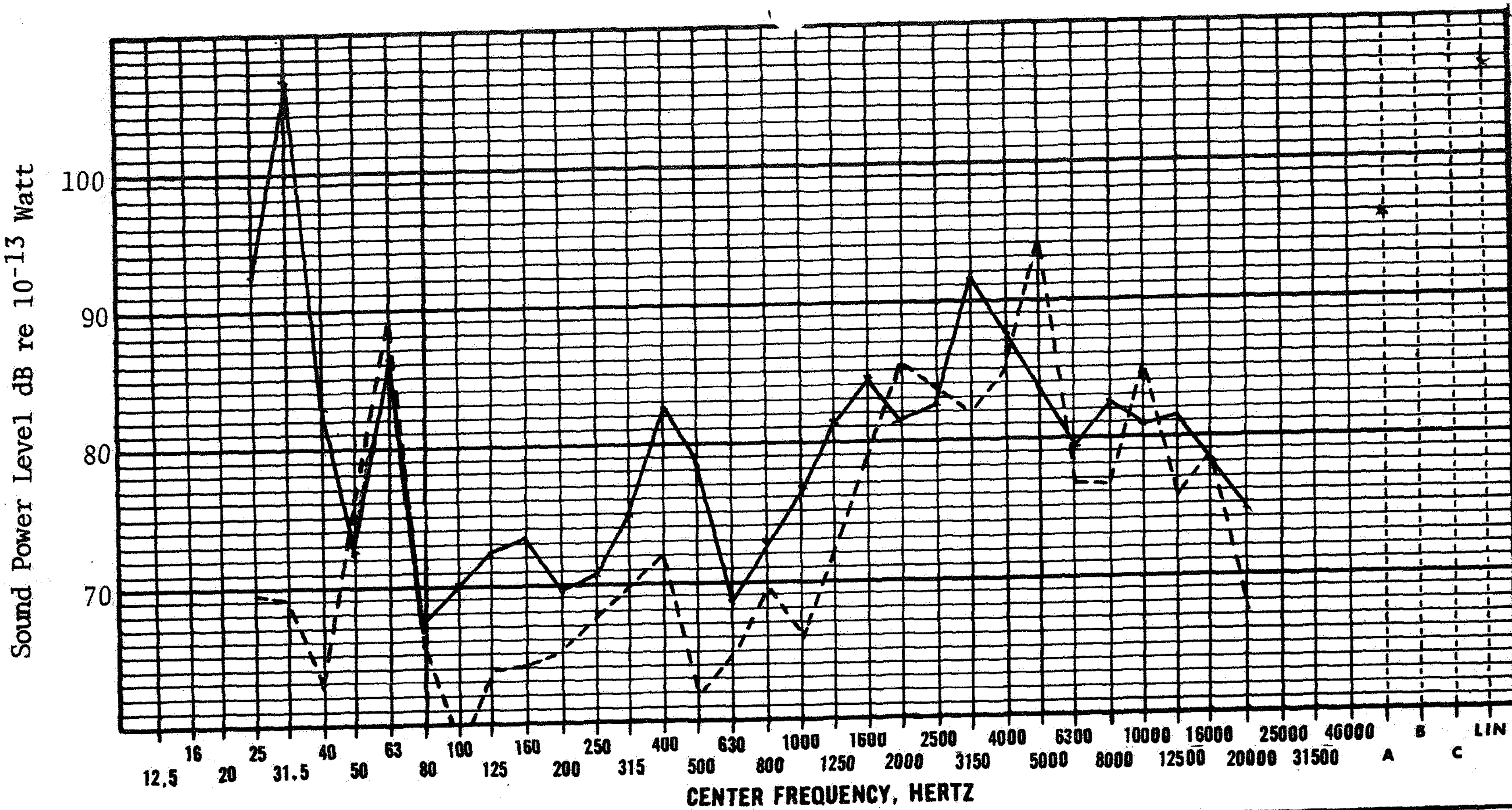
OCTAVE BAND ANALYSIS

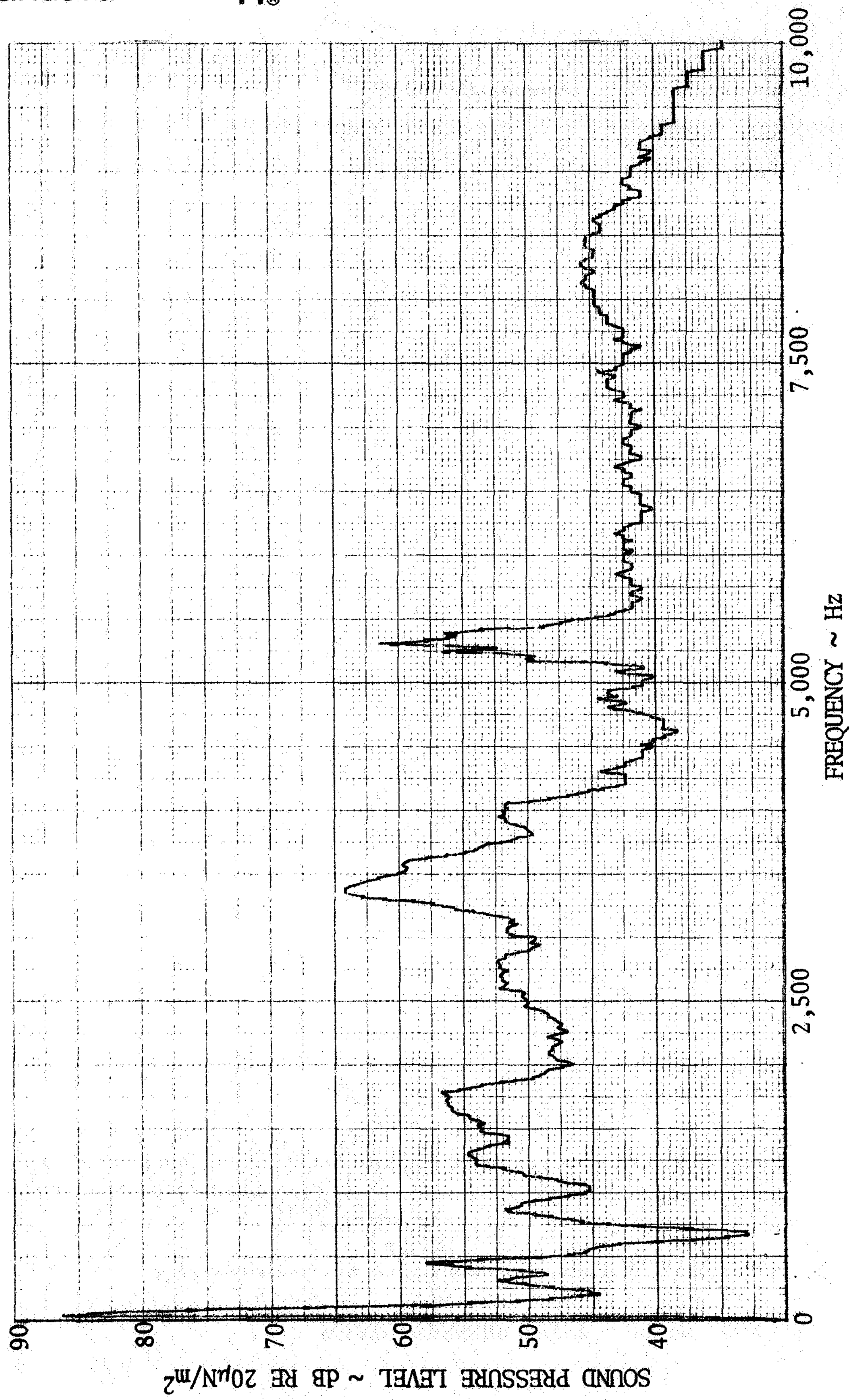
MOTOR NOISE CONTRIBUTIONS TO
TOTAL PLV FAN NOISE

FIGURE 21



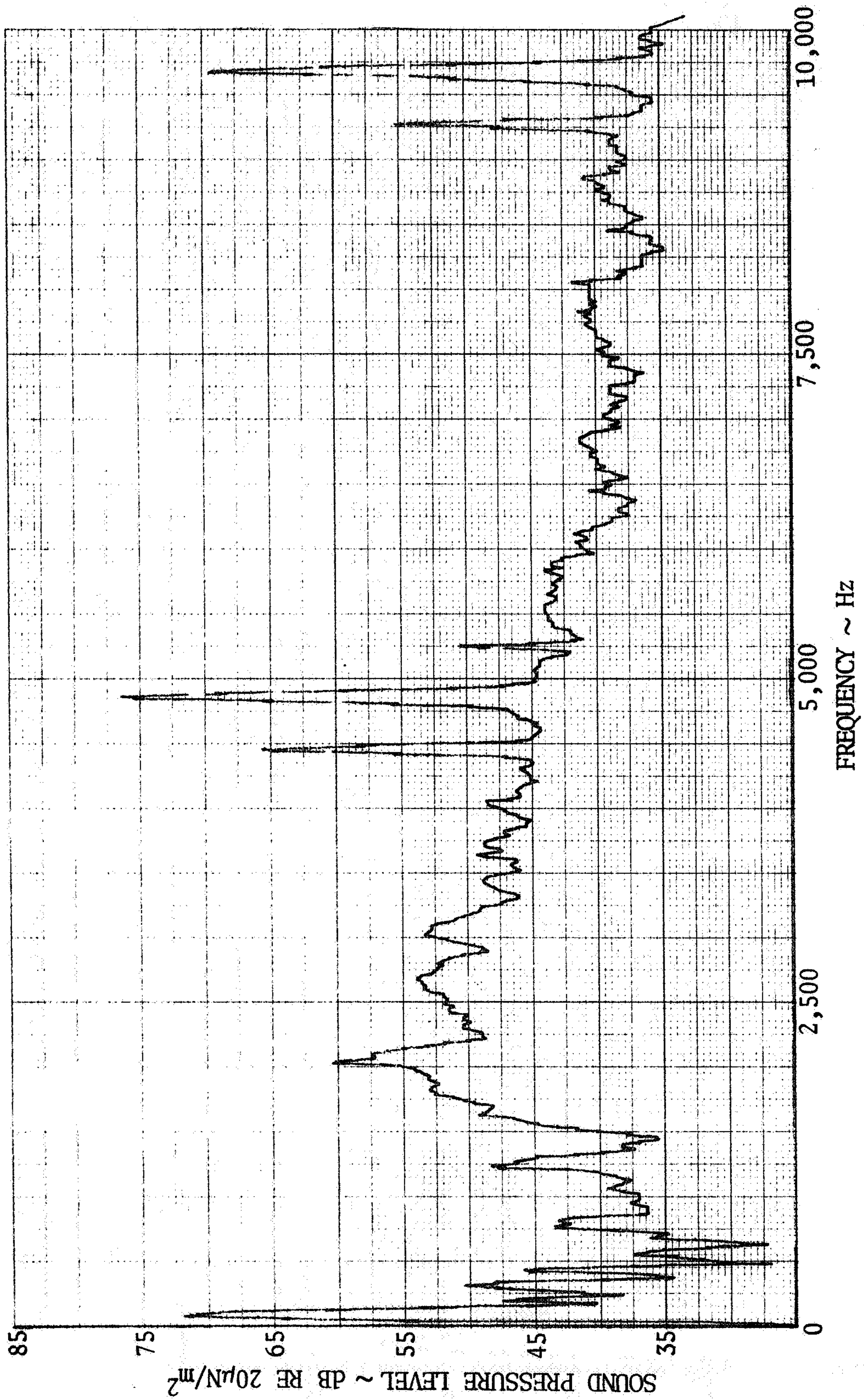
Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • ONE THIRD OCTAVE BAND ANALYSIS	Comments, Sketches, Etc.
TITLE LM SUIT COMPRESSOR AT 5 psia	—— INLET NOISE
Test Date ______ Run No. ______	– – – EXHAUST NOISE
Mic Location ______ Reel No. ______	
Analysed By ______ Identification No. ______	
Analysis Method ______ Sheet ____ of ____	

FIGURE 22



LM SUIT COMPRESSOR INLET NOISE

FIGURE 23



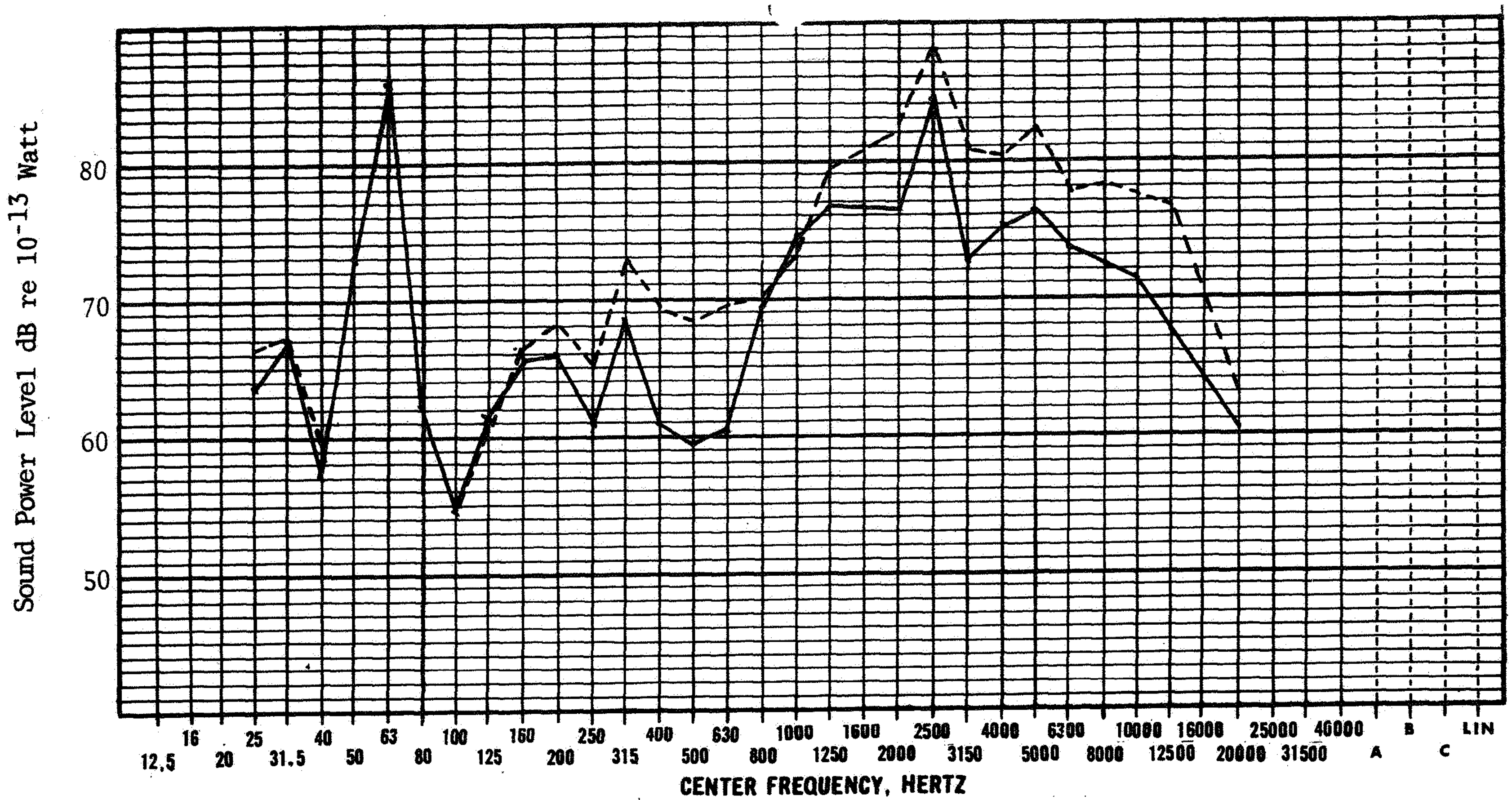
LM SUIT COMPRESSOR EXHAUST NOISE

FIGURE 24

rotor rubbing once per revolution. It would be expected for a balanced or non-rubbing rotor that the acoustic spectrum would not show tones at harmonics of shaft speed. Also, the levels of the harmonics of blade passing frequency would probably be several decibels lower in level than those shown in figure 24.

The 1/3 octave band sound power spectra for the CSM suit compressor inlet and exhaust noise are shown in figure 25. Several tones are apparent from this figure. The strong tone in the 63 Hz band most probably is due to power line noise and should not be considered as acoustical noise from the compressor. A second tone, in the 315 Hz band, is at rotor shaft speed, and probably is due to rotor imbalance. The strongest tone appears in the 2500 Hz band. Noise at this frequency is not related to aerodynamic sources, but probably is mechanical in origin and may be due to bearing noise. The rotor blade passing frequency at 4400 Hz does not appear in this plot.

Narrow band spectra of the inlet and exhaust noises are shown in figures 26 and 27 respectively. In the inlet noise, a narrow band random signal is seen at approximately 2600 Hz. The character of this signal is similar to the one seen in the spectrum from the LM suit compressor and could be due to noise sources in common to the two compressors such as edge tones or flow separation at the inlets. The blade passing frequency is seen at 4000 Hz and a second harmonic may be seen at 8000 Hz. The broad peak centered on 5500 Hz probably is due to vortex shedding. The exhaust noise spectrum is mainly broadband noise, with the "bearing noise" and blade passing frequency tones distinguishable above the broadband base.



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE CSM SUIT COMPRESSOR AT 14.7 psia

Test Date ______ **Run No.** ______

Mic Location ______ **Reel No.** ______

Analysed By ______ **Identification No.** ______

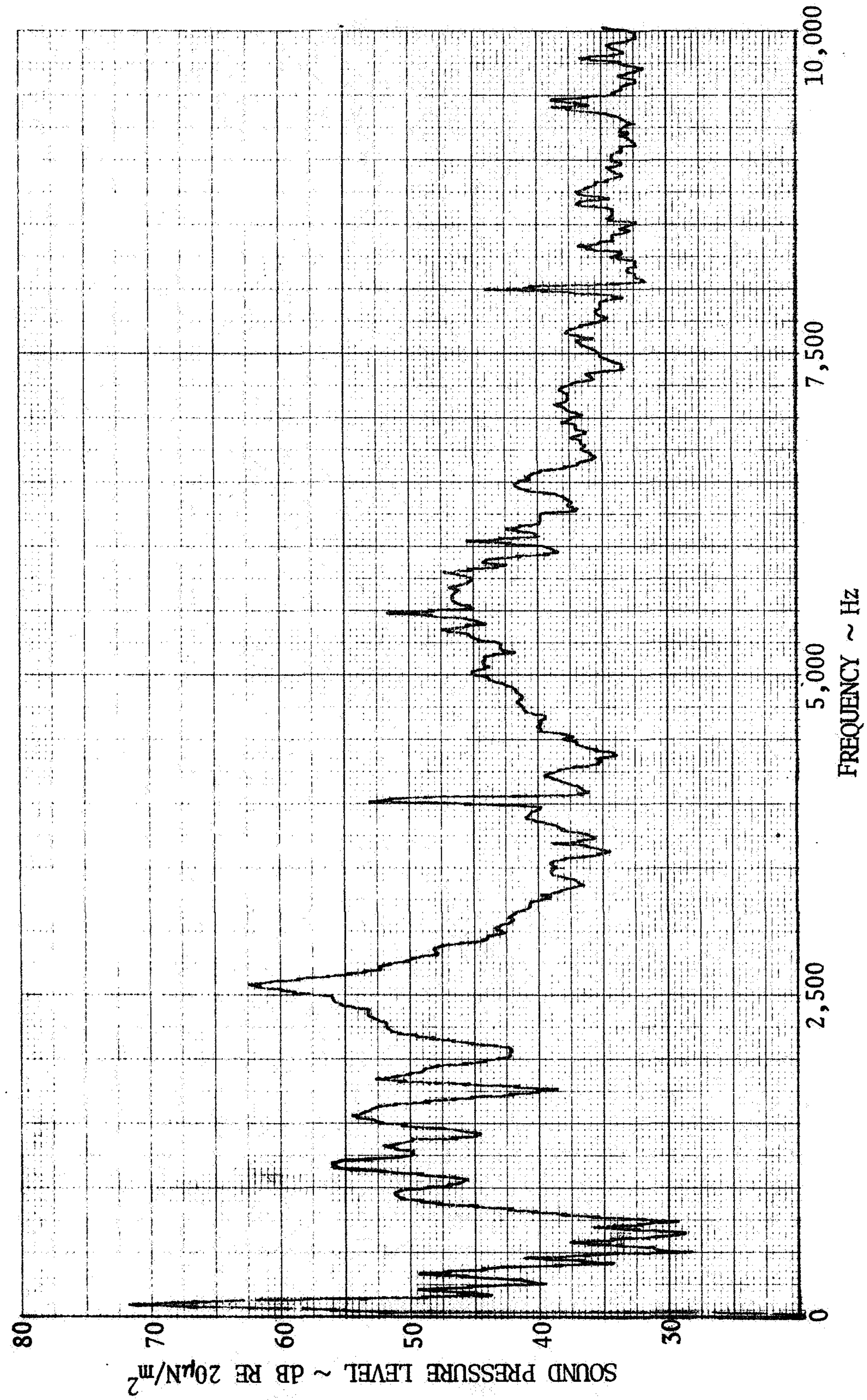
Analysis Method ______ **Sheet** ____ **of** ____

Comments, Sketches, Etc.

——— INLET NOISE

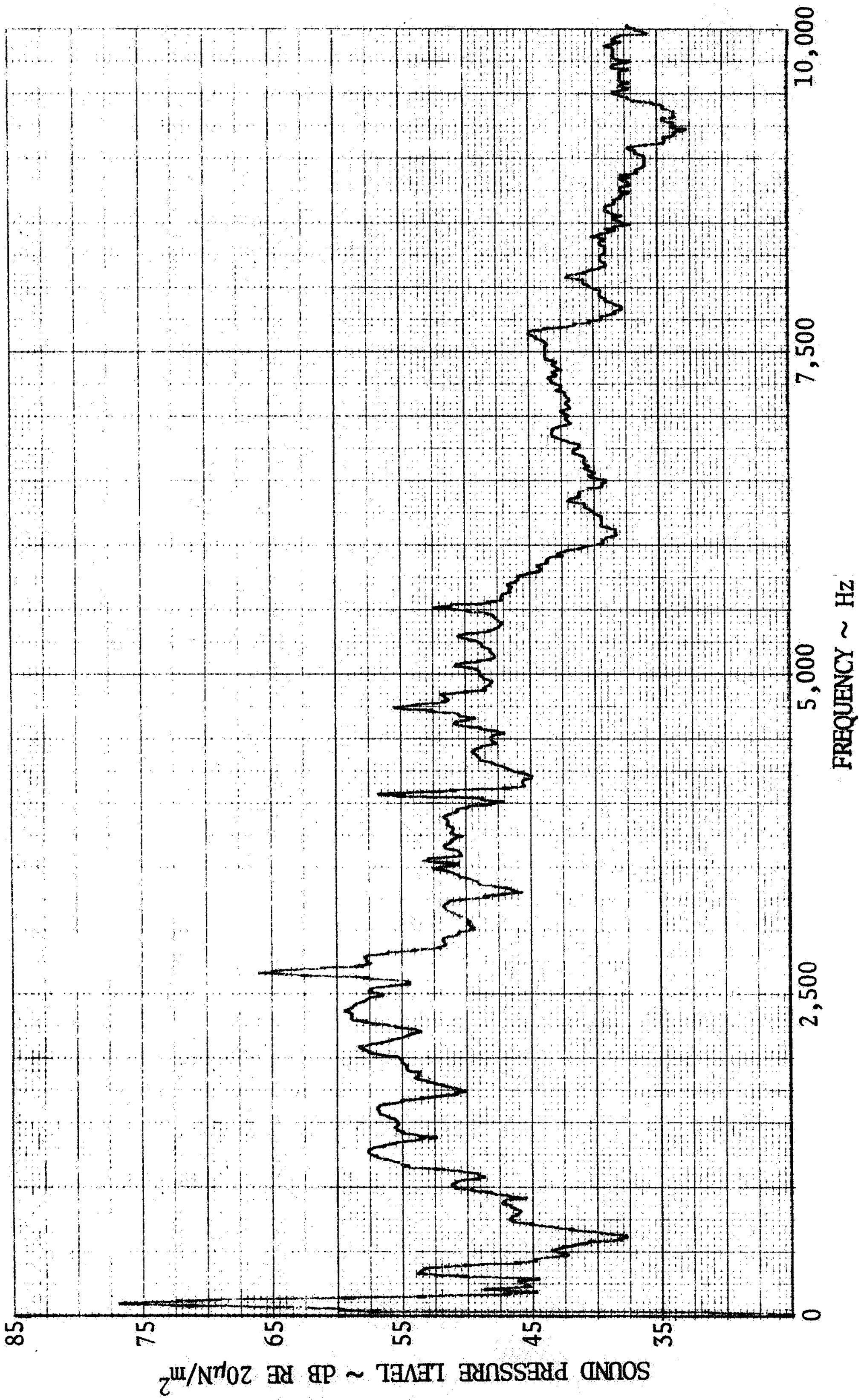
– – – EXHAUST NOISE

FIGURE 25



CSM COMPRESSOR INLET NOISE

FIGURE 26



CSM SUIT COMPRESSOR EXHAUST NOISE

FIGURE 27

NOISE ESTIMATING METHODS

In order to design the Space Shuttle fan and pump concepts and perform subsequent tasks, reliable and reasonably accurate fan, compressor, and pump noise estimating procedures were required. These procedures fall into two categories: empirically based and theoretically based. The empirically based procedures give typical fan noise spectra based on design and operating parameters. These procedures are of limited accuracy, but do allow quick and reasonably accurate estimates of standard fan noise. The second or theoretically based category includes more detailed procedures. The one to be discussed herein was developed at Hamilton Standard for axial fans. This procedure utilizes the fan design details, including blade shape, twist distribution, and other airfoil particulars and can be used to calculate the noise for a great variety of designs. This procedure is used in the axial fan noise trade-off study later in this report and for the development of a Space Shuttle fan design concept.

EMPIRICAL METHODS

Several methods, based mainly on measured fan and compressor noise data, require only easily available geometric and operational parameters such as fan type, pressure rise and discharge flow. By necessity, however, these simple methods are of limited accuracy , since they are representative of an average of data from many designs and do not take into consideration the details of blade geometry, vane geometry, airfoil sections used, off design operation, and so forth. They do, however, offer the means for quickly and easily estimating the noise of a particular fan with reasonable accuracy, providing it is a standard, reasonably well designed unit.

The majority of the methods reviewed provide an estimate of the sound power level (PWL) of the device, that is, of the total radiated acoustic power. In these cases, it is assumed that one half of the acoustic energy propagates to the intake and one half of the acoustic energy propagates to the exhaust. Thus, inlet or exhaust noise is 3 dB less than the total estimated noise. To estimate the sound pressure level (SPL), it must be assumed that the acoustic energy is radiated uniformly in all directions (that is, spherical radiation for total noise, hemispherical for intake and exhaust noise). The sound pressure level and sound power level are related by

$$SPL = PWL - 10 \log A + 10 \log \rho c_0 - K$$

where A is the area of the sphere; ρ is the atmospheric density; c_0 is the speed of sound; and K is a constant to account for units.

The resultant SPL for standard atmospheric conditions is given by

$$SPL = PWL - 20 \log R - 10.5$$

where R is the radius of the sphere in feet.

The noise estimating methods for pumps are based on large marine type pumps. Since the noise sources for the various geometries designed for quiet operation are understood, it is practical to rank the designs in order of increasing noise levels as follows:

centrifugal
diaphragm
screw
sliding vane
gear.

It also has become apparent from the tests conducted in this program that the motor noise generally dominates pump noise in a quiet design such as a centrifugal unit. Thus, it is important to include motor noise sources.

Fan Noise Estimating Procedures

Of the several methods reviewed, the following currently accepted fan noise prediction procedures were considered applicable to this program.

Aerodynamic Scaling

This method, although not strictly an estimating method, allows the prediction of fan broadband noise by aerodynamic scaling of the data from a similar fan design. For scaling, Hubbard(1) assumed that the broadband noise level varies as a function of the blade area and as the sixth power of the tip velocity. Also the frequency spectrum, retaining the same shape, is shifted in frequency by the ratio of velocities and chord lengths, where higher velocity and smaller chords raise the frequency. Thus the scaling parameters are:

$$\Delta dB = 60 \log \frac{V_t}{V_{t_{ref}}} + 10 \log \frac{A_B}{A_{B_{ref}}}$$

$$f \text{ ratio} = \frac{V_t}{V_{t_{ref}}} \bullet \frac{C_{ref}}{C}$$

Numbers in parentheses refer to the work listed under references.

Allen Method

Allen's Method [2] for predicting centrifugal and axial compressor noise requires any two of the following three parameters:

1. Input power (HP, horsepower)
2. Static pressure rise (ΔP, inches of H_2O)
3. Fan discharge flow (Q_d, in cfm)

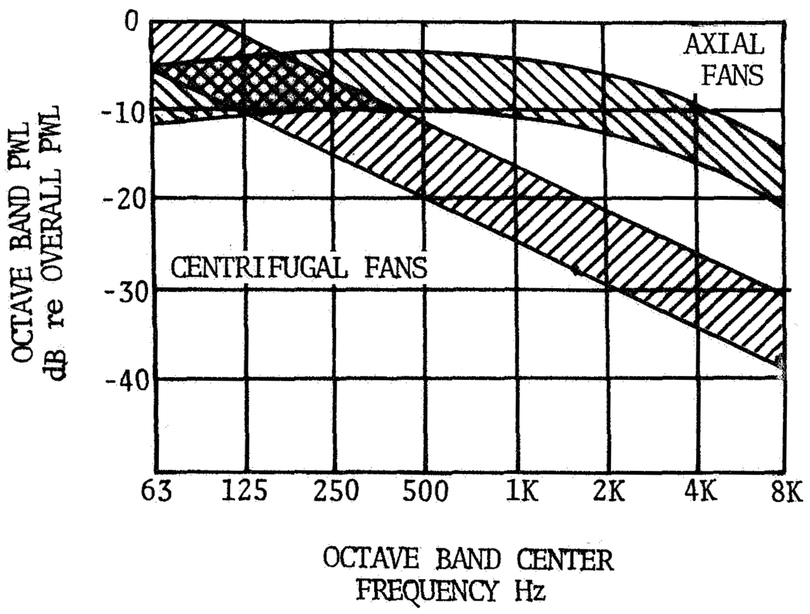
This scheme, which has a claimed accuracy of ± 4 dB for conventional fan designs, predicts PWL from the appropriate equation:

1. $PWL = 103 + 10 \log HP + 10 \log \Delta P$
2. $PWL = 68 + 10 \log Q_d + 20 \log \Delta P$
3. $PWL = 138 + 20 \log HP - 10 \log Q_d$

The octave band spectrum then can be found from the appropriate curve of figure 28.

FIGURE 28

SOUND LEVEL SPECTRA OF CENTRIFUGAL AND AXIAL - FLOW FANS



ASHRAE Method

This method, presented in the ASHRAE Guide and Data Book[3], estimates noise from several centrifugal and axial fan designs operating at or near their point of peak efficiency where the noise levels are at a minimum.

Table III presents the octave band base sound power levels for typical types of ventilation fans. These levels are referenced to three foot diameter fans operating at a rotational speed of 1000 rpm and are adjusted to the specific fan diameter and rotational speed, N, by

$$\Delta dB = 50 \log \frac{(N)\ (D)}{36{,}000} + 20 \log \frac{D}{36}$$

where N is in rpm and D is the fan diameter in feet.

In addition, 5 dB are added to the PWL in the octave band where the blade passage frequency occurs.

Buffalo-Forge Method

This procedure is based on the characteristic noise spectra of a number of typical fan designs including centrifugal and axial types[4]. These characteristics are presented in Table IV as baseline octave band levels for each type of fan. The column titled BFI is the "blade frequency increment", which is intended to account for the presence of the blade passing frequency tone. This increment is added to the octave band in which the blade frequency falls.

The base octave band levels of the fan are then adjusted by

$$\Delta dB = 10 \log Q_d + 20 \log \Delta P$$

to the specific fan operating conditions.

Sowers' Method

To evaluate the sound power level, Sowers [5] plots a normalized level given as

$$PWL - 10 \log \left(\frac{S\omega}{B}\right) \cdot \delta^2 \ ,$$

against an energy flux E, equal to the total energy of the air leaving the compressor stage per unit time and per unit area, where

$$E = \frac{H_T \bullet \dot{w}}{S} \quad ,$$

as shown in figure 29, where

PWL = sound power level ~ dB
S = annulus area ~ ft^2
ω = rotational speed ~ radians/sec
B = number of rotor blades
δ = hub - tip ratio
H_T = total enthalphy at the temperature T of the gas leaving the compressor ~ Btu/lb
T = total temperature ~ degrees Rankine
$\dot{w}$ = mass flow ~ lb/sec
E = energy flux ~ Btu/ft^2 - sec.

TABLE III

BASE SOUND POWER LEVELS FOR VARIOUS TYPES OF FANS IN DECIBELS RE 10^{-13} WATT

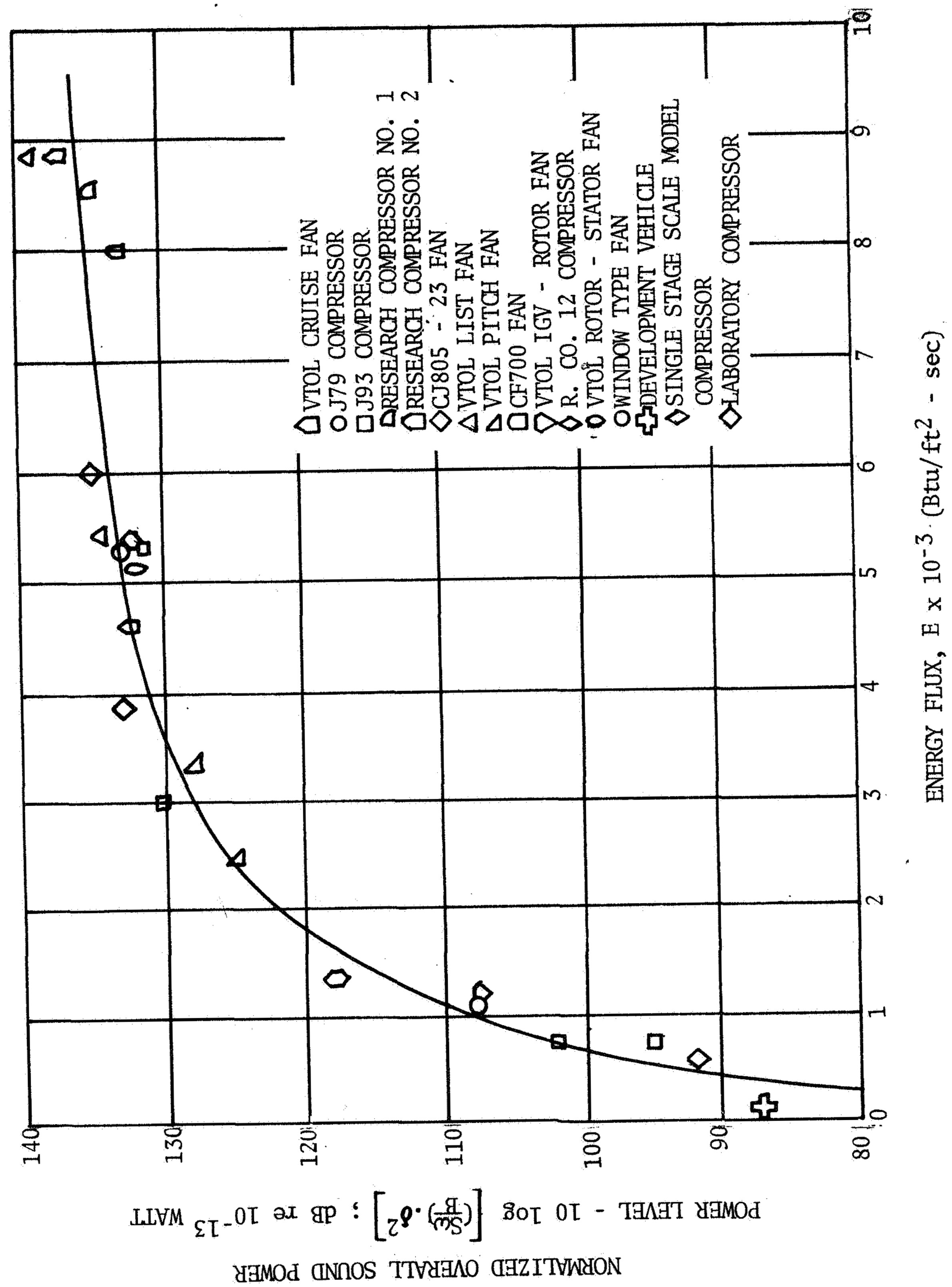
TYPE	DIAGRAM	DESCRIPTION	APPLICATIONS	BASE SOUND POWER LEVELS, dB re 10^{-13} watt — OCTAVE BAND CENTER FREQUENCIES - cps: 63	125	250	500	1000	2000	4000	8000
C-1		Centrifugal fan with backwardly curved airfoil blades.	1. General ventilation and air conditioning. 2. Industrial applications where corrosion, erosion, or dirt is not a major problem.	107	104	102	100	98	95	92	90
C-2		Centrifugal fan with backwardly curved or sloped, single thickness blades.	1. General ventilation and air conditioning. 2. Industrial applications where corrosion, erosion, or dirt is not a major problem.	107	105	103	104	103	98	94	89
C-3		Centrifugal fan with single thickness blades with forward curved heel and radial or nearly radial tip.	1. Used principally for industrial applications where medium to high pressure requirements must be met. May be used in moderately dirty applications.	118	114	104	102	100	98	99	97
C-4		Centrifugal fan with single thickness radial blades. Blades are relatively short in direction of air flow.	1. Industrial applications where corrosion or erosion is a problem, or dust loading is very heavy. Also used in conveying systems where material passes through the fan wheel.	113	113	106	106	103	98	95	94
C-5		Centrifugal fan with single thickness radial blades. Blades are relatively long in direction of air flow.	1. Industrial applications where relatively small volumes at high pressure are required.	124	121	114	114	110	107	104	101
C-6		Centrifugal fan with single thickness blades curved forward at both heel and tip.	1. General ventilation and air conditioning for low pressure, high capacity requirements	126	122	116	111	110	108	103	98
A-1		Axial fan with relatively long blades and small hub.	1. Designed to meet requirements of high capacity at very low pressures.	102	103	102	101	101	98	94	90
A-2		Axial fan where hub is about 50 percent of fan tip diameter.	1. General ventilation or air conditioning. 2. Industrial applications where corrosion, erosion, or dirt is not a major problem.	106	103	107	106	104	100	96	95
A-3		Axial flow fan with relatively short blades and large hub.	1. Industrial applications where requirement is for high pressure at medium capacity.	100	96	100	103	103	99	93	91

Reprinted by permission ASHRAE, Guide and Data Book, 1967. Base sound power levels have been adjusted upward by 10 dB to account for change in reference level from 10^{-12} watt to 10^{-13} watt.

TABLE IV

SPECIFIC SOUND POWER LEVELS (re 10^{-13} watt) AND BLADE FREQUENCY INCREMENTS FOR FANS OF VARIOUS TYPES

FAN TYPE	OCTAVE BAND CENTER FREQUENCY, Hz								BFI
	63	125	250	500	1000	2000	4000	8000	
Centrifugal, airfoil blade	45	45	44	42	41	36	28	20	3
Centrifugal, backwardly curved blade	45	45	44	42	41	36	28	20	3
Centrifugal, forward curved blade	50	48	48	44	38	34	31	25	2
Centrifugal, radial blade	58	55	53	53	48	43	40	39	5-8
Tubular centrifugal	56	53	53	48	47	42	38	35	4-6
Vaneaxial	52	49	51	52	50	47	45	35	6-8
Tubeaxial	54	52	56	54	52	50	47	40	6-8
Propeller	61	58	59	57	55	55	53	41	5-7



NORMALIZED OVERALL POWER OF COMPRESSOR AND FAN NOISE

FIGURE 29

Motor Noise Sources

The estimating procedure for motors is based on a calculated velocity level associated with system imbalance. These imbalance forces are assumed to drive the entire assembly in some shell mode of radiation. The model assumed here is that of the force applied to a body immersed in a fluid. The power radiated by such a body is given by McLachlan(6) as

$$PWL = 10 \cdot \log \left[\frac{1.36 \left(\frac{\omega}{c_o}\right)^2 F_o^2}{12\pi\, \rho_o\, c_o} \left(\frac{Q + Q^1}{\frac{m}{\rho_o} + Q^1} \right) \right] + 130$$

where c_o is the speed of sound in fps, F_o the force in pounds, m the mass of the body in slugs, Q the displaced volume of the body being excited in ft^3, Q^1 the entrained volume of the fluid being excited in ft^3, ρ_o the density of the environmental atmosphere in $slugs/ft^3$ and ω the rotational speed in radians per second.

The determination of the force due to dynamic unbalance is based on the measured or specified maximum allowable imbalance. This force, F_o, is applied to the entire radiating body at the fundamental rotational frequency.

Other sources of descrete tones are:

Vane frequency;
Bearings - Ball frequency, train frequency, inner race frequency, outer race frequency;
Motor slot frequency.

Each of the above sources will have a fundamental and perhaps several harmonics depending on the sharpness of the pulse generated.

Bearing frequencies are calculated from

$$\text{Train frequency} = \frac{\frac{OD}{2} + \frac{ID}{2} - D_B}{ID + OD} \times \text{rotational frequency}$$

$$\text{Ball frequency} = \left(\frac{\frac{OD}{2} + \frac{ID}{2} + D_B}{D_B} \right) (\text{train frequency})$$

First race frequency = (rotational frequency - train frequency) (n)

Second race frequency = (train frequency) (n) ,

where ID is the race inner diameter, OD is the race outer diameter, D_B is the ball bearing diameter, and n, the number of balls.

Correlation with Apollo Hardware Data

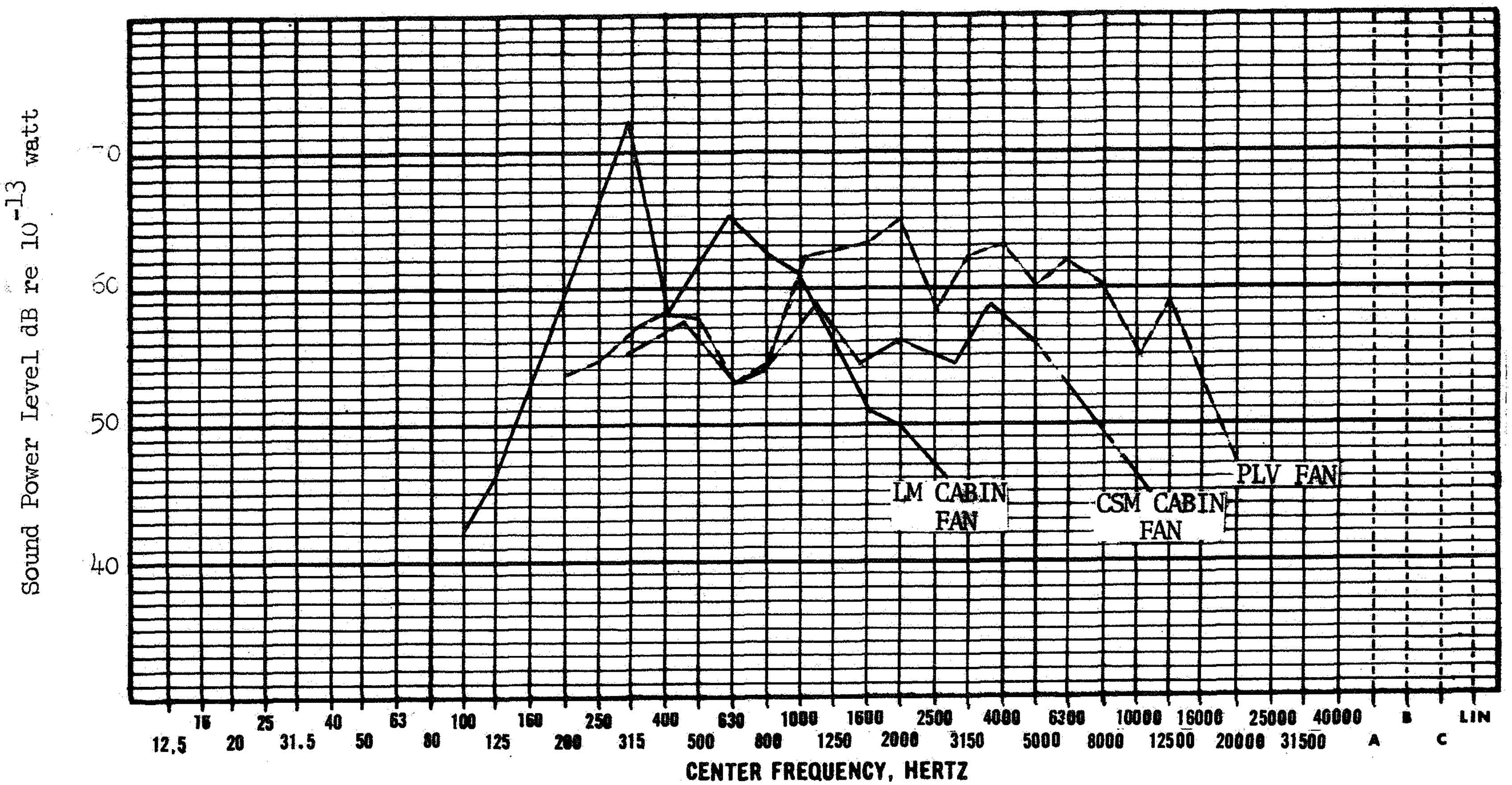
In order to asses the applicability, relative accuracy, and absolute accuracy of the estimating methods described above, a correlation was made of estimates and the data obtained on the Apollo fans, compressors, and pumps. It is apparent from the development of some of the estimating procedures that they are based on relatively large ventilation fans, and that similar levels and frequency envelopes might be predicted, but with the frequency axis displaced. Therefore, frequency scaling-parameters were investigated also as a means of improving the estimates.

Fan Noise Correlation

Figure 30 shows the PLV, CSM cabin, and LM cabin fan noise levels normalized to PLV fan parameters using the aerodynamic scaling procedure previously described on page 50. Note that the fan inlet and exhaust noise levels were summed into total noise levels for this figure. Also, the CSM and LM cabin fans were adjusted in level and frequency to account for the differences in their geometries and operating conditions compared to those of the PLV fan. The correlation in the mid frequencies (i.e. between 400 and 2000 Hz) is seen to be within about 10 dB. If the fans were geometrically and aerodynamically similar and the data correlation scheme exact, the normalized spectrum from each fan would collapse to a single curve. This is not quite the case. In fact the CSM fan and LM fan high-frequency noise are both low. Also the tones which dominate the LM fan noise spectrum are, of course, not predicted.

Figure 31 shows estimates made using equation 2 of the Allen method for the three axial fans. This fan estimating method and others assume that the fans are operated on standard day, sea level conditions where the density, ρ, is constant. However, both the LM and CSM cabin fans were tested at 5 psia ambient pressure. Thus the normalized sea level pressure rise to be used in the estimates should be adjusted by the ratio of 14.7 to 5 psia. This effectively appears as a noise level adjustment of 9 dB $\left(\text{i.e. } 20 \log \frac{14.7}{5}\right)$.

The estimated LM and CSM cabin fan noise levels have been adjusted by 9 dB to account for the ambient pressure difference. As may be seen from the results in figure 31, the LM cabin fan noise levels are underestimated, while the PLV and CSM cabin fan noise levels are overestimated.



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • ONE THIRD OCTAVE BAND ANALYSIS

TITLE ACOUSTIC CORRELATION WITH AERODYNAMIC SCALING

Test Date ________ Run No. ________

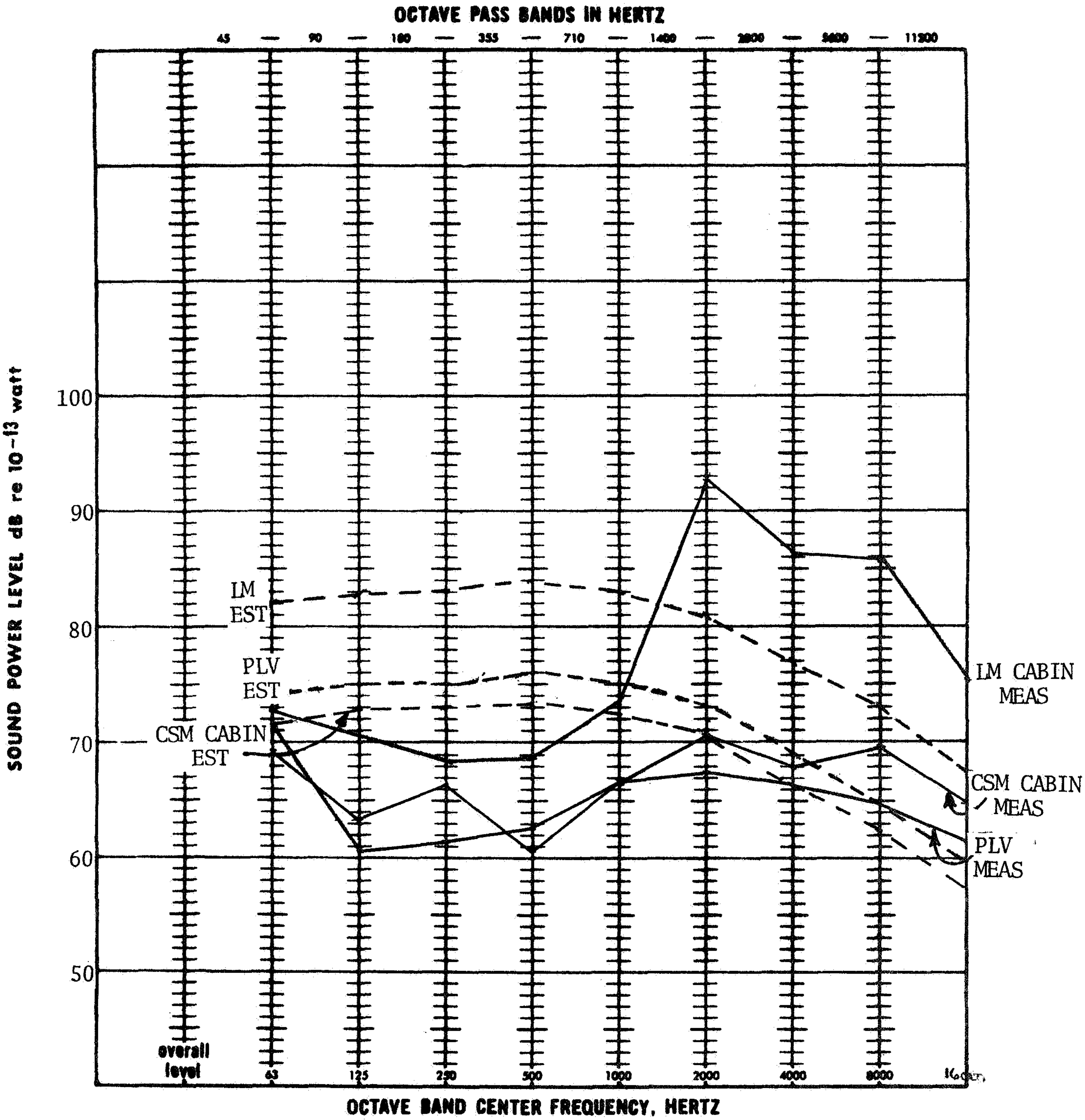
Mic Location ________ Reel No. ________

Analysed By ________ Identification No. ________

Analysis Method ________ Sheet ____ of ____

Comments, Sketches, Etc.

FIGURE 30



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OCTAVE BAND ANALYSIS

FAN NOISE CORRELATION USING THE ALLEN METHOD

FIGURE 31

Better agreement could be obtained by shifting the Allen estimates up in frequency. This would be consistent with the estimating method since it is based on larger fans which have lower frequency noise components than the small Apollo fans. However, even with a frequency shift, the levels are not adequately estimated.

Figure 32 shows the correlation given by the ASHRAE Method. Although the method tends to overpredict, the predicted trends are in fair agreement with the test data. Again, better agreement could be obtained by shifting the estimated levels up in frequency.

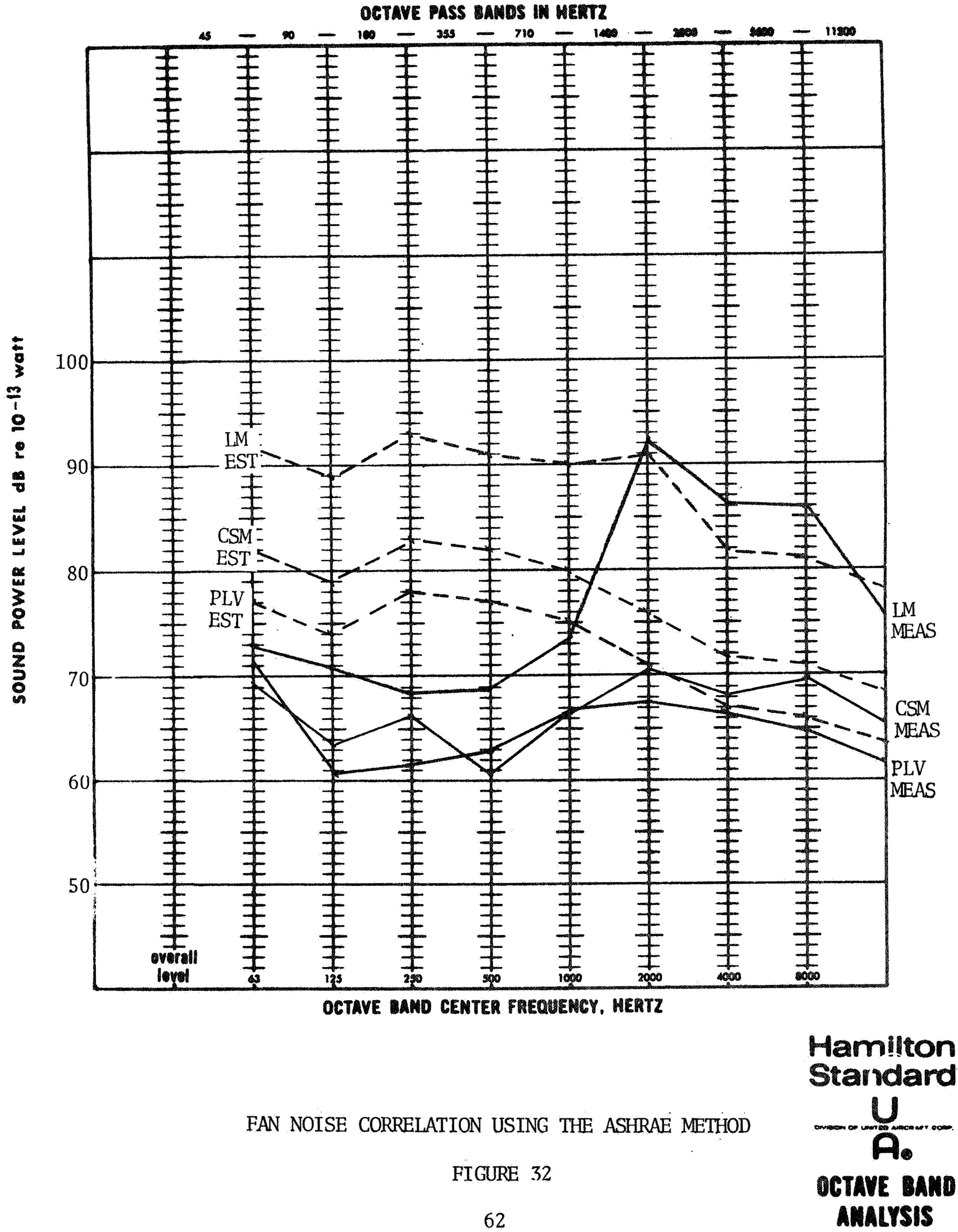
Figure 33 shows the predictions made using the Buffalo-Forge method and adjusting the LM and CSM cabin fan levels by 9 dB to account for the reduced test ambient pressure. Again, a significant improvement could be achieved by shifting the estimate in frequency to account for the smaller fan size. A frequency shift, as described in step 3 of the procedure defined on page 69, was applied to these estimates and the results are shown in figure 34. The agreement between measured and estimated levels for the PLV and CSM fans is seen to be quite good. The LM fan noise, however, is underestimated by the method. This should not be too surprising, since this fan has a very small rotor-stator spacing and the combination of 11 blades and 12 vanes gives rise to strong interaction tones which propagate out the duct. This design certainly is not typical of a low-noise design where such close proximity of the stator assembly to the rotor would be avoided.

Compressor Noise Correlation

Figure 35 shows a comparison of estimated and measured PWL for the CSM and LM suit compressors using the Allen method. Since both units were tested at 5 psia, 9 dB have been added to the estimates to adjust the head rise correction. It may be seen from figure 35 that the levels are significantly overestimated at the low frequencies and that the spectrum shapes are not well represented.

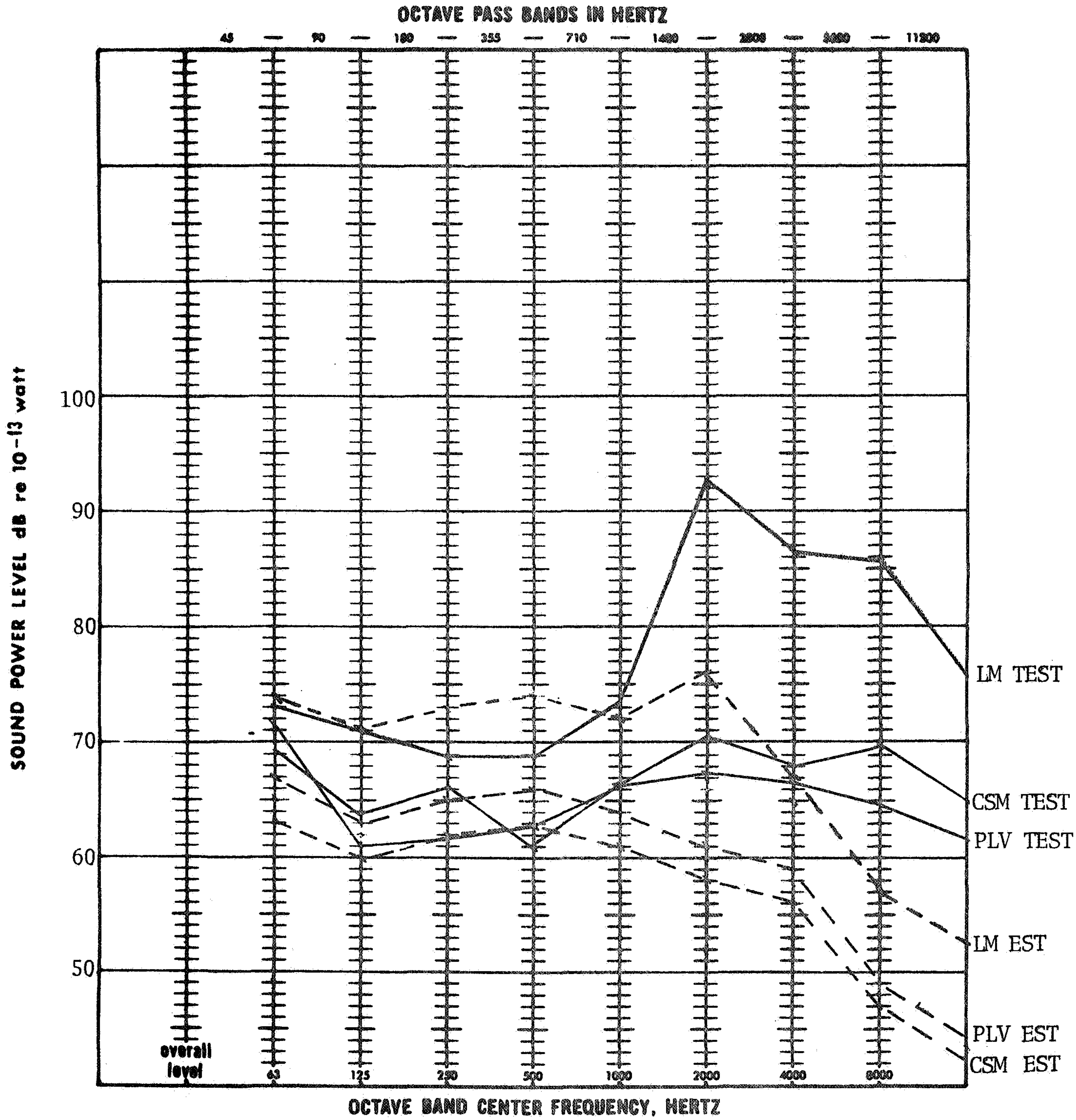
Figure 36 shows the CSM and LM compressor estimated levels using the ASHRAE guide method. This method also appears to over predict significantly.

Figure 37 shows the compressor noise estimates using the Buffalo-Forge method with the ambient pressure adjustment. Correlation with the LM high frequency noise is good, although the low frequency noise is over predicted. Correlation with the CSM compressor data is not as good, but suggests a frequency scaling to shift the estimated low frequency band levels upward to adjust for size difference. Figure 38 shows the reestimated levels using the Buffalo-Forge method with frequency adjustment. The agreement is seen to be much improved.



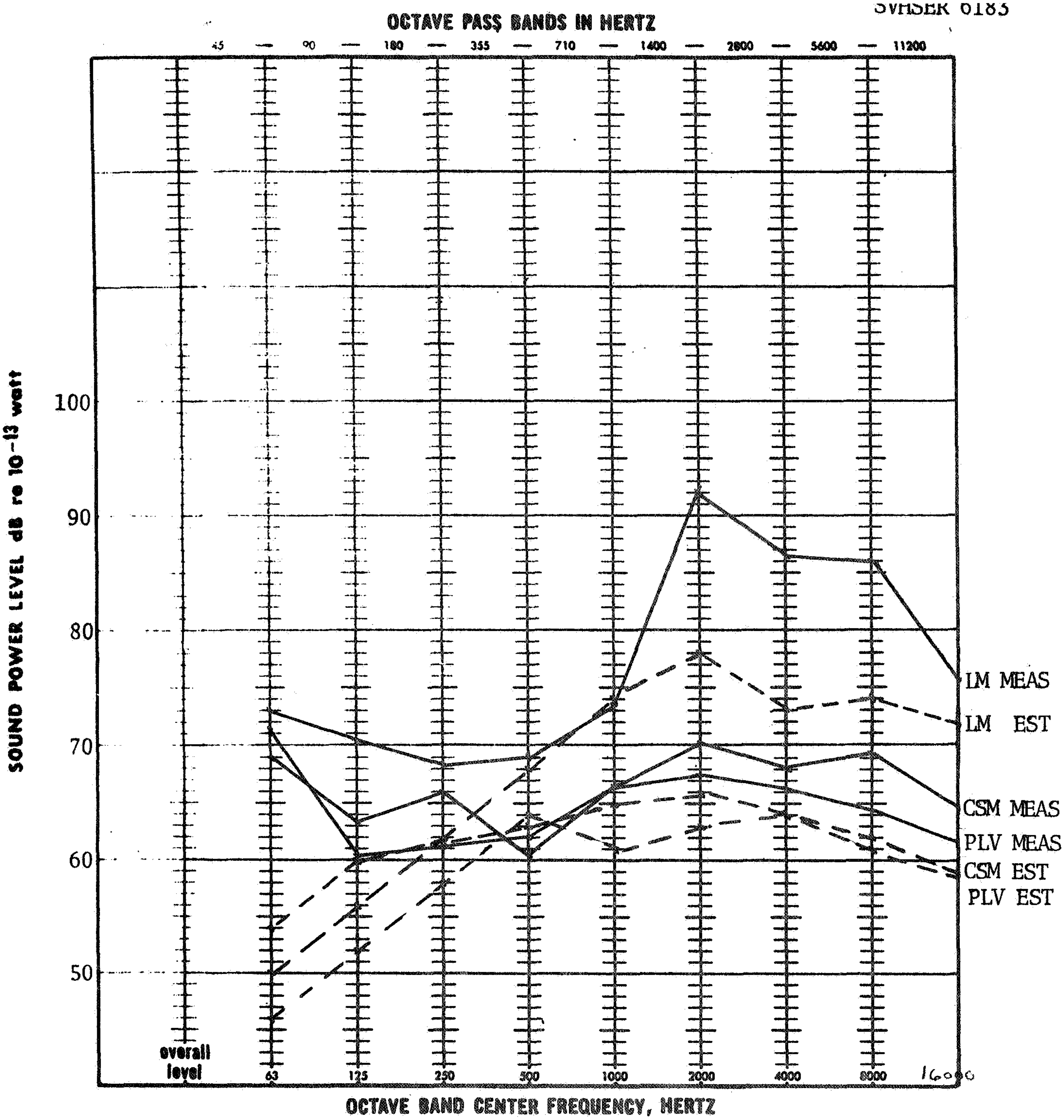
FAN NOISE CORRELATION USING THE ASHRAE METHOD

FIGURE 32



FAN NOISE CORRELATION USING THE BUFFALO-FORGE METHOD

FIGURE 33



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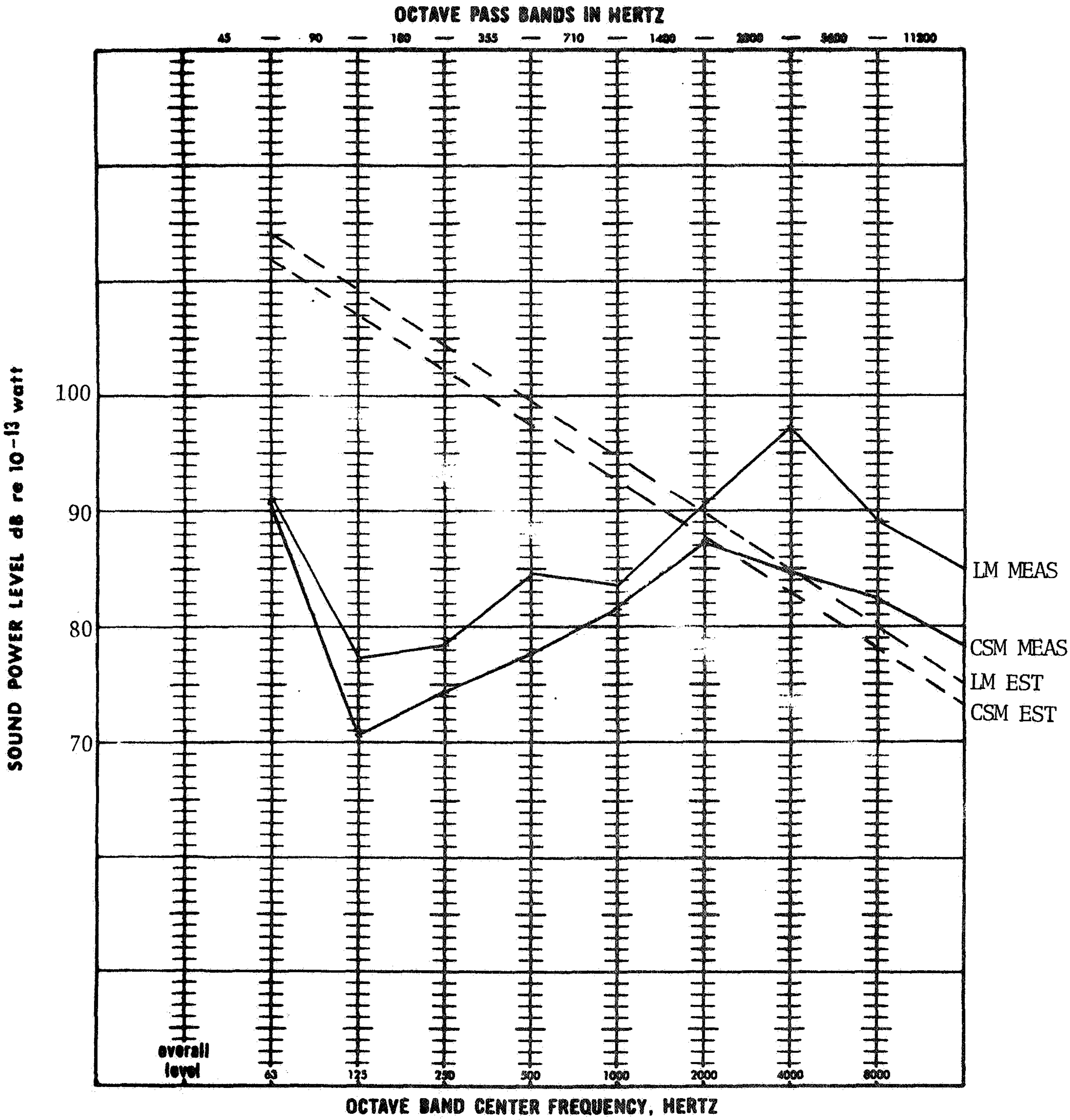
OCTAVE BAND ANALYSIS

FAN NOISE CORRELATION USING THE MODIFIED BUFFALO-FORGE METHOD

FIGURE 34



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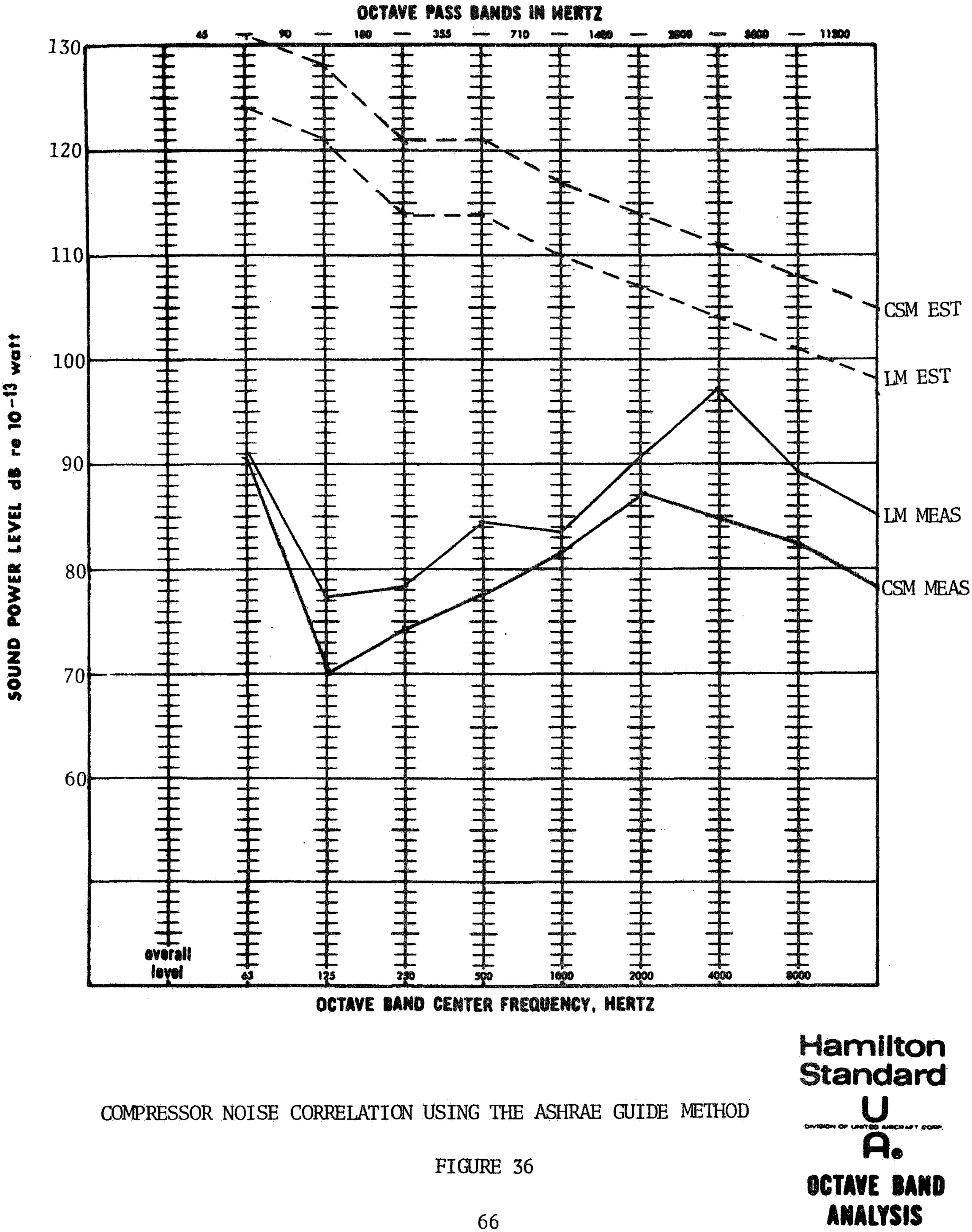
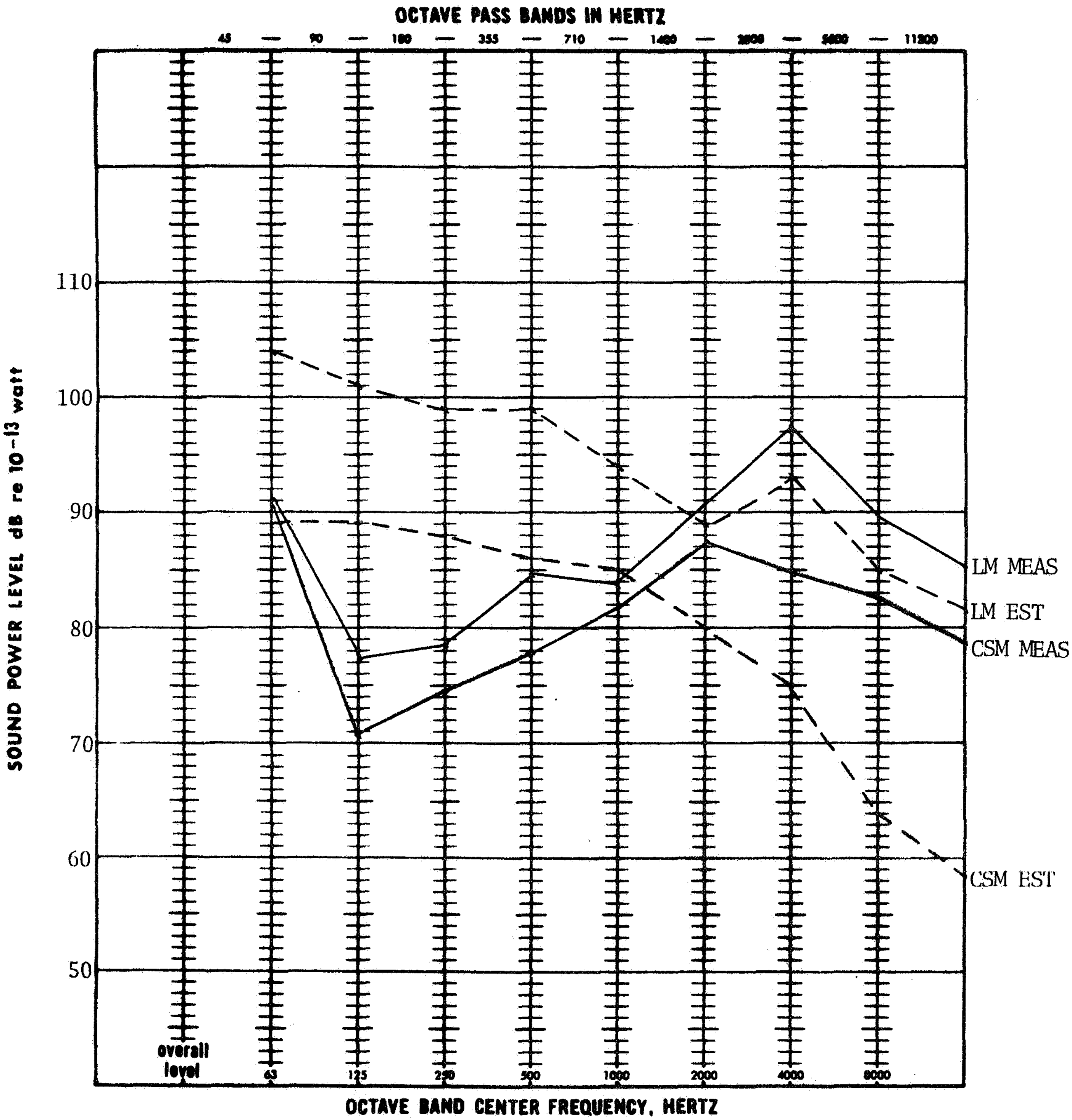
COMPRESSOR NOISE CORRELATION USING THE ALLEN METHOD

FIGURE 35



COMPRESSOR NOISE CORRELATION USING THE ASHRAE GUIDE METHOD

FIGURE 36



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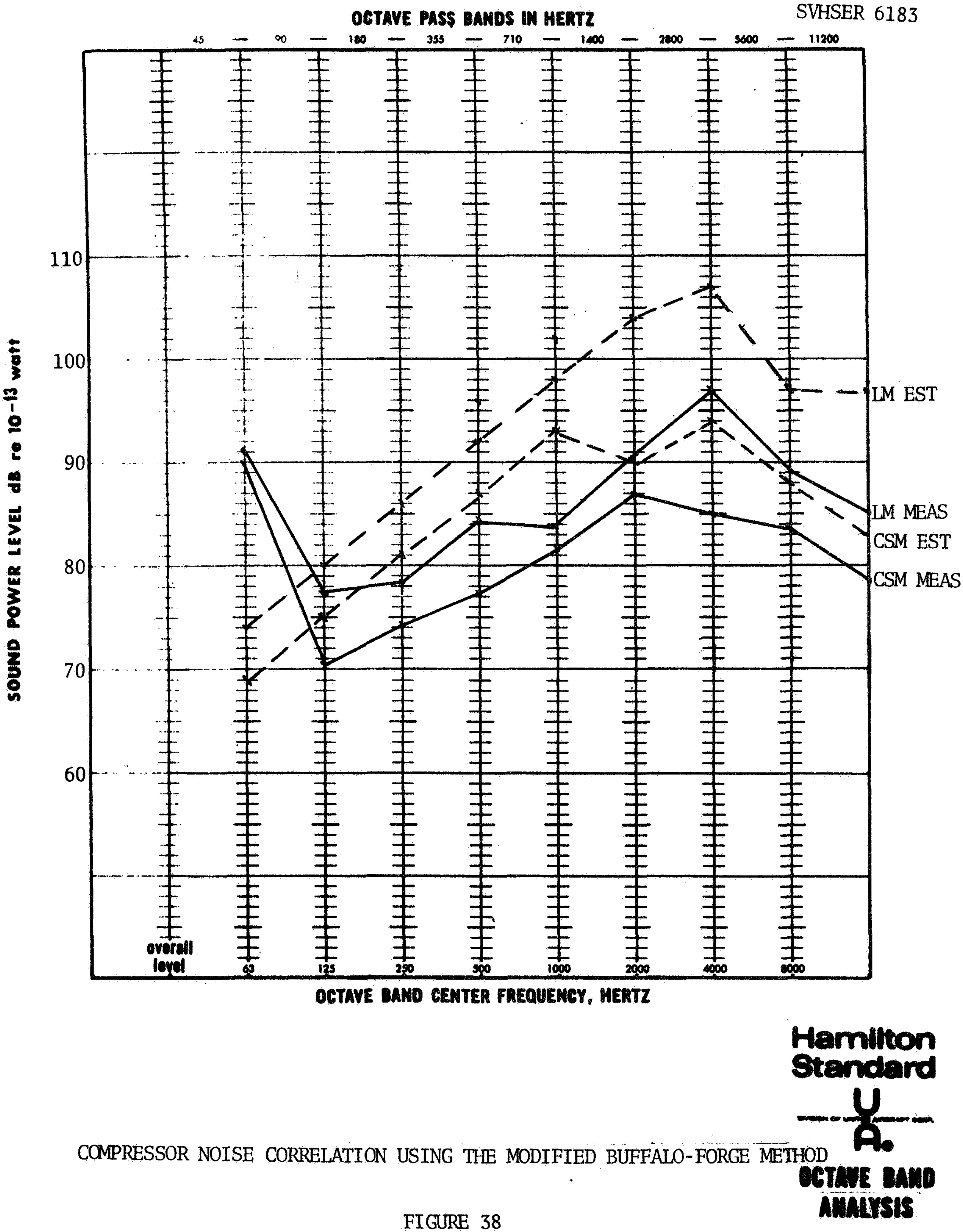
COMPRESSOR NOISE CORRELATION USING THE BUFFALO-FORGE METHOD

FIGURE 37



COMPRESSOR NOISE CORRELATION USING THE MODIFIED BUFFALO-FORGE METHOD

FIGURE 38

It thus is concluded on the basis of this correlation that the Buffalo-Forge method with a frequency scaling parameter based on unit rpm gives the best correlation with the Apollo hardware test data. To avoid confusion in further sections this new, improved method has been named the Hamilton Standard Empirical Fan Noise Estimating Procedure. (1)

Hamilton Standard Empirical Fan Noise Estimating Procedure

This procedure, which is an improvement on the method in reference 4, allows the estimation of the noise from typical fan designs, including centrifugal and axial types. The procedure is applicable only to fans using best state-of-the-art design and manufacturing practice. Poorly designed machines will be inefficient and therefore noisier than predicted by this method.

Present state-of-the-art squirrel cage fans in the size range of consideration have efficiencies of about 50 percent. The unrevised Buffalo-Forge base sound levels, as shown in Table IV, are for large fans with over 70 percent efficiency. For this procedure, these base sound levels have been revised in Table V to reflect a 50 percent efficient squirrel cage fan. Data for only those types of fans tested under this program are shown in this table.

The steps required to obtain a fan noise estimate are as follows:

Step 1. - A reference octave band spectrum is obtained from Table V based on the fan type.

Step 2. - A frequency scaling parameter is calculated by dividing the fan rpm by 1000 rpm.

Step 3. - The spectrum from step 1 is shifted up or down in frequency according to figure 39 using the frequency scaling parameter obtained in step 2. Note that in shifting up in frequency by, for example, one octave band (frequency scaling parameter between 1.41 and 2.83) the 63 Hz octave band of the reference spectrum found in step 1 becomes the 125 Hz band, the 125 Hz band becomes the 250 Hz band, etc.

Step 4. - If the frequency shift from step 3 is up in frequency, the missing octave bands are filled in using a slope of minus 6 dB per octave. Therefore, if the spectrum was shifted 2 octave bands, the value of the missing 125 Hz band takes on the value of the 250 Hz octave band minus 6 dB and the missing 63 Hz band becomes the value of the 250 Hz band minus 12 dB.

(1) This procedure was recommended by Bolt Beranek, and Newman, Inc., under contract to Hamilton Standard.

TABLE V

SPECIFIC SOUND POWER LEVELS (re 10^{-13} watt) AND BLADE FREQUENCY INCREMENTS FOR FANS OF VARIOUS TYPES

FAN TYPE	OCTAVE BAND CENTER FREQUENCY, Hz								BFI
	63	125	250	500	1000	2000	4000	8000	
Squirrel Cage Centrifugal, forward curved blade	(1) 50	48	48	44	38	34	31	25	2
	(2) 49	51	52	49	47	43	40	35	2
Centrifugal, radial blade	58	55	53	53	48	43	40	39	5-8
Vaneaxial	52	49	51	52	50	47	45	35	6-8

(1) Used for comparative studies in this report.
(2) Revised to account for lower-expected efficiencies from 5 to 8 inch diameter (rotor) units.

<u>Step 5.</u> - An adjustment, to account for the operating condition of the fan is calculated from

$$\Delta dB = 20 \log \Delta P + 10 \log Q_d$$

where ΔP is the fan static pressure rise in inches of water and Q_d is the fan discharge flow in cfm. This adjustment is added to each octave band level in step 4.

<u>Step 6.</u> - The blade passing frequency, given by

$$BPF = rpm \times number\ of\ blades/60$$

is computed. The blade frequency increment (BFI) from Table V is added to the level of the octave band spanning the blade passing frequency. Octave band upper and lower frequencies are given in Table VI.

NOTE: The BFI for axial flow fans should be added only if the fan is under non-uniform inflow or has propagating rotor/stator interacting tones. The fan will not have propagating interaction tones if the wall velocity, V_w, of the interaction tone is subsonic. V_w is given by

$$V_w = \frac{BV_t}{B-V}$$

where B is the number of rotor blades, V is the number of stator vanes, and V_t is the rotor tip velocity.

Step 7. - Steps 1 to 6 give the octave band PWL for the total fan noise. Inlet and exhaust noise are assumed to be equal and can be estimated by subtracting 3 dB from the total PWL. To calculate SPL, use

$$SPL = PWL - 10 \log A + 0.5$$

where A is the area, in square feet, over which the SPL is assumed constant. If it is assumed that the sound radiates uniformly in all directions (spherical spreading) then the conversion becomes

$$SPL = PWL - 20 \log R - 10.5$$

where R is the distance, in feet, from the fan center to the point where the noise estimate is desired.

The octave band SPL's may then be summed to give overall noise, converted to dB(A) values, used to estimate dBNC, etc. Note that the above procedure assumed free field radiation. Any additional attenuation due to ducting, plenums, etc. must be accounted for to obtain the noise estimate of the installed unit. Attenuation curves for ducts, elbows,plenums, etc. may be found in standard acoustic or noise control texts.

Example 1: CSM Suit Compressor

Step 1. - Line 1 of Table VII is from Table V line 3 (Centrifugal, radial blade).

Step 2. - Fan rpm = 22,000 ∴ frequency scaling parameter = 22,000/1000 = 22.

Step 3. - From figure 39, it is found that the spectrum should be shifted up in frequency by 4 octave bands. The adjusted spectrum is shown in line 2 of Table VII.

TABLE VI

FREQUENCY LIMITS FOR FULL OCTAVE BANDS

OCTAVE BAND CENTER FREQUENCY, Hz	LOWER LIMIT, Hz	UPPER LIMIT, Hz
63	-	90
125	90	180
250	180	355
500	355	710
1000	710	1400
2000	1400	2800
4000	2800	5600
8000	5600	-

TABLE VII

SAMPLE NOISE ESTIMATE FOR THE CSM SUIT COMPRESSOR

LINE NO.	CALCULATED IN STEP NO.	OCTAVE BAND CENTER FREQUENCY, Hz								
		63	125	250	500	1000	2000	4000	8000	16000
1	1	58	55	53	53	48	43	40	39	-
2	3	-	-	-	-	58	55	53	53	48
3	4	34	40	46	52	58	55	53	53	48
4	5	69	75	81	87	93	90	88	88	83
5	6	69	75	81	87	93	90	94	88	83

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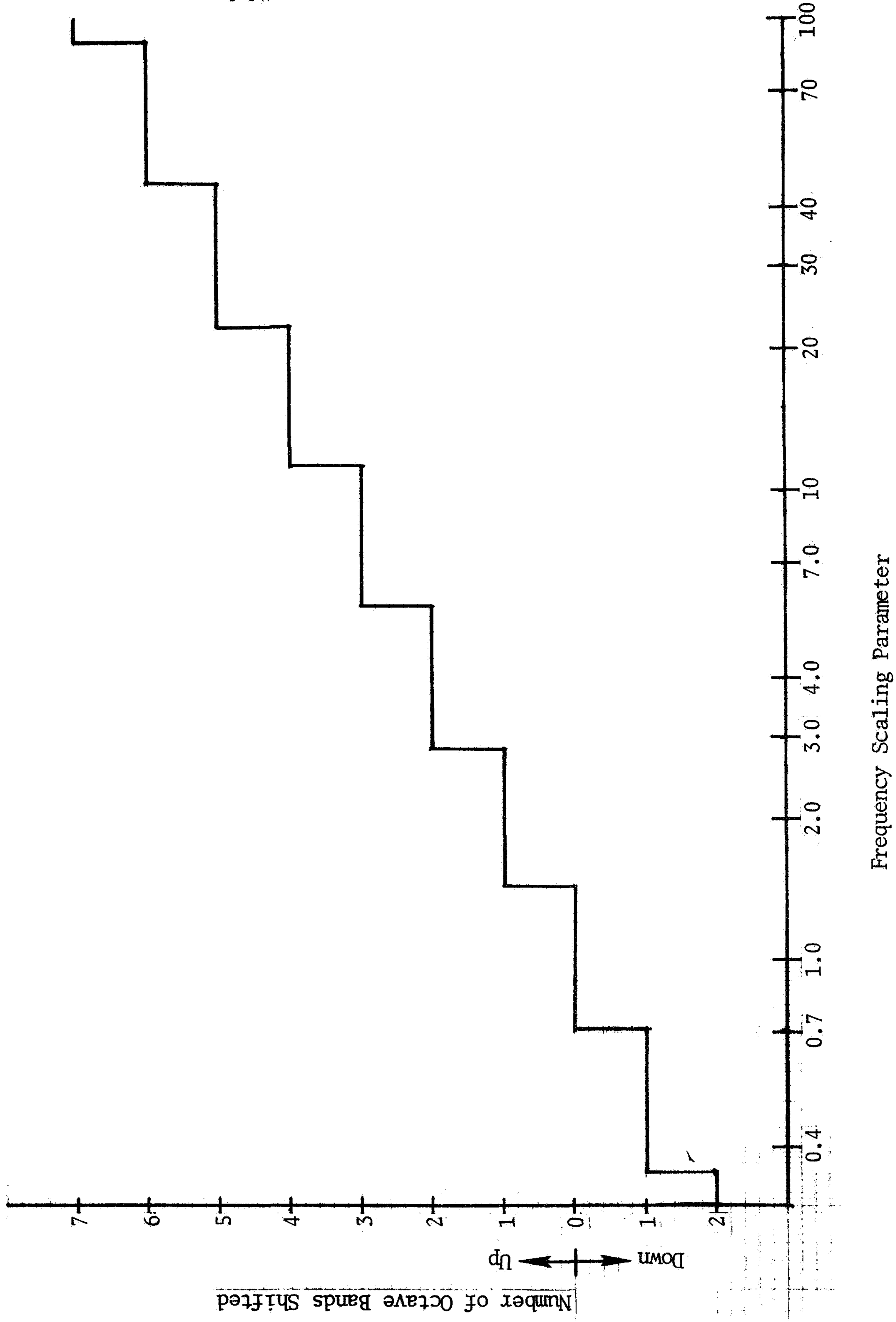


FREQUENCY SHIFT ADJUSTMENT GRAPH

FIGURE 30

Step 4. - The values for the 63 to 500 Hz bands are filled in with a 6 dB/octave roll-off, as shown in line 3 of Table VII.

Step 5. - The fan pressure rise is 10.5 inches of water at a discharge flow of 27 cfm. Thus

$$\Delta dB = 20 \log 10.5 + 10 \log 27 = 34.7 \approx 35$$

This adjustment is reflected in line 4 of Table VII.

Step 6. - BPF = rpm x No. blades/60 = 22,000 x 12/60 = 4400 Hz. From Table VI, this frequency falls in the 4000 Hz band, and from Table V, the BFI is 6. Thus 6 dB should be added to the 4000 Hz band, as shown in line 5 of Table VII.

Example 2: Axial Fan

Step 1. - Line 1 of Table VIII is from Table V line 4 (vaneaxial).

Step 2. - Fan rpm = 11,000.: frequency scaling parameter = 11,000/1000 = 11.

Step 3. - From figure 39, it is found that the spectrum should be shifted up in frequency by 3 octave bands. The adjusted spectrum is shown in line 2 of Table VIII.

Step 4. - The values for the 63 to 250 Hz bands are added using a 6 dB/octave roll-off. See line 3 of Table VIII.

Step 5. - The fan pressure rise is 2.5 inches of water at a discharge flow of 400 cfm. Thus:

$$\Delta dB = 20 \log 2.5 + 10 \log 400 = 34$$

This adjustment is shown in line 4 of Table VIII.

Step 6. - BPF = rpm x No. blades/60 = 11,000 x 3/60 = 550 Hz From Table VI, 550 Hz is in the 500 Hz octave band and from Table V, the BFI is 7. Thus 7 dB are added to the 500 Hz band, as shown in line 5 of Table VIII.

TABLE VIII

SAMPLE NOISE ESTIMATE FOR AN AXIAL FAN

LINE NO.	CALCULATED IN STEP NO.	OCTAVE BAND CENTER FREQUENCY, Hz								
		63	125	250	500	1000	2000	4000	8000	16000
1	1	52	49	51	52	50	47	45	35	-
2	3	-	-	-	52	49	51	52	50	47
3	4	34	40	46	52	49	51	52	50	47
4	5	68	74	80	86	83	85	86	84	81
5	6	68	74	80	93	83	85	86	84	81

Pump and Motor Noise

The CSM pump motor imbalance noise was estimated using the previously described procedure developed by McLachlan [6]. The following data were used for the estimate:

$$F_o = 0.6058 \text{ lb}$$
$$\omega = 367 \text{ Hz} = 2303 \text{ radians/sec}$$
$$\rho_o = 0.0024 \text{ slugs/ft}^3$$
$$\omega/c_o = 2.09$$
$$c_o = 1100 \text{ ft/sec}.$$

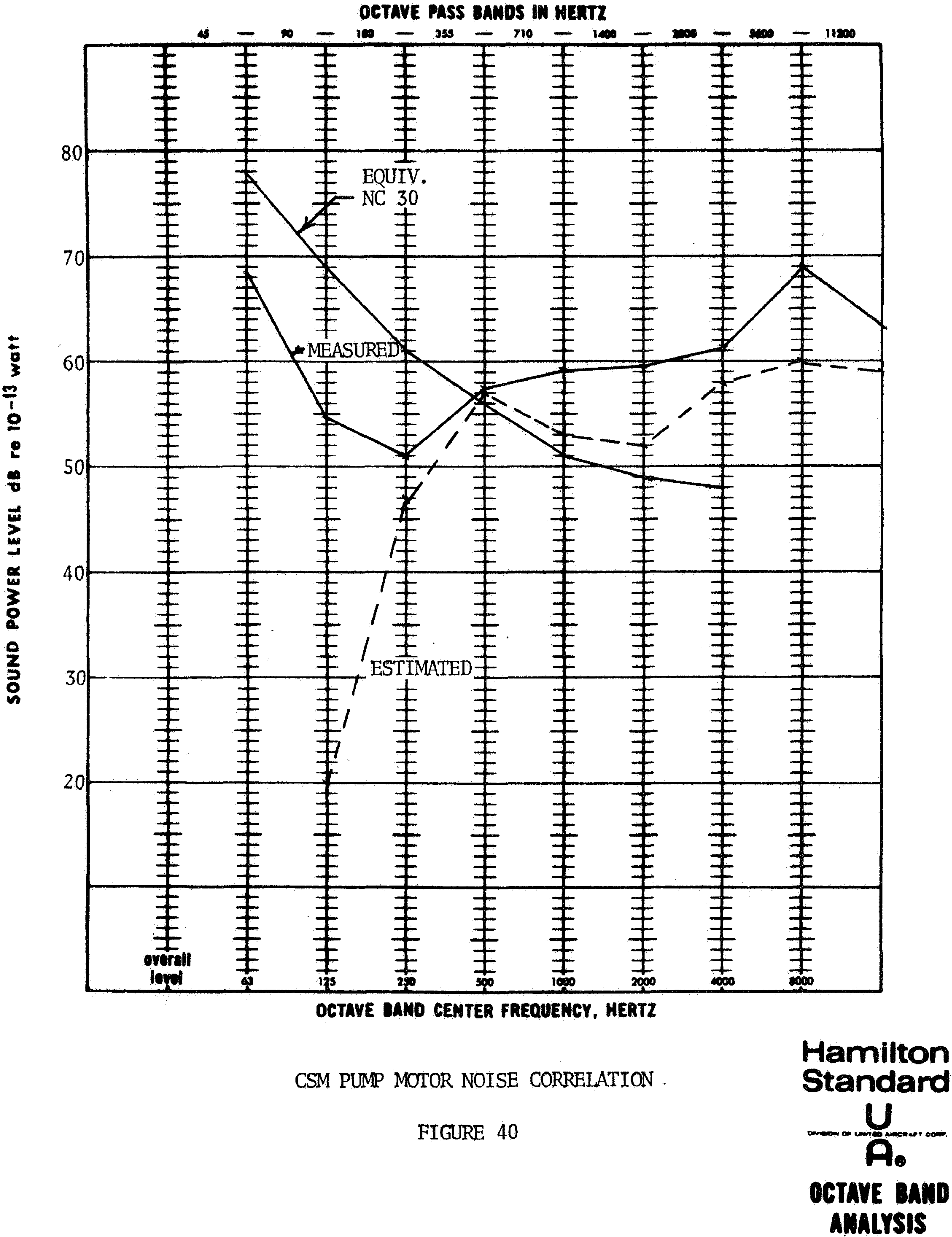
These data give a PWL of 56 dB re 10^{-13} watts at 367 Hz. Other components are:

Pump vane frequency	2933 Hz
Pump end bearing	
Train	134 Hz
Ball	644 Hz
Inner Race	1622 Hz
Outer Race	942 Hz
Second Bearing	
Train	133 Hz
Ball	621 Hz
Inner Race	1633 Hz
Outer Race	932 Hz

These components, summed into octave bands, are shown in figure 40 with the measured CSM pump-motor assembly noise. The correlation is seen to be excellent above 250 Hz. At 250 Hz and below the measured noise level is significantly below NC-30 and is not considered significant.

HAMILTON STANDARD AXIAL FAN NOISE CALCULATION PROCEDURE

The previously described generalized fan noise estimating procedures are limited to standard fan designs operating at or near to their design conditions. Also, they do not recognize detail of blade geometry, solidity, spacing, and so forth. As such, these methods are by necessity of limited accuracy. Recently, a comprehensive fan noise calculation procedure was developed at Hamilton Standard for the estimation of noise from low tip speed, low pressure ratio propulsive fans (Hamilton Standard Q-Fans™). This unified procedure is very powerful, since it relates the noise generated



CSM PUMP MOTOR NOISE CORRELATION

FIGURE 40

by the fan to elemental design and operating parameters. Thus it can calculate the generated noise as a function of detail design parameters such as rotor blade twist distribution and rotor blade camber distribution, as well as general parameters such as tip speed, diameter and input power.

Due to the similarity between Q-Fans™ and the axial flow fans envisioned to meet the Shuttle requirements, the procedure is applicable to the calculation of the noise from these ventilation fans. Therefore, this method can be used to design the Shuttle fans both aerodynamically and acoustically as well as to predict the noise of existing designs.

It was the objective of the study discussed below to correlate the calculated and measured noise levels of the PLV and LM axial flow fans tested earlier in this program. The calculation procedure was to be adjusted, to a limited extent, by empirical coefficients to establish agreement with the ventilation fan test data, since the existing coefficiencts were based on data from large propulsive fans. The calculation procedure then was used to optimize fan designs for minimum noise.

Fan Noise Calculation Procedure

In the calculation procedure the 1/3 octave band sound power level (PWL) contributions from rotor tones, rotor broad-band, stator tones, and stator broad-band are estimated. These are then summed to give a 1/3 octave band PWL for the specified fan at the specified operating condition.

The input data consist of the geometric definitions of the rotor and stator blades (that is, chord, blade angle, camber, and so forth) and aerodynamic definitions (that is, profile drag, lift slopes, axial and swirl components, and so forth) at each of 10 radial stations, as well as the gross design and operating parameters such as tip speed, input power, rotor thrust and diameter.

The stator noise is due to velocity perturbations in the stator inflow caused by the passing of the upstream rotor. With adequate spacing between the rotor and stator, only the viscous wakes of the rotor blades cause the interaction noise. The periodic velocity profile behind the rotor is calculated from the Silverstein (7) wake formulas using the profile drag coefficients and mean flow parameters from the aerodynamic performance calculation. These formulas predict a periodic train of pulses in the flow into the stator. However, recent evidence (8) (9) shows that the viscous wakes are highly turbulent. This leads to a random amplitude and frequency modulation of the pulses, which generates broad-band noise.

Stator forces due to the inflow perturbations are calculated from the Sears, Kemp and Horlock (10) (11) (12) theories for wing lift response. The Sears theory treats an airfoil with a small sinusoidal velocity perturbation superimposed on the classical uniform inflow. With the velocity perturbation model Sears formulated a theory to account for wing lift response. Kemp then generalized Sears theory into a more useable form. The most recent Horlock theory generalizes the Sears theory to include a chordwise component in the sinusoidal velocity disturbance. The Hamilton Standard lift response calculation further generalizes the Horlock theory to account for the random component in a manner similar to Liepmann's(13) generalization of Sears' work.

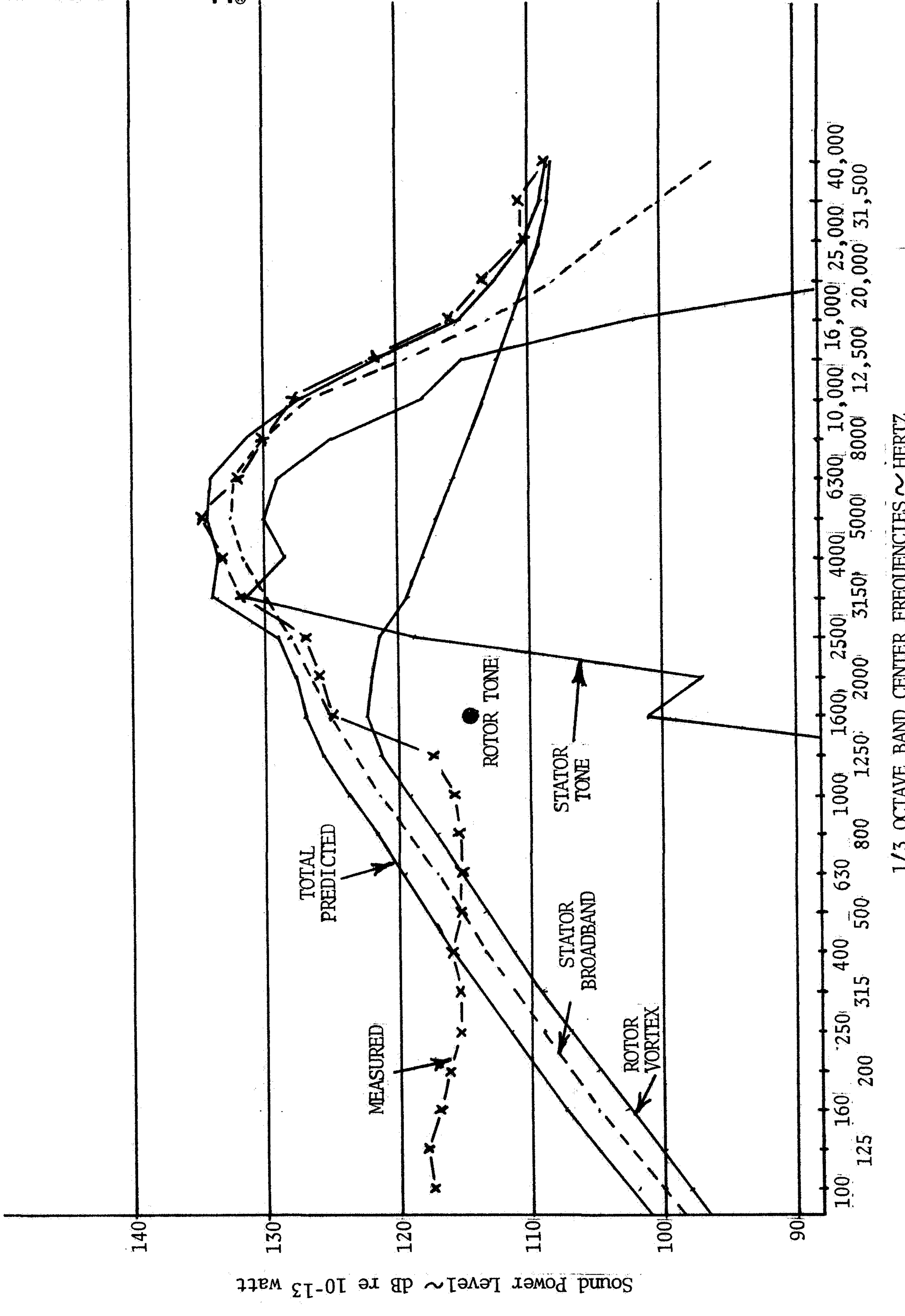
The stator radiation is calculated from the Hamilton Standard modulation theory using the forces determined above. This modulation theory, which was developed to account specifically for turbulence in the blade wakes in fans, models the stator as a circular array of dipole sources pulsed with random amplitude and phasing. The pulses have amplitudes with the values corresponding to the Silverstein(7) formulas and mean phasing determined from the vane pulsing order. Randomness of the pulses is characterized by standard deviations of the pulse amplitudes and pulse arrival times.

The rotor tone noise due to steady and unsteady loading is calculated from the Lowson(14) formulas with loading characteristics derived from Hamilton Standard's test experience. Vortex shedding noise is predicted from a modification of the Hamilton Standard empirical fan correlation which has been extensively refined over the past ten years. A more detailed description of this procedure is contained in reference (15).

A comparison (described in reference 16) between measured and calculated levels for a small propulsion fan is shown in figure 41. The spectrum is seen to peak in the vicinity of the third harmonic of blade passing frequency, where the dominant noise sources are stator tones and stator broad-band. These components drop rapidly in level at high frequencies where the rotor vortex shedding noise becomes dominant. The agreement in the mid- and high frequency bands, where the levels are subjectively the loudest, is seen to be good. The discrepancy at low frequencies may be due to acoustic and/or aerodynamic duct effects or possibly due to fan jet noise.

Empirical Coefficients

The wakes generated by the rotor are not, in general, uniform. Rather, they exhibit a high degree of turbulence which gives them a quality of randomness. For example, if one were to superimpose a number of these wakes (even those generated by repeated passes of one blade), the peak amplitude would not remain constant but would vary over some range with a near Gaussian distribution. Similarly, the position of the peak would vary over some range. The pulse train represented by the rotor wakes, then is seen to exhibit both amplitude and frequency modulation. Since this modulation is random, it results in the generation of broad-band noise at the stators. In the calculation procedure,



COMPARISON OF CALCULATED AND MEASURED FAN NOISE LEVELS (from Ref. 16)

FIGURE 41

the randomness of the pulses is characterized by standard deviations of the pulse amplitudes and pulse arrival times. The values of the standard deviation are determined empirically. The values used in the computer program prior to this correlation were based on test data from a model propulsive fan tested by Hamilton Standard in 1970 (see reference 16).

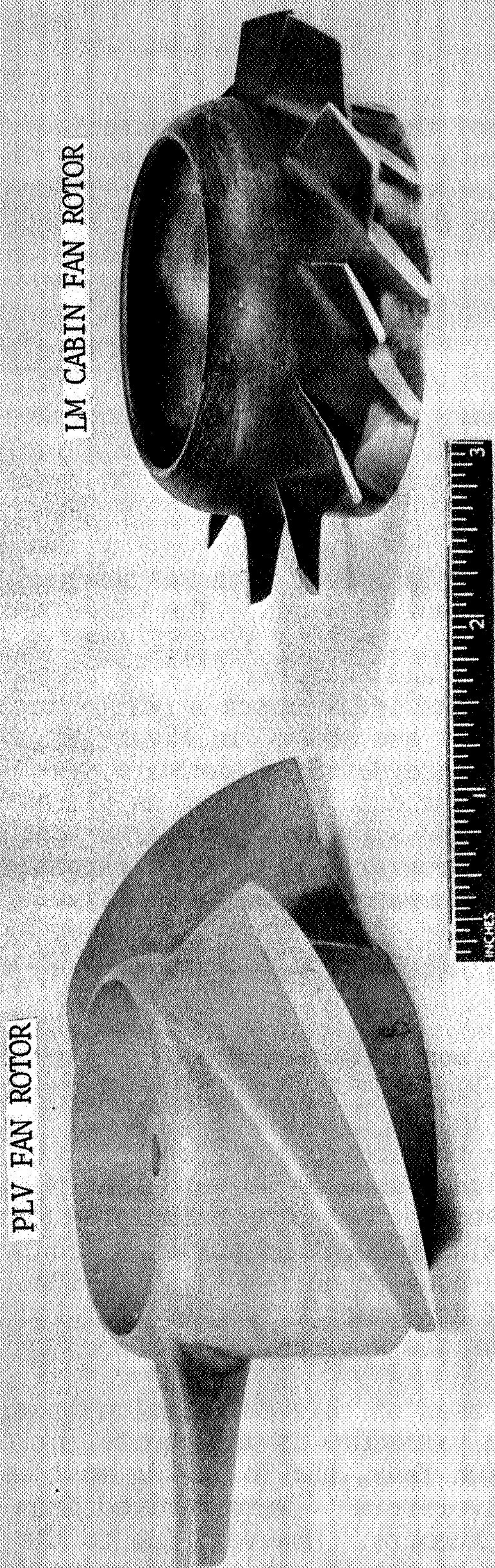
Preliminary Correlation

A preliminary correlation was undertaken using the coefficients from the propulsive fan. The initial correlation would provide a basis for determining the appropriate correlation factors for the ventilation fans tested in this program.

The LM cabin fan input data was derived based on the measured performance data and from layout drawings. The blade section drag coefficients were estimated by assuming a complete airfoil section and then adjusting it by using a factor from Smith and Schaefer [17] to account for the modified trailing edges which were machined off to match a performance requirement. This rotor along with the PLV rotor are shown in figure 42 and the stators and outer housings in figure 43. Since detailed hardware drawings for the PLV fan could not be obtained, the input data was based on dimensions derived from the test hardware blade and vane sections. Measured performance data was used as input to the computer program. It thus is expected that the calculations for the PLV fan are not as accurate as would be possible if dimensions from detailed drawings were available since rotor and stator blade design details such as twist, camber, and airfoil section could not be accurately determined.

Figures 44 and 45 show the preliminary correlation for the LM and PLV fans, respectively. It is seen from figure 44 that the tones are significantly underpredicted in the calculation. Also, the broad-band noise peaks at a frequency lower than measured. The velocity variations present in the wakes of the rotor blades show up as turbulent pulses coming from the trailing edges of the rotor. The noise calculated from the blade wake pulse amplitude modulation (PAM) component of noise is too low in level. Also, the rotor tones and broad-band do not contribute significantly to the calculated levels. Similar lack of agreement between calculated and measured levels may be seen in figure 45 for the PLV fan.

Although based on this correlation it would appear at first glance that the calculation procedure is inadequate for the calculation of noise from small ventilation fans, the following must be considered. The wake shapes measured by Silverstein [7] were derived from large scale airfoils operating at high Reynold's Numbers. However, due to the low tip speeds, small blade chords, and in the case of the LM cabin fan, reduced pressure operation, the blade tip section Reynold's Numbers were very low, approximately 130,000 for the PLV fan and 20,000 for the LM cabin fan, rather than 1,000,000 or higher typical of larger size airfoils. It is well known that reducing the airfoil section



PLV AND LM CABIN FAN ROTORS

FIGURE 42

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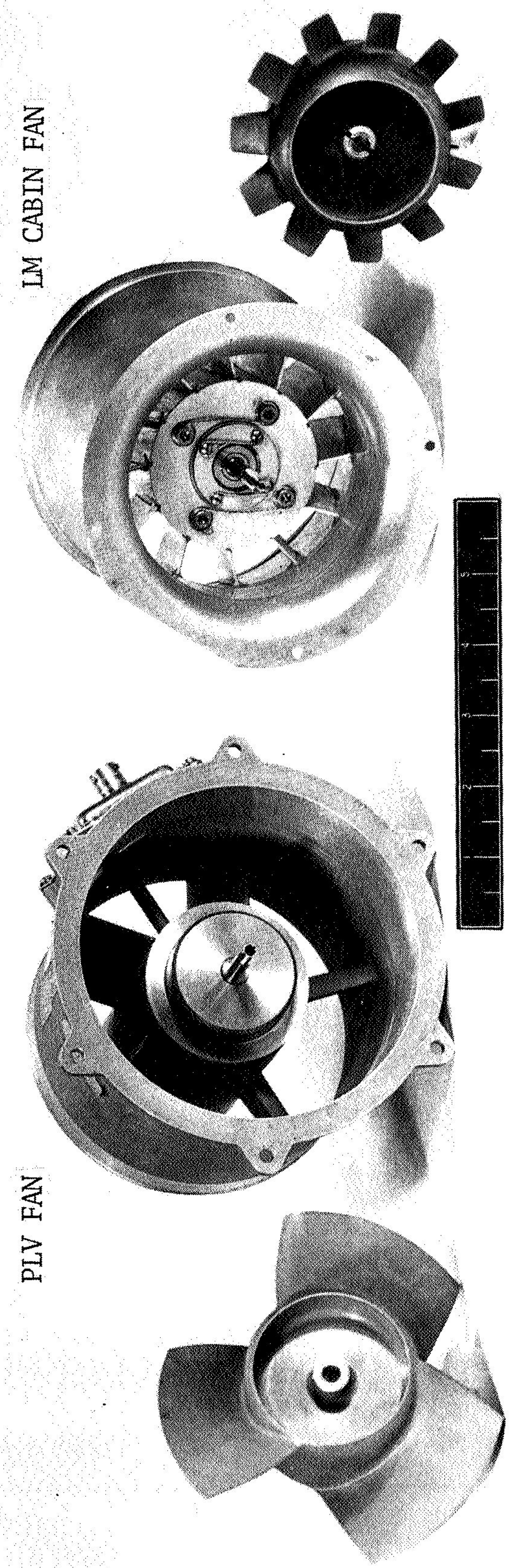

PLV AND LM CABIN FANS

FIGURE 43

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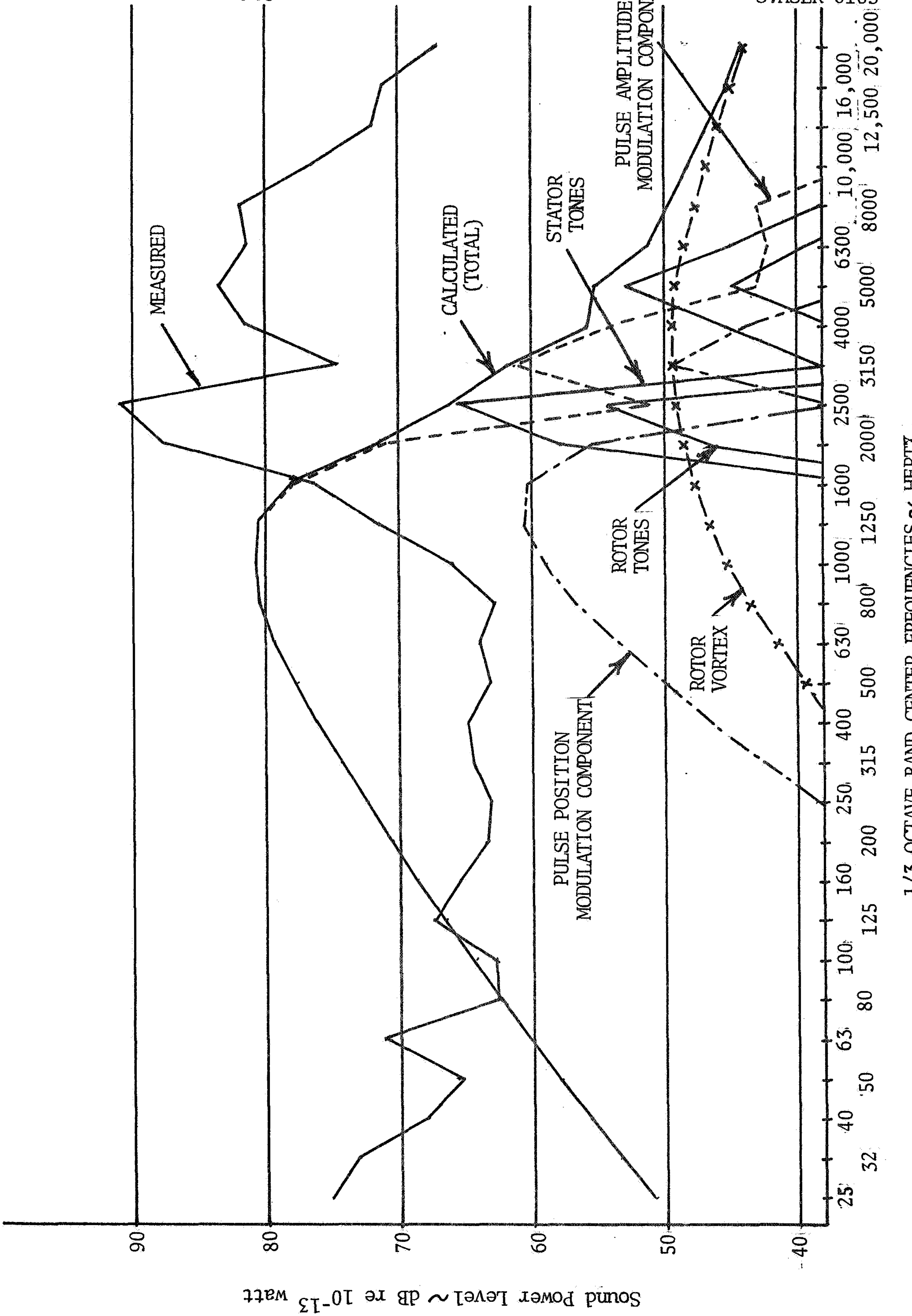
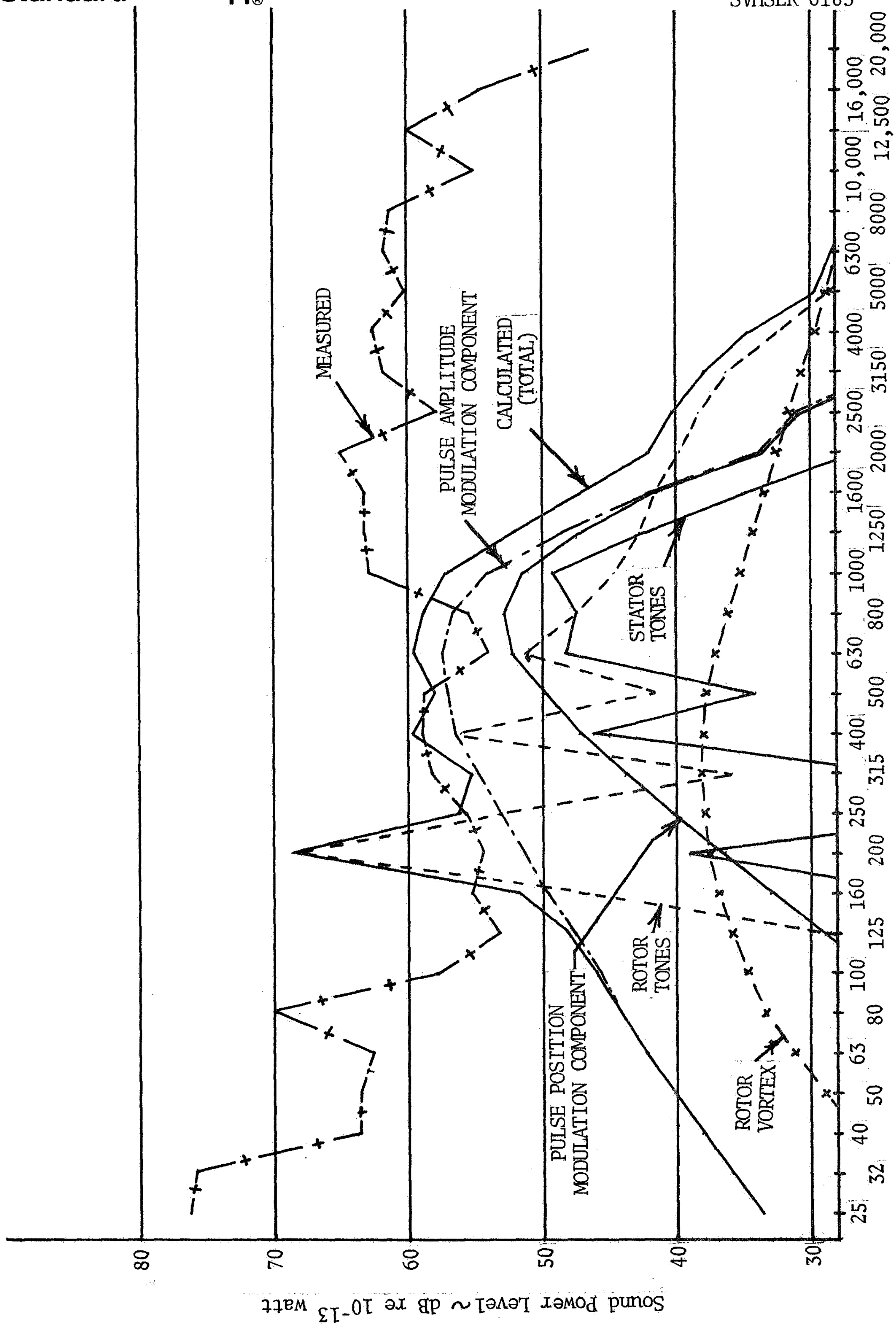


LM CABIN FAN - COMPARISON OF INITIAL PREDICTIONS WITH MEASURED NOISE

FIGURE 44



1/3 OCTAVE BAND CENTER FREQUENCIES ~ HERTZ

PLV FAN - COMPARISON OF INITIAL PREDICTIONS WITH MEASURED NOISE

FIGURE 45

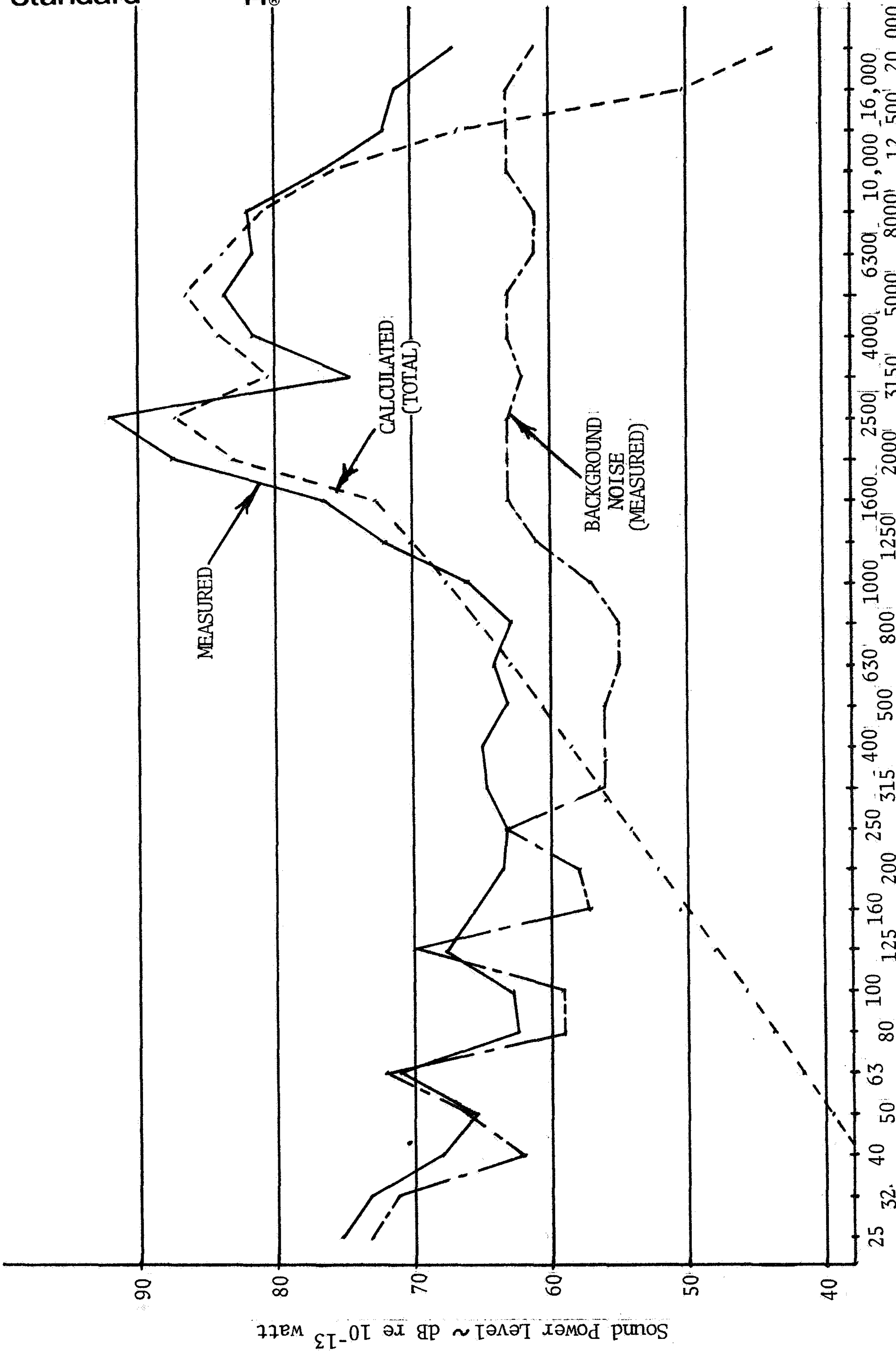
Reynold's Numbers results in an increase in profile drag, typically resulting in an increase by a factor of five for reducing the Reynold's Number from greater than 1,000,000 to approximately 100,000. Operation of an airfoil at this lower Reynold's Number would produce stronger wakes from the rotor blades. However, it is believed also that the wakes are narrower and more elongated at low Reynold's Numbers. These longer and narrower wakes would give rise to stronger higher frequency noise components than those measured for the typical propulsive fans operating with blade sections at high Reynold's Numbers. The narrower wakes would result in an increase in the amplitude of the stator tones and an increase in both the amplitude and the frequency of the stator broad-band noise components due to pulse position modulation. Reduction in the level of the stator broad-band noise components due to pulse amplitude modulation would also occur. As may be seen from figure 44, the above trends would improve the correlation between test and prediction for the LM cabin fan noise.

In the case of the PLV fan, a conspicuous disagreement appears between the predicted rotor tones and the measured level which indicates an absence of tones. The propulsive fan used to establish the empirical coefficients in the noise prediction method was run out-of-doors. In this environment, one would expect greater turbulence than in a quiet test chamber. However, the initial estimates of coefficients for the maximum non-uniform blade loading (see reference 14) were input to the computer program as 50 percent of the steady blade loading component - the same values as used for the outdoor propulsive fan. It is probable that the flow distortion was considerably less for the fan tested in the chamber , where considerable care was taken to insure undisturbed inflow to the fan.

Determination of New Coefficients

The correlation improvement effort consisted of determining the suitable factors defining the rotor wakes which best fit the LM cabin fan data. These were determined by an iterative process. The comparison using the final combination selected is shown in figure 46. It is seen from this figure that the correlation is within about ±5 dB over the mid frequency range. Note that both peaks in the measured spectrum are predicted. The lower frequency peak is slightly underpredicted while the higher frequency peak is slightly overpredicted. The low frequency noise in the test data appears to be mainly background noise.

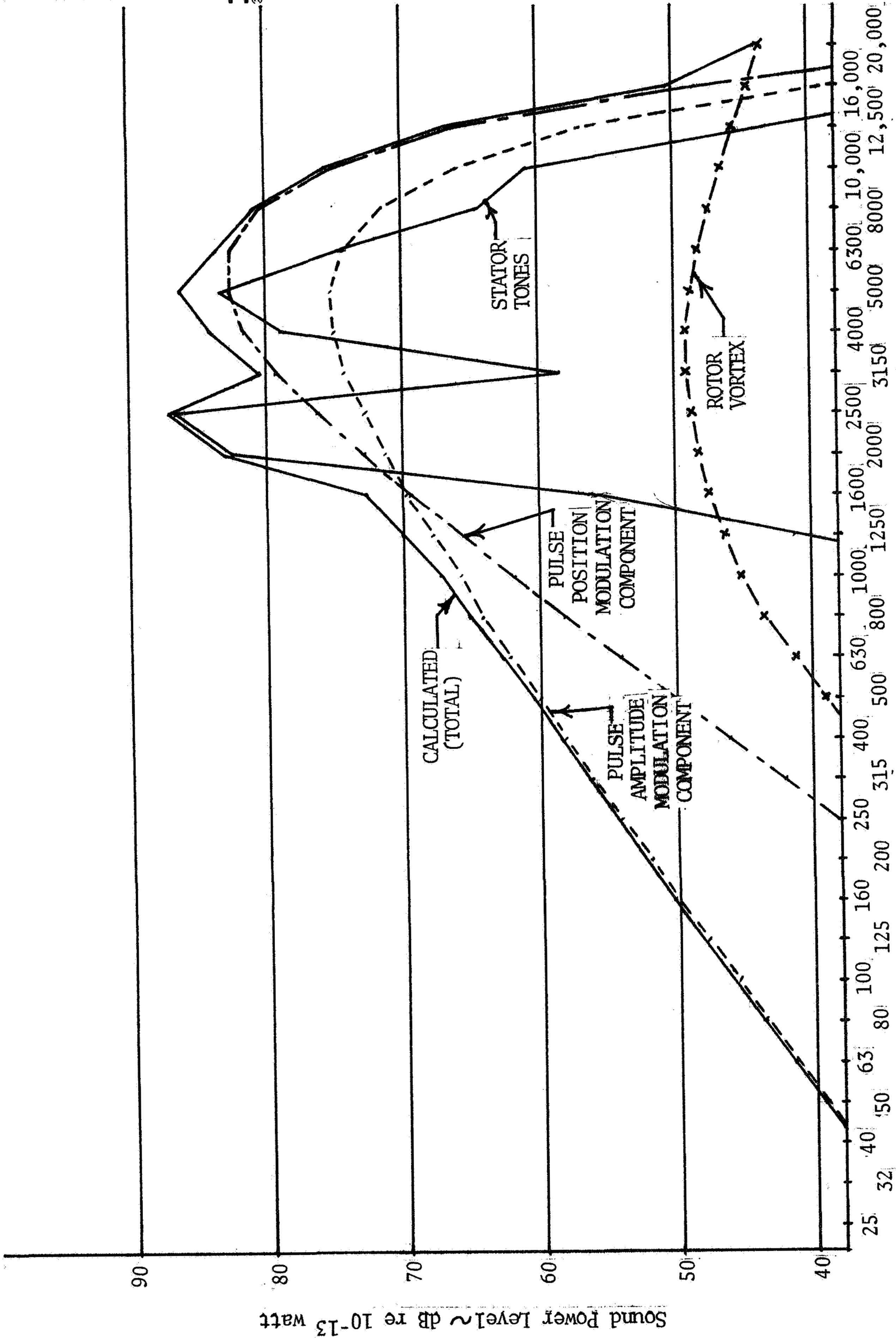
Figure 47 shows the several noise components which are calculated. The dominant noise source is predicted to be stator noise. The two peaks are the stator fundamental tone and a second harmonic. The high frequency broad-band noise appears to be due to the PPM component of the stator noise. Rotor noise contributed only at the very high frequencies where the stator noise has dropped substantially in level.



1/3 OCTAVE BAND CENTER FREQUENCIES ~ HERTZ

LM CABIN FAN - COMPARISON OF FINAL PREDICTIONS WITH MEASURED NOISE

FIGURE 46



LM CABIN FAN - PREDICTED TOTAL AND COMPONENT NOISE LEVELS

FIGURE 47

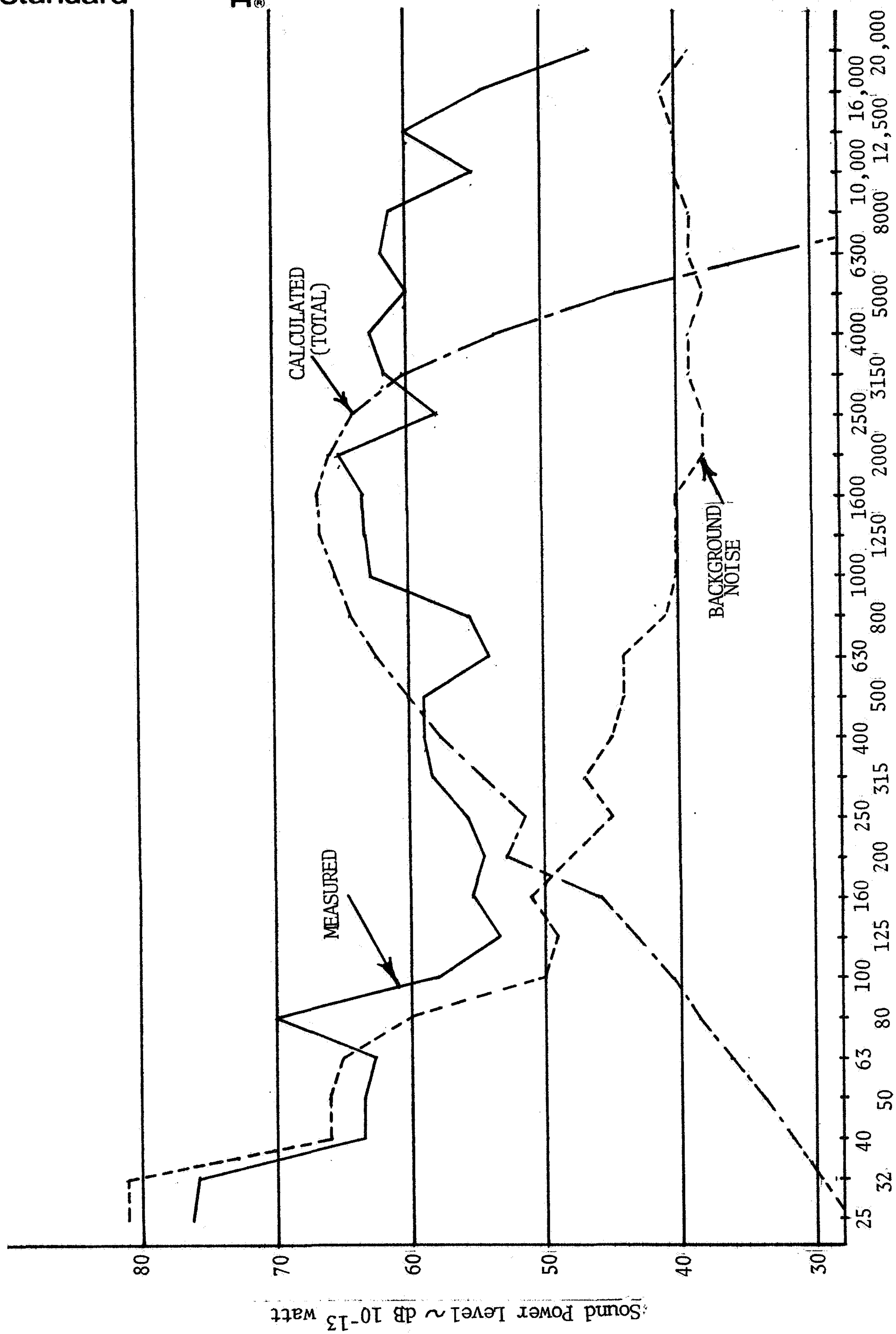
Since these coefficients were based on test data from a typical small ventilation fan, it would be expected that they would apply to other,similar fans. Thus the noise from the PLV fan was calculated using the same coefficients as were derived for the LM fan. The correlation, shown in figure 48, is not as good as was obtained from the LM fan. However the mid frequency noise, which is most important in rating annoyance of fan noise, is well predicted. The high frequency noise, above 4000 Hz, which is usually less important in annoyance rating, is significantly under predicted.

In order to improve the correlation, other noise sources which might be significant in this size fan were investigated. One possible source neglected in these calculations is that due to flow over the rotor blade airfoil trailing edges. A procedure developed by Chanaud and Hayden(18) was applied to the PLV fan, assuming a relative tip speed of 108 feet per second and a calculated boundary layer displacement thickness of 0.0112 feet. The results of the calculation are shown in figure 49. A similar calculation was performed for boundary layer radiation using the procedure developed by Mugridge and Morfey(19). The result of this calculation is summarized in figure 49 also. It is seen that neither of these sources adequately explains the measured high frequency noise levels of the PLV fan. Both predict levels which are significantly below the measured levels.

Since the high frequency noise of the PLV fan did not appear to be due to aerodynamic sources, mechanical sources were investigated. In order to assess the mechanical noise sources, the PLV fan motor was operated alone, that is without the fan rotor, at the same rotational speed as measured during the total fan assembly noise data acquisition. Octave band measurements of the motor noise were made at the same radius as for the total fan assembly. These measured sound pressure levels then were integrated into octave band sound power levels.

The motor sound power levels are summarized in figure 50, where they are compared to the total fan assembly noise levels previously measured. As this figure shows, the motor noise exhibits significant energy above 500 Hz; in fact, motor noise is seen to exceed the total fan noise levels in the 2000 Hz and 8000 Hz bands. Although the motor was not operating with the same loads during the isolated motor noise test as during the fan noise tests, the motor noise levels shown in figure 50 are considered representative.

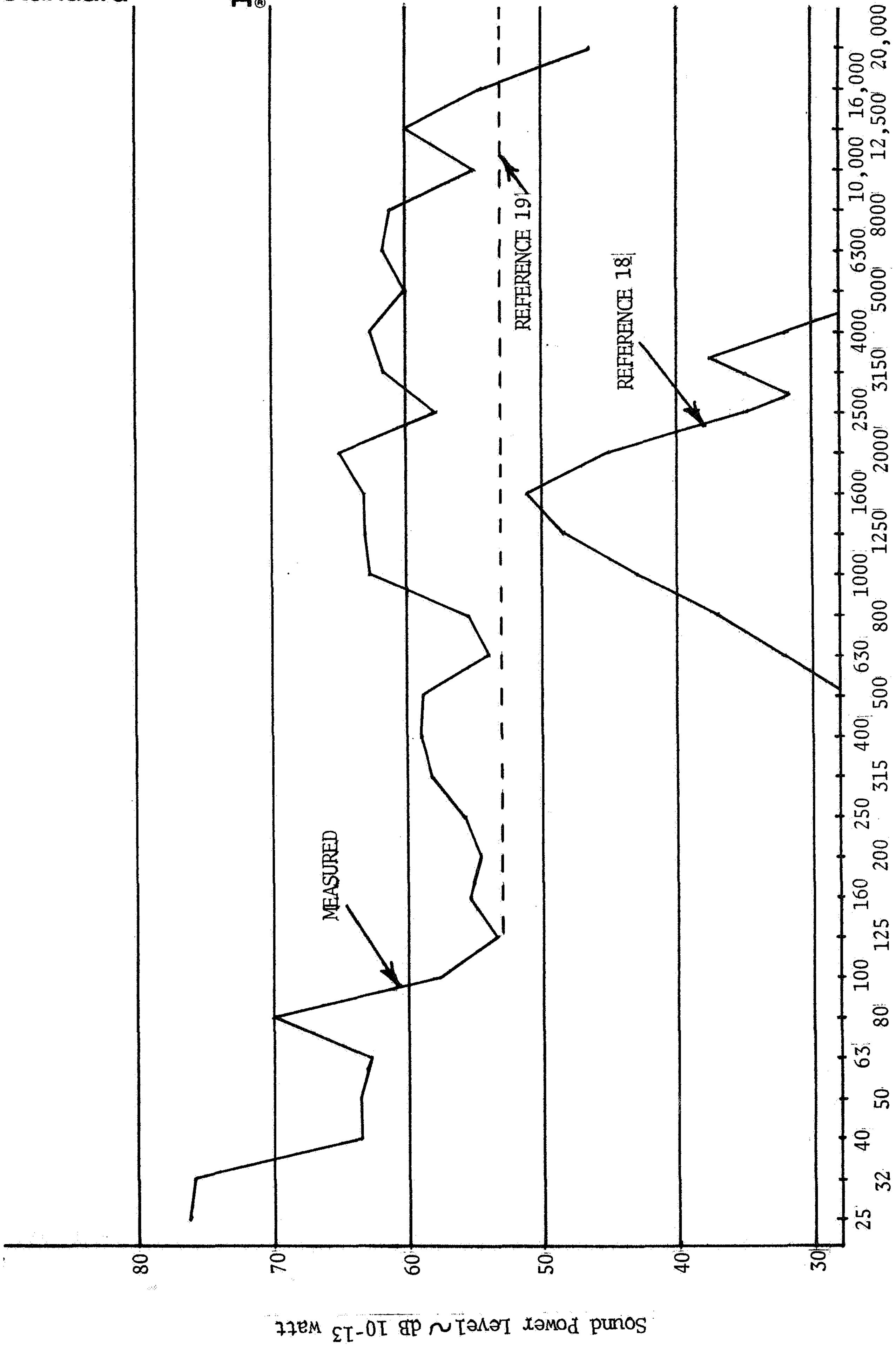
Figure 51 shows the measured total fan assembly noise, the calculated PLV fan aerodynamic noise (derived from figure 48), and the measured motor noise to define the components of the PLV fan noise. It is apparent from this figure that the mid frequency noise, between 250 Hz and 3000 Hz, is due to aerodynamic sources whereas the high frequency noise is due to mechanical sources, probably the motor bearings.



1/3 OCTAVE BAND CENTER FREQUENCIES ~ HERTZ

PLV FAN - CORRELATION OF PREDICTED AND MEASURED NOISE

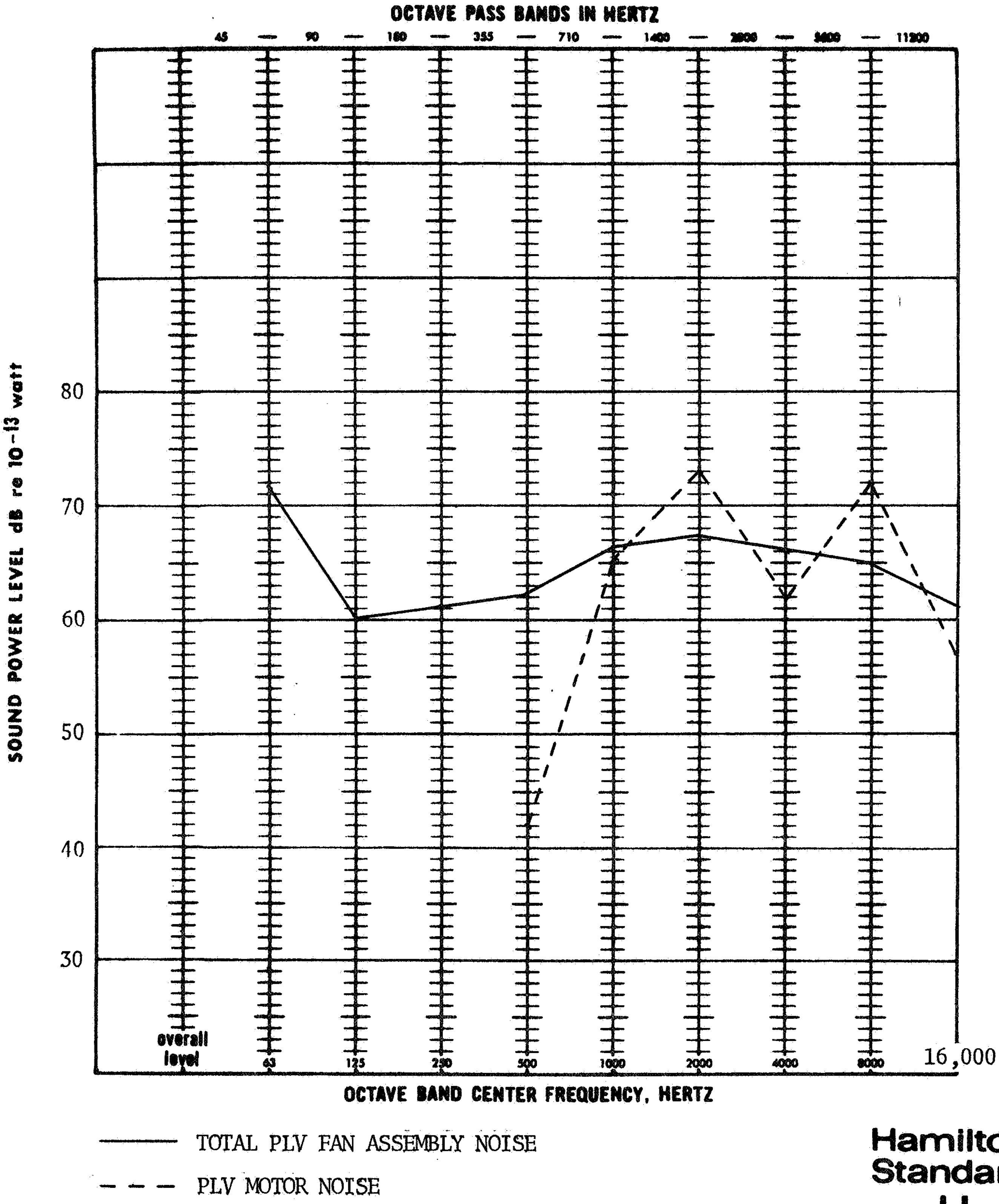
FIGURE 48



1/3 OCTAVE BAND CENTER FREQUENCIES ~ HERTZ

PLV FAN - COMPARISON OF NOISE SOURCES

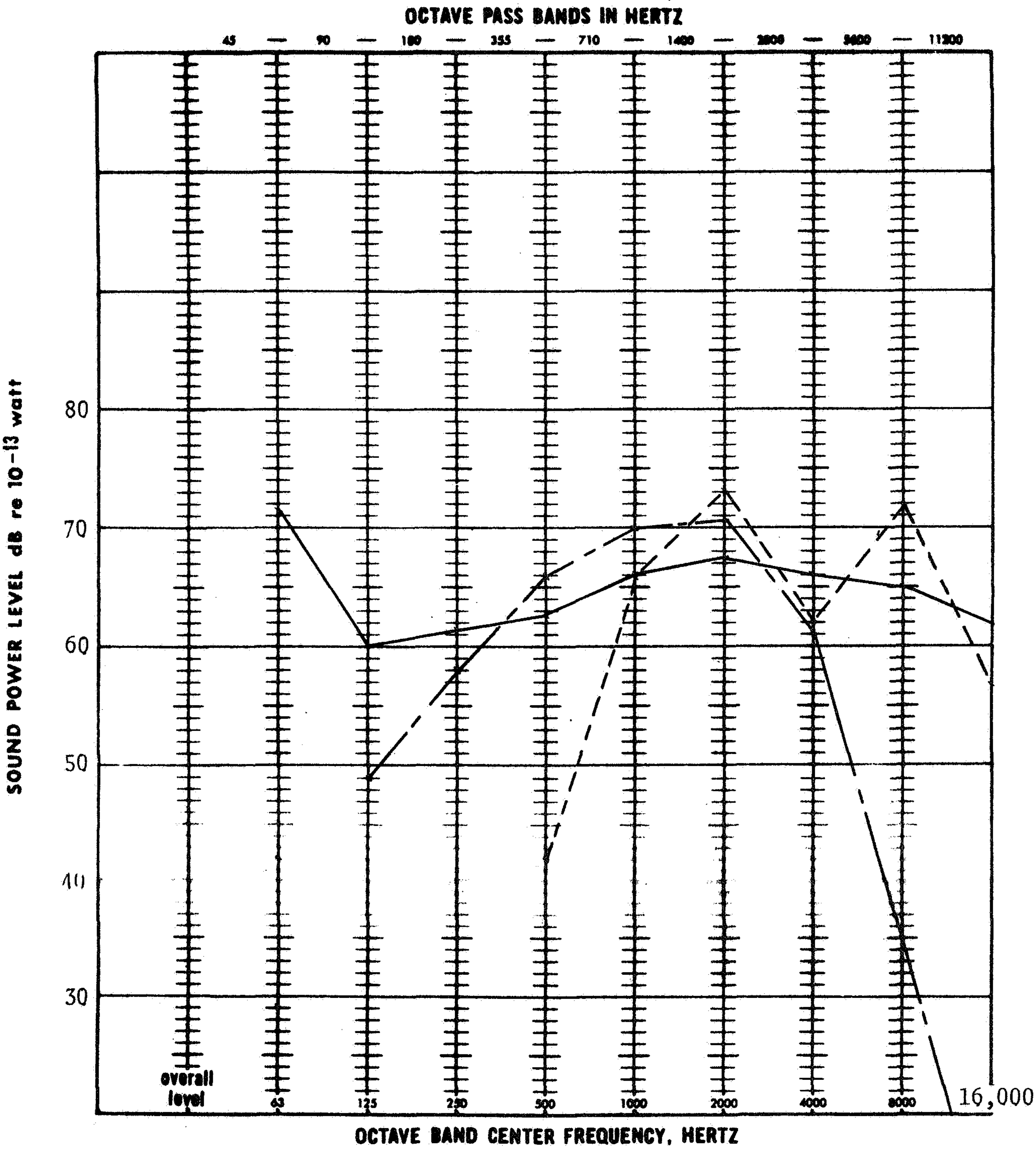
FIGURE 49



PLV FAN - COMPARISON OF MOTOR AND TOTAL NOISE
FIGURE 50

Hamilton Standard
DIVISION OF UNITED AIRCRAFT CORP.
OCTAVE BAND ANALYSIS

HSF 1070 8/69



——— TOTAL PLV FAN ASSEMBLY NOISE

— — — PLV MOTOR NOISE (DATA)

—— — —— PLV FAN AERODYNAMIC NOISE (ESTIMATE)

PLV FAN - SUMMARY OF NOISE SOURCES
FIGURE 51

Hamilton Standard
DIVISION OF UNITED AIRCRAFT CORP.

OCTAVE BAND ANALYSIS

HSF 1970 8/69

PRELIMINARY CONCEPT DEFINITION

To define fan and pump concepts for the Space Shuttle application a wide variety of commercial fans and pumps was selected for evaluation. For these units the supplier furnished hardware characteristics were combined with an estimate of unit noise to determine the most applicable candidate. The Hamilton Standard Empirical Fan Noise Estimating Procedure was used to estimate the noise of a variety of fans and compressors whose performance characteristics satisfy the Space Shuttle requirements. The preferred units then were purchased for noise evaluation, and modified to obtain noise reductions.

SPACE SHUTTLE EC/LS SYSTEM FAN AND PUMP REQUIREMENTS

The Space Shuttle EC/LS System fan and pump requirements were obtained from our on-going study effort performed by Hamilton Standard for North American Rockwell, Inc., the Shuttle Orbiter prime contractor. At this point in the program the performance requirements listed in Table IX were derived and were used to evaluate the preliminary concepts.

TABLE IX

PROJECTED SHUTTLE ECS FAN AND PUMP PERFORMANCE REQUIREMENTS

ITEM	FLOW	PRESSURE	ΔP	FLUID	NOISE LEVEL*
Cabin Fan	400 cfm	14.7 psia	2.5" H_2O	Air	NC 30
Avionics Fan	300 cfm	14.7 psia	4" H_2O	Air	NC 30
Waste Management Fan	75 cfm	14.7 psia	6.3" H_2O	Air	NC 30
Cabin Heat Transport Loop Pump	400 lb/hr	20 psia	20 psi	Water	NC 30

* Based upon requirements of Fan and Pump Noise Control Study.

IDENTIFICATION OF CONCEPTS

The cabin and avionics fan aerodynamic requirements are such that they can be met by the same unit. Since the cabin fan is most probably in closer proximity to the crew, its requirements were used for evaluation.

All types of fan and pump geometries are considered applicable to the identification of concepts except those having an obviously short life, such as flex hose (peristaltic) pumps. The Space Shuttle fans and pumps are intended to utilize a 208V, 400 Hz, 3 phase AC power source. As such, unit speeds in the range of 5,500 rpm to 22,000 rpm are anticipated. For these rotational speeds, the resultant specific speeds of the units indicate an axial flow cabin fan and a centrifugal flow waste management fan for high aerodynamic efficiency. Thus several units of these specific types were evaluated for the respective applications.

On this basis, the following candidate concepts were considered:

Cabin Fan

Axial Fans

- Low Speed (approximately 5500 rpm)
- Medium Speed (approximately 8000 rpm)
- High Speed (approximately 11,000 rpm and higher)
- 2-Stage

Centrifugal

Squirrel Cage

Waste Management Fan

Axial Fan

Centrifugal

- Backward Swept Blading
- Radial

Mixed Flow

Cabin Heat Transport Loop Pump

Gear

Turbine

Sliding Vane

Centrifugal

EVALUATION OF CONCEPTS

Suppliers were contacted and supplier catalogs were searched to obtain representative fan and pump units. A list of the companies who had prospective hardware in the required performance range is given in Table X.

TABLE X

LIST OF COMPANIES WITH PROSPECTIVE HARDWARE

IN REQUIRED PERFORMANCE RANGE

FAN COMPANIES
Dynamic Air Engineering, Inc. Eastern Industries General Dynamic/Electric Boat Globe Industries, Inc. Hamilton Standard, Division of United Aircraft Corp. Hartzell Propeller Fan Company IMC Magnetics Corp. Joy Manufacturing Company Lamb Electric Rotron Incorporated Torin Corp.
PUMP COMPANIES
Aurora Pump Cardinal Pump Sales, Inc. Dean Brothers Pumps, Inc. Dresser Industries, Inc. Eastern Industries Gast Manufacturing Corp. Globe Industries, Inc. Hypro, Inc. Micropump Corp. Oberdorfer Pump Division Roper Pump Company Tuthill Pump Company Vanton Pump & Equipment Corp. Vickers Aerospace Division W. H. Nichols Company

Cabin Fan Comparison

The various fans were compared by projecting weight and power to a flight status.

Motor weight was estimated using the following relationship derived from motors in the 200 watt output range - with a 70% efficiency.

$$\text{Motor Weight} = 1.0 \left(\frac{\text{Output Watts}}{100}\right) \left(\frac{12000}{\text{rpm}}\right) = \text{lbs}$$

Fan efficiencies were also projected to present state-of-the-art levels for each type of fan. All of the fans fall into a specific speed range close to that required for peak efficiency.

The efficiency of 50% for the squirrel cage fan represents present development status. Axial fans have been developed extensively for both aircraft and submarine use and hence 70% efficiency is attainable with present designs.

Table XI shows a comparison of estimated flight weight and power for the potential candidates. All of these fans have specific speeds in or near the good design range. Noise estimates for these fans were made and are shown in figure 52.

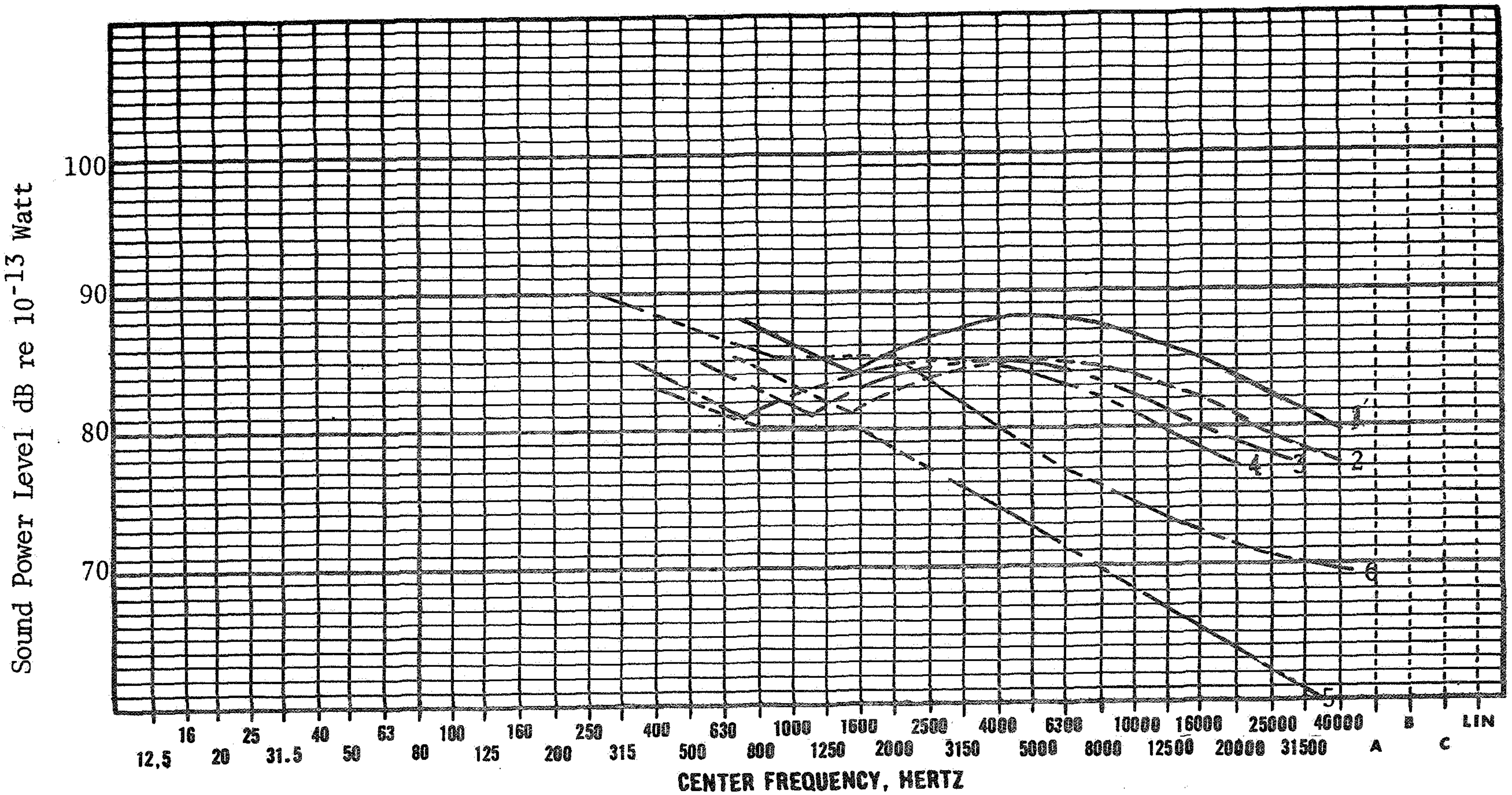
TABLE XI

PROJECTED FLIGHT DESIGN CABIN FAN COMPARISON

400 cfm and static ΔP of 2.5 inches H_2O

TYPE UNIT	SPEED rpm	ACTUAL SPECIFIC SPEED 1000 rpm	GOOD EFFICIENCY SPECIFIC SPEED RANGE 1000 rpm	FAN EFFICIENCY %	FAN INPUT POWER watts	WEIGHT FAN lbs	WEIGHT MOTOR lbs	WEIGHT TOTAL lbs
2 Stage Axial	11000	159	60-150	70	169	3.8	1.9	5.7
High Speed Axial	12000	113	60-150	70	169	3.6	1.7	5.3
Medium Speed Axial	7500	71	60-150	70	169	5.7	2.8	8.5
Low Speed Axial	5500	52	60-150	65	182	7.8	4.0	11.8
Squirrel Cage Centrifugal	3870	36	18-30	50	236	7.0	4.9	11.9
Radial Blade Centrifugal	3500	33	15-50	70	169	12.5	5.9	18.4

This initial comparison indicates the high speed axial to be favored from a weight and power standpoint. However, the squirrel cage appears to be superior from a noise standpoint.



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE FAN 1 CANDIDATES: BUFFALO FORGE METHOD

Test Date ______ Run No. ______

Mic Location ______ Reel No. ______

Analysed By ______ Identification No. ______

Analysis Method ______ Sheet ____ of ____

Comments, Sketches, Etc.

1 2-Stage Axial, 11,000 rpm
2 High Speed Axial, 12,000 rpm
3 Medium Speed Axial, 7500 rpm
4 Low Speed Axial, 5500 rpm
5 Squirrel Cage, 5800 rpm
6 Centrifugal, 5500 rpm

FIGURE 52

Waste Management Fan Comparison

The waste management fan must produce a higher head at lower flows than does the cabin fan. This dictates a centrifugal fan to operate in a good specific speed regime at practical motor speeds. A comparison of various concepts considered is shown in Table XII.

TABLE XII

FLIGHT DESIGN WASTE MANAGEMENT FAN COMPARISON

75 cfm and static ΔP of 6.3 inches H_2O

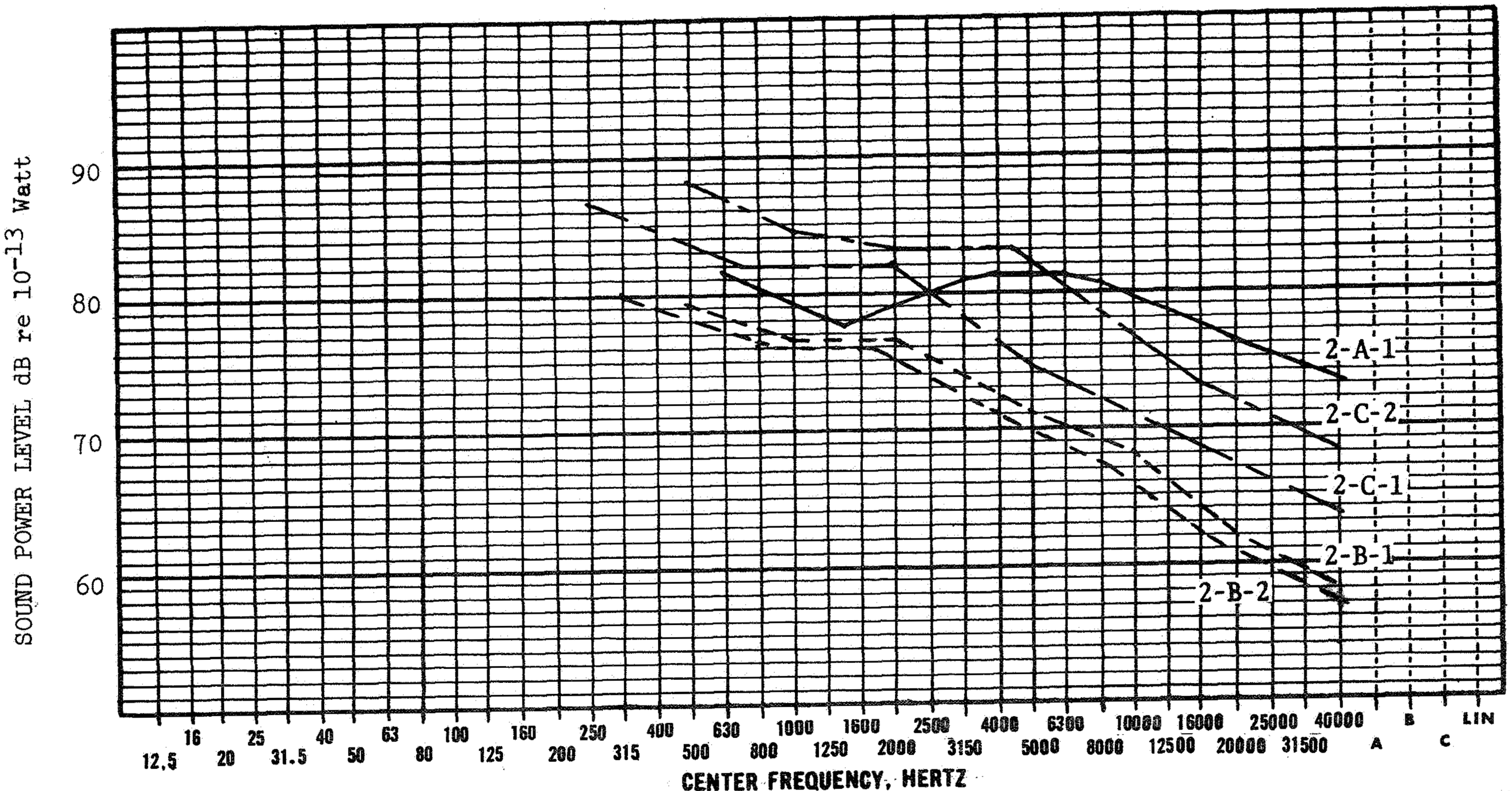
TYPE UNIT	SPEED rpm	ACTUAL SPECIFIC SPEED 1000 rpm	GOOD EFFICIENCY SPECIFIC SPEED RANGE 1000 rpm	FAN EFFICIENCY %	FAN INPUT POWER watts	WEIGHT		
						FAN lbs	MOTOR lbs	TOTAL lbs
Centrifugal High Speed	11500	15.9	15-50	70	80	2.8	1.2	4.0
Centrifugal Low Speed	3500	4.8	15-50	55	101	9.2	5.2	14.4
Mixed Flow	15000	20.7	20-70	60	93	2.2	1.1	3.3
Axial	23000	31.7	60-150	50	111	1.4	0.9	2.3
Squirrel Cage	7700	10.6	15-30	40	139	4.2	3.2	7.4

For the above table

$$\text{Motor Weight} = 1.5 \left(\frac{\text{watts}}{100}\right)\left(\frac{12000}{\text{rpm}}\right) .$$

This relationship is based on data from motors in the 100 watt range.

Noise predictions for the waste management unit fans are shown in figure 53. Once again it appears that the squirrel cage fan has a distinct advantage in noise level. The mixed flow and centrifugal fans are best from the standpoint of weight and power.



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE FAN 2 CANDIDATES: BUFFALO FORGE METHOD

Test Date ______ **Run No.** ______

Mic Location ______ **Reel No.** ______

Analysed By ______ **Identification No.** ______

Analysis Method ______ **Sheet** ___ **of** ___

Comments, Sketches, Etc.

2-A-1	1 Stage Axial, 11,500 rpm
2-B-1	Squirrel Cage, 7700 rpm
2-B-2	Squirrel Cage, 5450 rpm
2-C-1	Centrifugal, 3500 rpm
2-C-2	Centrifugal, 8700 rpm

FIGURE 53

Liquid Loop Pump Evaluation

As previously noted, pump noise measurements conducted earlier in this program reflected mostly motor noise. However, assuming the motor noise does not dominate, relative pump noise levels were predicted on the basis of larger industrial pumps. The ranking of pump concepts in order of increasing noise is centrifugal, diaphragm, screw, sliding vane, and gear. Although no data exists on isolated pumps of the size required for this program, the above ranking is considered valid since the noise sources for these types of pumps are understood. Table XIII presents the noise estimate of these pumps relative to a baseline centrifugal unit.

TABLE XIII

RELATIVE PUMP NOISE LEVELS

PUMP TYPE	RELATIVE NOISE
Centrifugal	Baseline
Diaphragm	+5dB
Screw	+8dB
Sliding Vane	+10dB
Gear	+15dB

Since the centrifugal pump was estimated to be the quietest, several of this type of pump were included in the selected candidates.

Table XIV lists the various pumps and characteristics.

TABLE XIV

CABIN HEAT TRANSPORT LOOP PUMP CANDIDATES
500 lbs/hr and ΔP = 20 psi

TYPE UNIT	SPEED rpm	WEIGHT lbs	VOLUME in^3	POWER watts
Centrifugal	10,000	2.5	30	150
Centrifugal	7,600	2.7	53	150
Centrifugal	3,450	2.9	60	200
Gear	1,800	3.9	61	150
Turbine	3,500	4.7	74	150
Sliding Vane	1,800	3.5	55	150

SELECTION OF TEST HARDWARE

The original program plan had been to select a single cabin fan and a single waste management fan for test verification of noise predictions and further improvement. However, selection of a clear winner was not possible. The fans with the highest efficiency were also predicted to be substantially noisier than the less efficient squirrel cage fan.

In keeping with the objectives of the program to achieve efficient operation with low noise and to establish design criteria for quiet operation, testing of the quietest unit was considered important. On this basis the NASA and Hamilton Standard concluded that verification testing be done on two different types of cabin fans rather than a cabin fan and a waste management fan. With this approach, a comparison of the noise sources could be made for two different types of fans with the same flow and pressure rise capabilities.

Pump selection was straight forward since the lowest noise design was also light and efficient.

PROCUREMENT OF VERIFICATION HARDWARE

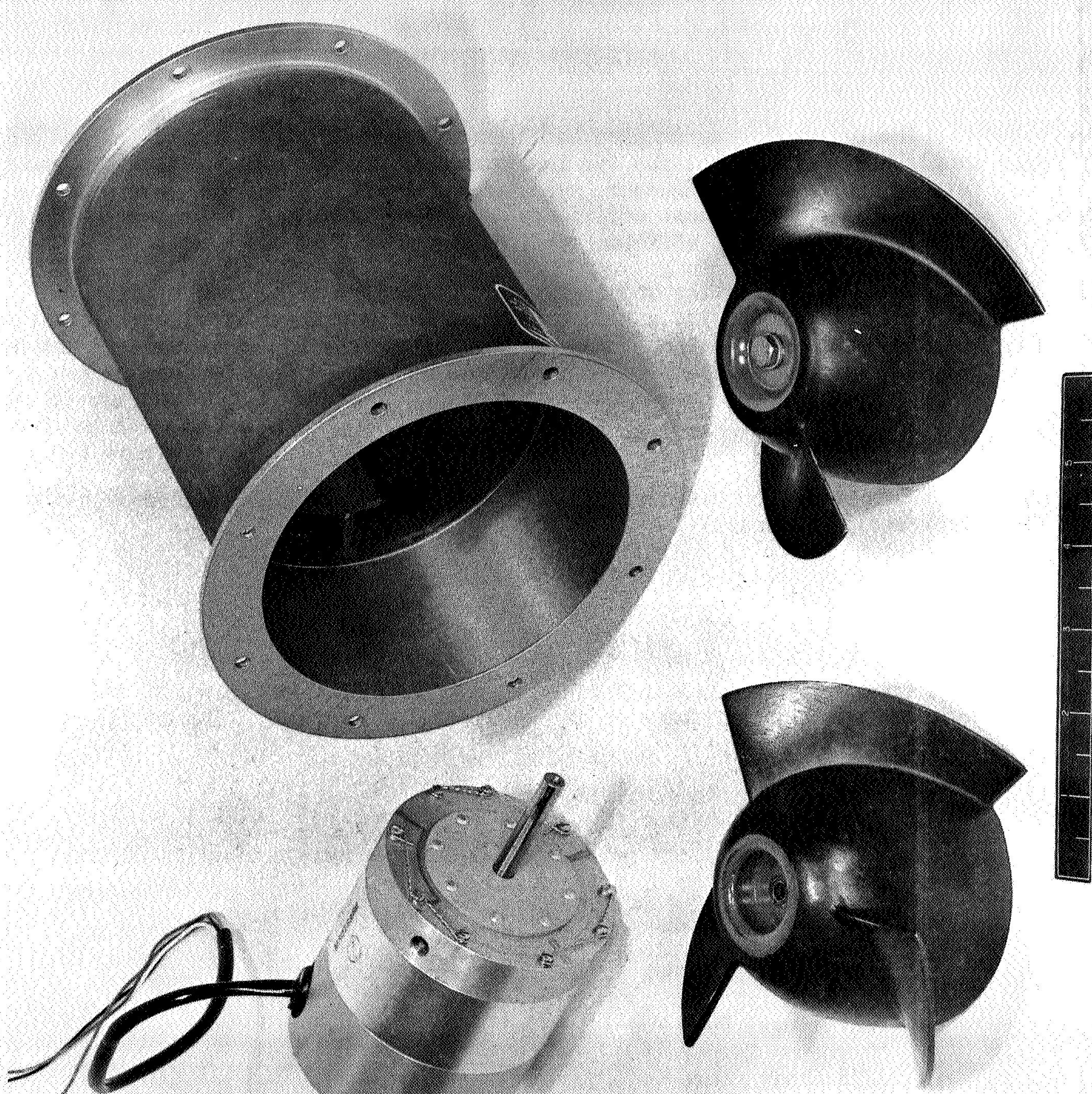
The data presented in Tables XI and XIV determined which units were selected for purchase of the verification hardware. The units purchased were the following

- Axial Fan - Model M5171B - 1A
  Dynamic Air Engineering, Inc.
  620 East Dyer Road
  Santa Ana, California 92705

- Squirrel Cage Fan - Simplex Unit PS-502
  Rotron, Incorporated
  Woodstock, New York

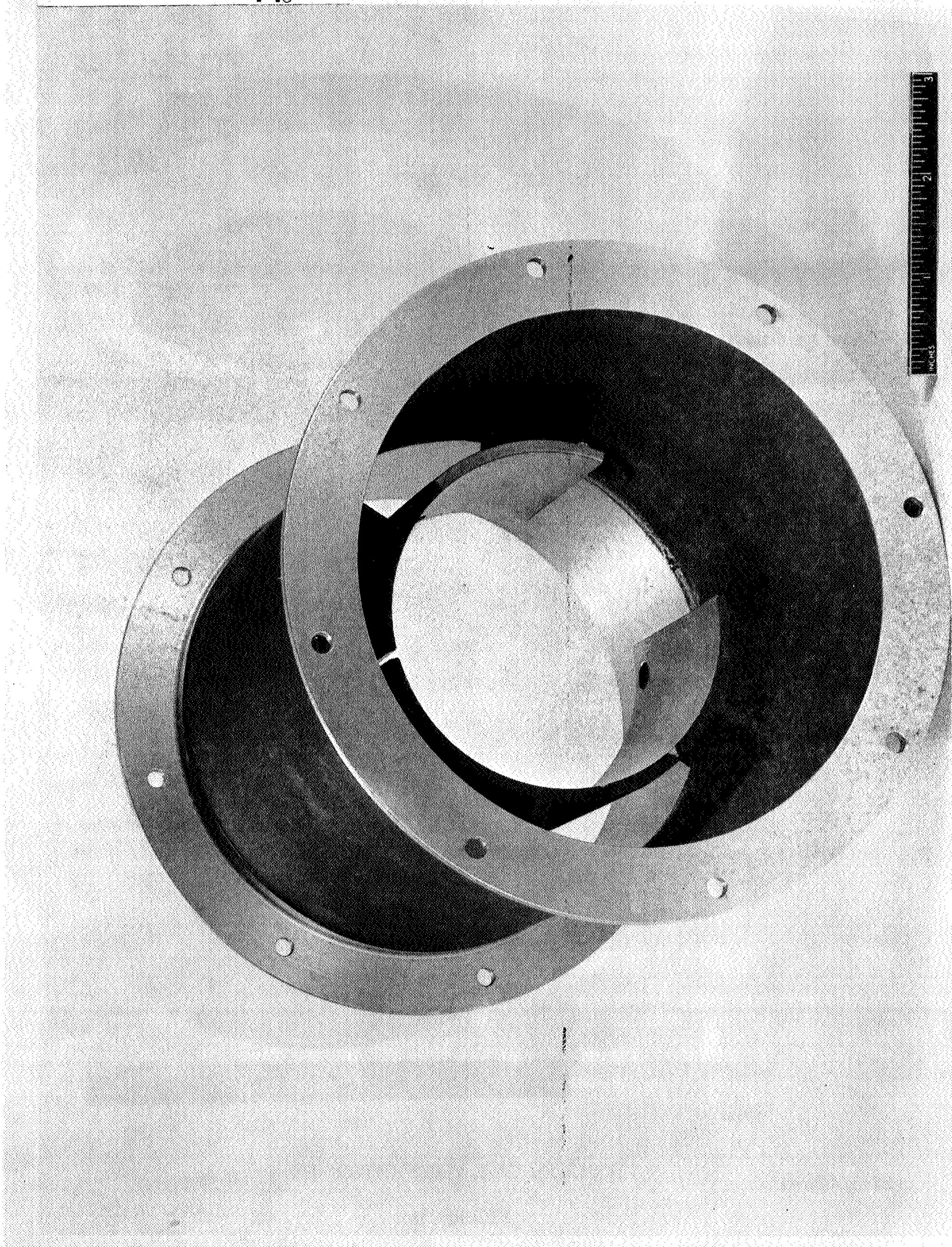
- Centrifugal Pump Model 10-70-316
  Micropump Corporation
  1021 Shary Court
  Concord, California

Photographs of the hardware in the "as received" condition are shown in figures 54 through 58.



DISASSEMBLED AXIAL FLOW FAN AND EXTRA ROTOR
FIGURE 54

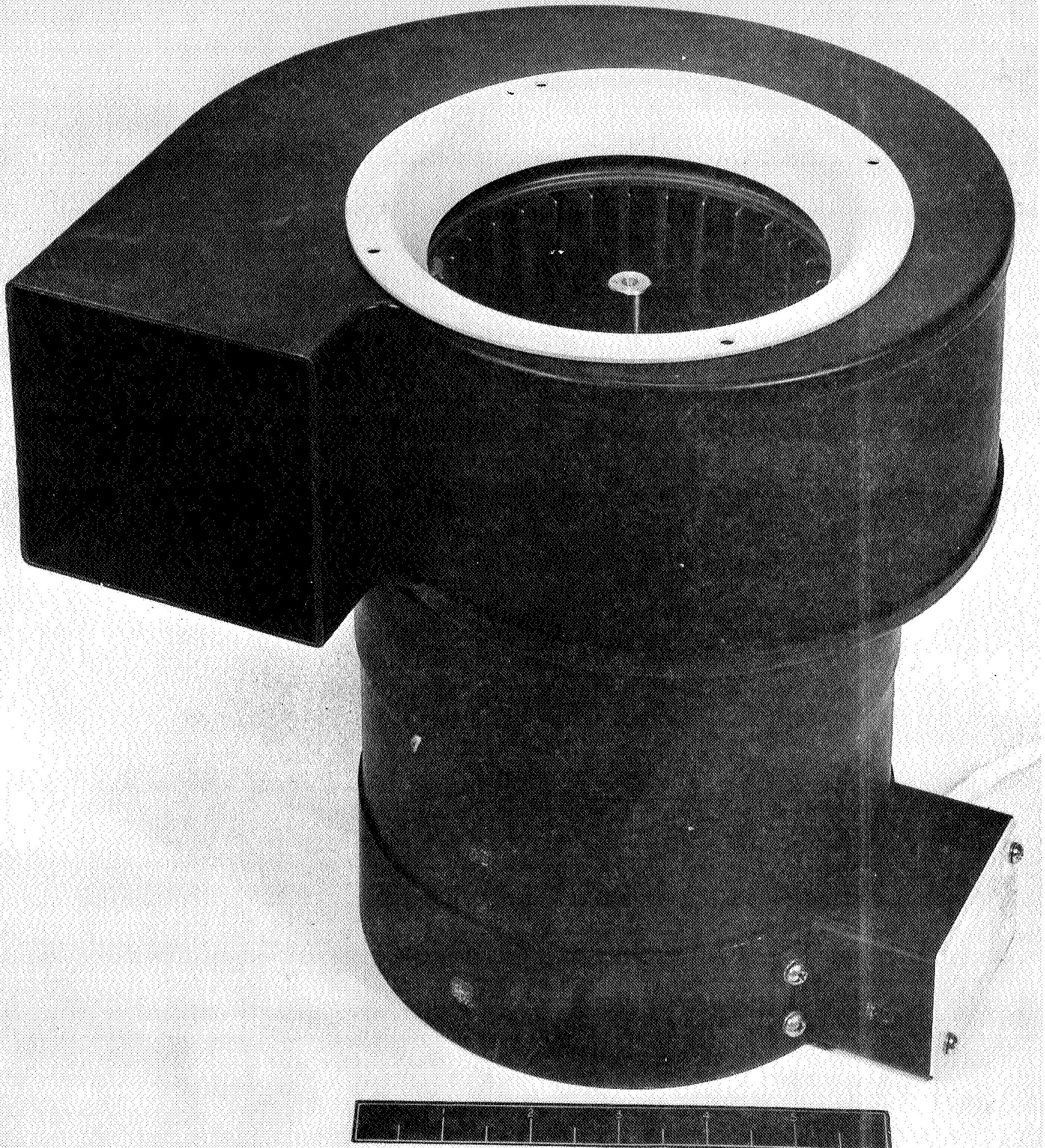
SS 10619-4



AXIAL FAN HOUSING

FIGURE 55

SS 10620-4



SS 10624-4

SQUIRREL CAGE VERIFICATION FAN

FIGURE 56

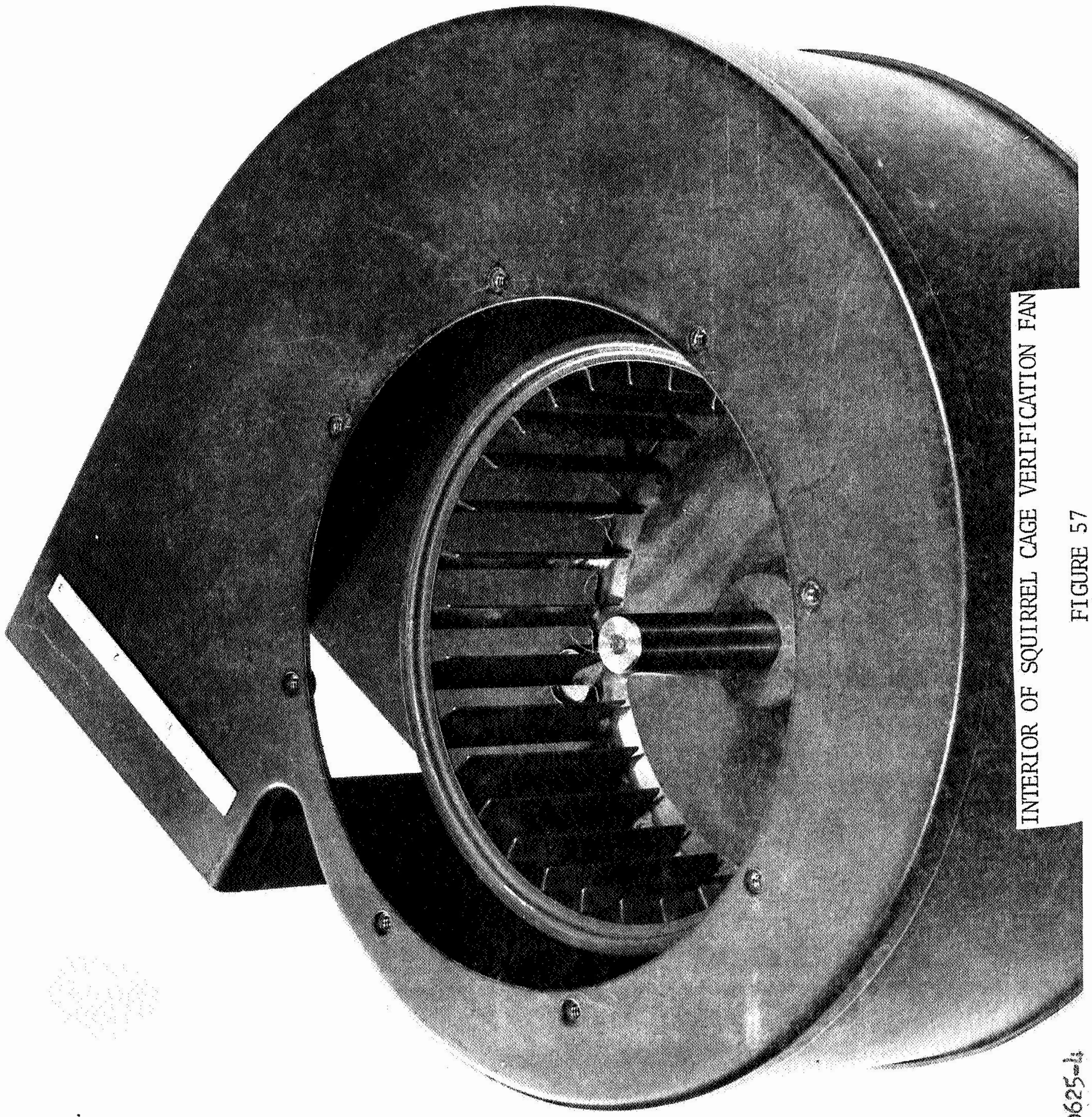
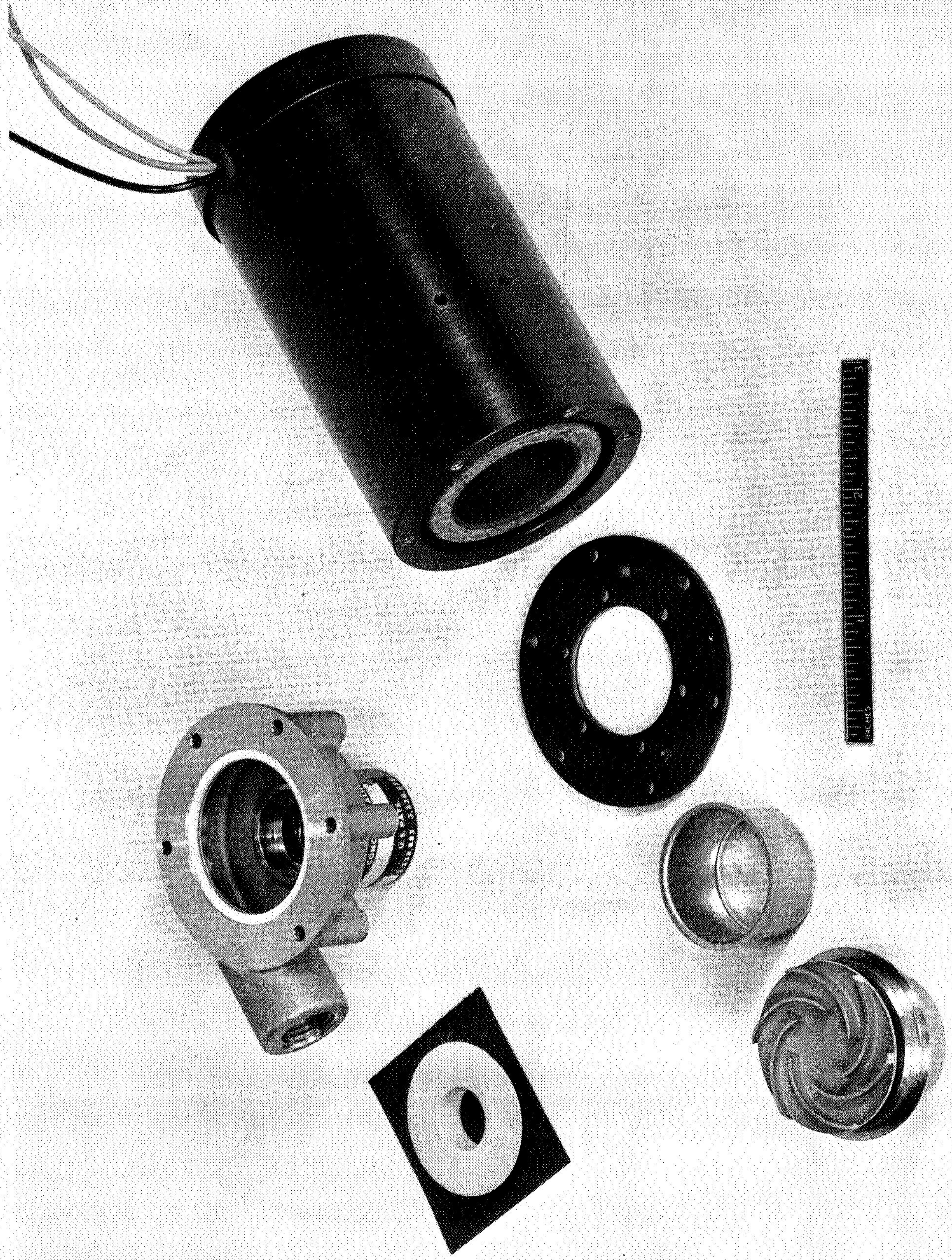


FIGURE 57

INTERIOR OF SQUIRREL CAGE VERIFICATION FAN

SS 10625-4



DISASSEMBLED VERIFICATION CENTRIFUGAL PUMP

FIGURE 58

SS 10621-4

Figures 54 and 55 show the axial fan and housing. Both a two-bladed and three-bladed rotor were purchased. Figures 56 and 57 are photographs of the squirrel cage unit. Figure 58 shows the centrifugal pump in a disassembled state.

VERIFICATION HARDWARE TEST PROGRAM

There were three purposes for this test program. The first was to show further correlation of the noise estimated by the Hamilton Standard Empirical Fan Noise Estimating Procedure with noise measured for commercial units. Acoustic noise measurements were made on the two purchased fans and on the single pump in their "as received" condition to establish baseline noise levels of commercial off-the-shelf hardware. The second purpose was to isolate, identify, and analyze the source characteristics of the fan and pump noises. The purpose of this analysis was to derive and design modifications to reduce or eliminate these noise sources. Finally, the third purpose was to demonstrate the actual noise reduction and performance improvement achieved from the hardware modifications.

BASELINE TESTS

Test Hardware Description

The two fans and one pump tested in this phase of the program were a Dynamic Air axial flow fan, Rotron squirrel cage fan, and Micropump centrifugal water pump. These were selected as a result of the Preliminary Concept Definition study described in the previous section.

The axial fan was tested with a three-bladed and a two-bladed rotor.

The motors driving these three units were tested alone also.

The disassembled Dynamic Air Engineering model M5171B-1A axial flow fan with both its rotors is shown in figure 54. The rotors are 5.25 inches in diameter and have 0.070 inches constant thickness blades. These are driven by a 208 VAC, 3 phase, 400 Hz motor running at a speed of approximately 12,000 rpm, which is supported by five unevenly spaced constant thickness case diffuser vanes. The diffuser vanes can be seen more clearly in figure 55. The diffuser's inside diameter is 3.75 inches and the outside diameter is 5.25 inches.

The spacing between the rotor blades and diffuser vanes is 0.45 inches and rotor tip clearance is 0.050 inch. The overall length is 7.5 inches and the weight is seven pounds.

Figures 56 and 57 show the Rotron, Incorporated, model PS-502 squirrel cage fan. The rotor has thirty, 0.030 inch thick, forward curved sheet metal blades with a 4.5 inch inside diameter, 5.25 inch outside diameter and 2.25 inch length. This is driven by a 115 VAC, single phase, 400 Hz motor running at a speed of 3870 rpm. The rotor discharges into a 3.5 inch wide increasing area collecting scroll which has a 3.5 by 3.5 inch discharge. The cutwater is located 7/16 inch from the 5.25 inch rotor, yielding a clearance to diameter ratio of 8 percent. The test unit was 10 inches long and weighed thirty pounds.

The disassembled Micropump Corporation model 10-70-316 centrifugal pump is shown in figure 58. The six bladed backward swept blades are 0.075 inches high and fluid discharges from their 1.30 inch outside diameter into an increasing area collecting scroll with a cutwater 0.050 inches from the rotor. A teflon thrust plate with a 1/2 inch inside diameter entrance port rests on the rotor blades. The rotor is magnetically coupled to a 208 VAC, three phase, 400 Hz motor which drives the pump at approximately 9000 rpm. The overall length is 5.25 inches and the weight is 2.5 pounds.

Test Facility Description

All testing was conducted in Hamilton Standard's anechoic chamber. This chamber has a volume of approximately 3000 cubic feet and provides an essentially free field environment at distances of up to five feet from the source for frequencies over the range of 90 to 6000 Hz. The background noise in the test chamber is below 17 dB over the frequency range of 90 to 11,200 Hz, as measured by octave bands. Since this level is 10 or more dB below the octave band levels of the design goal of NC-30, background noise levels in the test environment are not considered a problem.

In order to isolate the fan inlet and exhaust noise levels, a plywood acoustic muffler was constructed. This muffler, internally lined with sound absorbing polyurethane open cell foam, was attached to the fan inlet or discharge by means of a six foot long duct. Also, a sliding door was provided at the muffler inlet to control the flow and pressure drop to the fan. The ducts were externally covered with fiberglass and lead impregnated vinyl to eliminate noise transmission through the duct walls.

In addition to the anechoic chamber the test facility consists of the control room and an outdoor motor/generator and voltage controller. The generator output is fed into the power console located in the control room. Here, voltage and current were measured. The control room also contained the pump water reservoir, back pressure valve, flow meter and appropriate temperature and pressure measurements. The water lines and electrical lines passed through a sealed passage into the anechoic chamber where the remaining instrumentation and facilities were located. The pump inlet and outlet pressure gages were placed in an isolated location of the chamber. All the fan pressures were measured on a portable manometer board, placed approximately ten feet away from the fan. The fan inlet temperature measurement was made with a portable thermocouple while the fan speed was measured with a stroboscope.

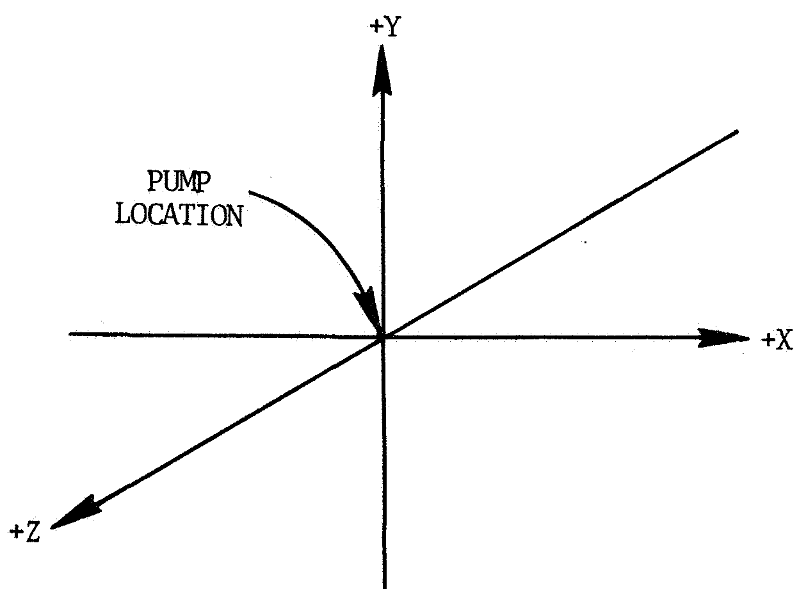
Test Description

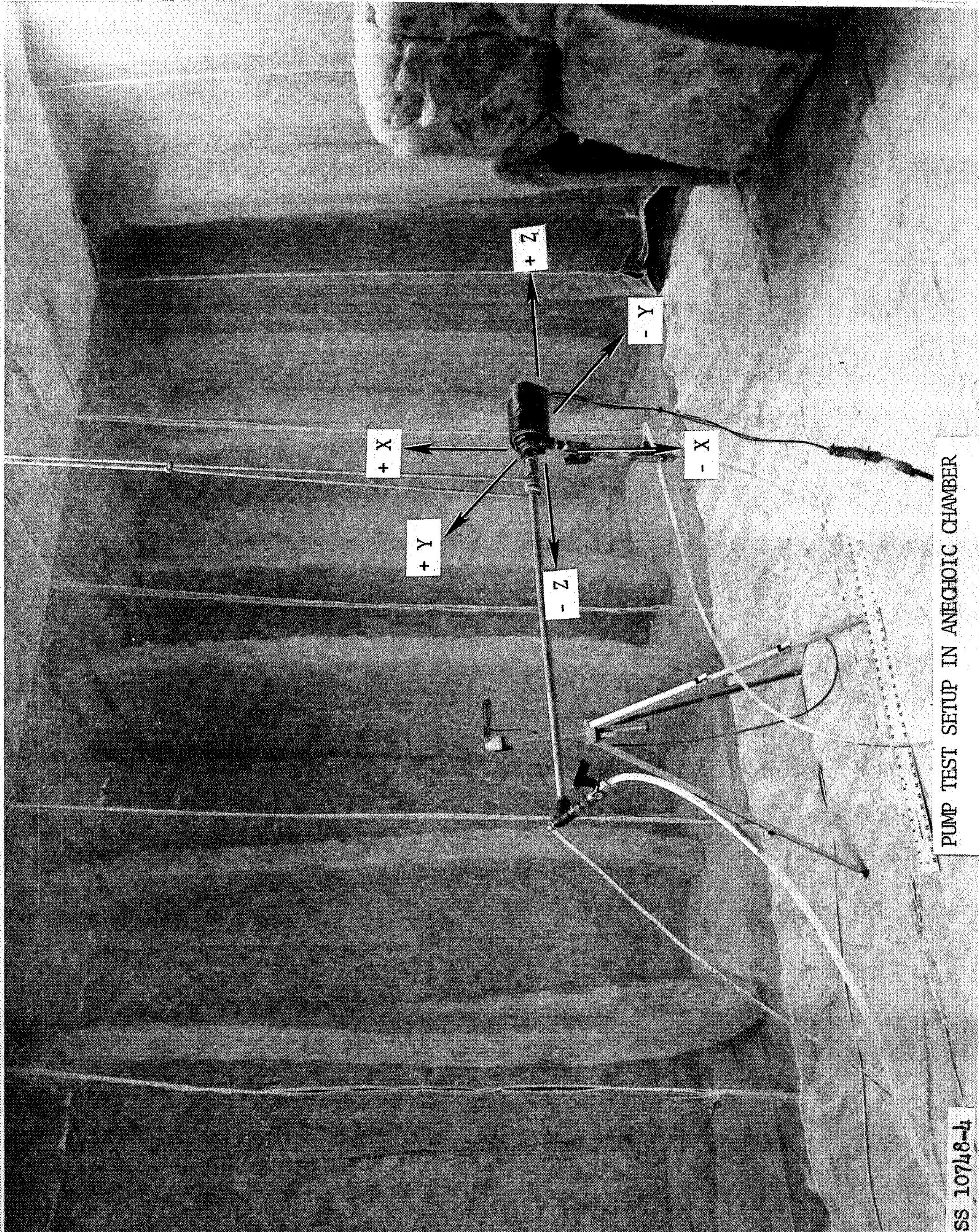
The pump was suspended at the approximate center of the chamber by Bungee cord at approximately three feet above the floor as shown in figure 59. Noise measurements were made at three feet from the center of the pump, at the 20 equally spaced locations defined in Table XV.

TABLE XV

CARTESIAN COORDINATES OF PUMP MICROPHONE LOCATIONS - FEET

X	Y	Z
0	2.79	±1.08
1.74	1.74	±1.74
2.79	1.08	0
1.08	0	±2.79
2.79	-1.08	0
1.74	-1.74	±1.74
0	-2.79	±1.08
-1.74	-1.74	±1.74
-2.79	-1.08	0
-1.08	0	±2.79
-2.79	1.08	0
-1.74	1.74	±1.74

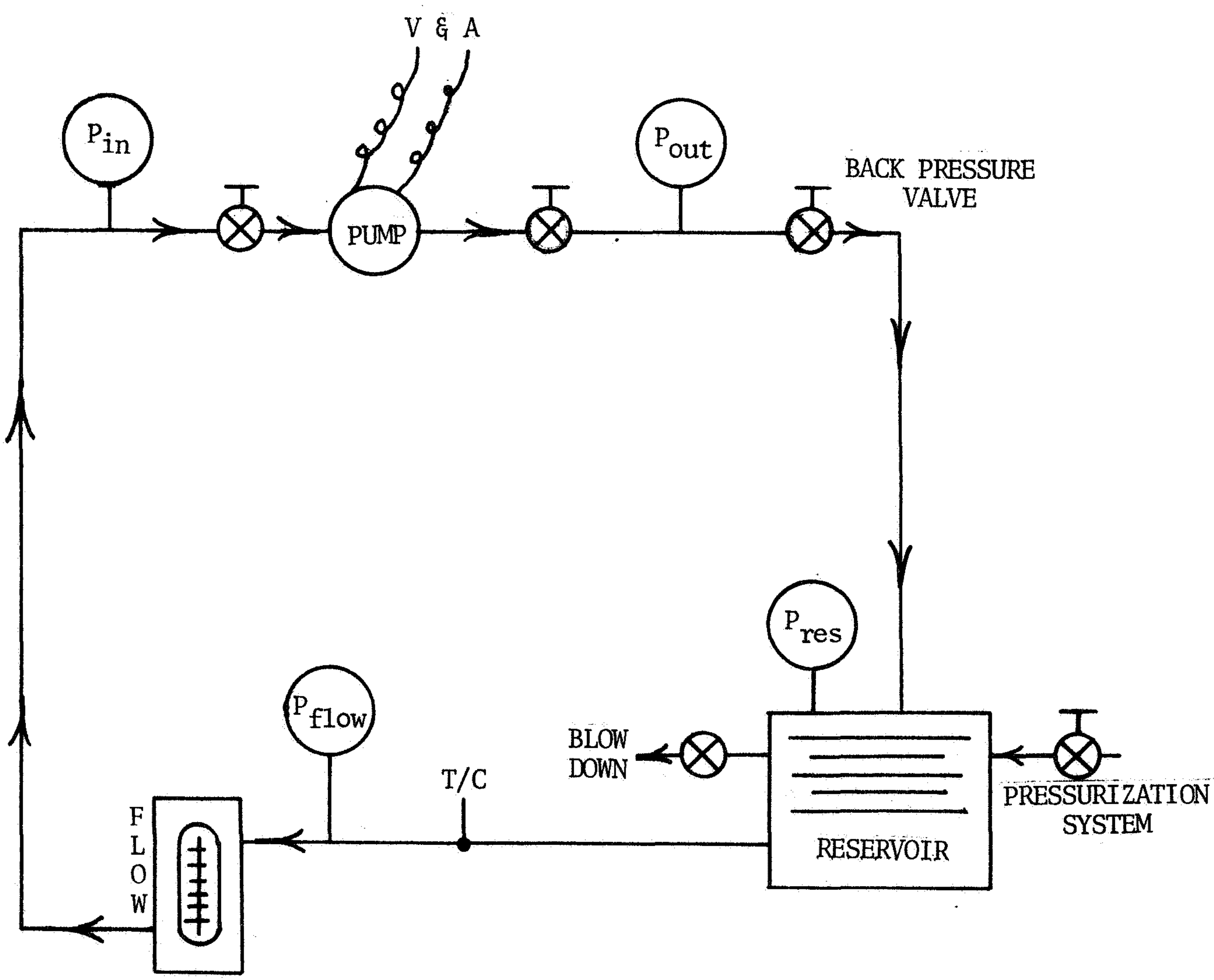




PUMP TEST SETUP IN ANECHOIC CHAMBER

FIGURE 59

The pump test schematic is given in figure 60. The pump performance point was set by varying the backpressure valve. The pump pressure rise was obtained by taking the difference between outlet and inlet pressure readings. Flow was recorded from the calibrated flow meter. The system pressure level was varied by pressurizing the nine gallon capacity water reservoir with air. No speed readings were taken on the totally enclosed pump, but the pump motor voltage and current were monitored continuously in the control room.



PUMP TEST SETUP

FIGURE 60

Tables XVI, XVII and XVIII present the data for the "as received" verification hardware. In all runs with a three-phase power source the voltage in the three phases was equal. In the runs where the current varied between phases the three values of current are tabulated.

The variation in fan current was due to running at 134 VAC rather than at the 208 VAC design point. This reduction in fan input voltage was necessary on the three-bladed axial fan to establish a performance point consistent with Space Shuttle operation.

TABLE XVI

"AS RECEIVED" AXIAL FAN PERFORMANCE DATA
(400 Hz, 3 Phase)

Noise Measurement Set-Up	2 Bladed		3 Bladed		Motor
	Inlet	Outlet	Inlet	Outlet	
cfm	445	425	450	440	-
$\Delta P''H_2O$	2.56"	3.04"	2.6"	2.5"	-
rpm	11800	11800	9150	8900	12,300
Volts	195	200	134	134	193
Amps/phase	1.6	1.6	2.4 3.6 3.2	2.4 3.5 3.2	-

A comparison of the two-bladed data and the three-bladed fan data in Table XVI shows that the three-bladed unit produces the required head and flow at a lower speed, with essentially the same hardware volume and weight. As such, this unit was rated to be better than the two-bladed fan.

TABLE XVII

"AS RECEIVED" SQUIRREL CAGE FAN PERFORMANCE DATA
(115V, 400 Hz, 1 Phase)

Noise Measurement Set-Up	Inlet	Outlet	Motor
cfm	300	300	-
$\Delta P''H_2O$	2.56	2.45	-
rpm	3870	3840	4140
Volts	115	118	115
Amps	5.36	5.3	4.0

TABLE XVIII

"AS RECEIVED" CENTRIFUGAL PUMP PERFORMANCE DATA
(200V, 400 Hz, 3 Phase)

	Unit	Motor
Flow lbs/min	7.7	-
P_{in} psia	4.0	-
ΔP psi	24.5	-
rpm	9000	-
Volts	193	190
Amps	.36 .42 .44	.27 .30 .30

A typical fan setup is shown in figure 61. During inlet noise measurements, the fans were fitted with generous bellmouths to provide a smooth inflow to the inlet. Measurements were made along an arc at a three foot radius from 0 degrees (on axis) to 160 degrees, in 20 degree increments. In the case of outlet noise test of the squirrel cage fan two measurement sweeps were made perpendicular to each other since the outlet geometry has two axes of symmetry.

The setup and instrumentation for both fans are illustrated schematically in figures 62 and 63 for inlet and outlet noise testing. The fan performance points were set by adjusting the throttle valve located in the muffler. Fan total inlet to fan static outlet pressure rise was set. The X symbol marked on figures 62 and 63 shows the location of the differential pressure pickups for determining fan pressure rise. The flow was determined by measuring the dynamic head in the bellmouth or duct entrance to the fan. The total pressure probe was removed after test conditions were set. Thus two tests were conducted for each fan configuration. The first was to set the fan to the desired operating point and to measure the aerodynamic performance of the unit. Then the aerodynamic total pressure probes were removed and the holes in the duct were filled. The unit was rerun at the same point while the noise was measured. Since flow varies with speed and fan ΔP, both of these parameters were monitored during the testing to assure steady state operation.

The above precaution was necessary to avoid any noise generation by the total pressure probes themselves and to prevent any rotor inlet flow disturbances. Static pressure pickups which do not protrude into the duct were still used to measure pressure rise with no effect on noise.

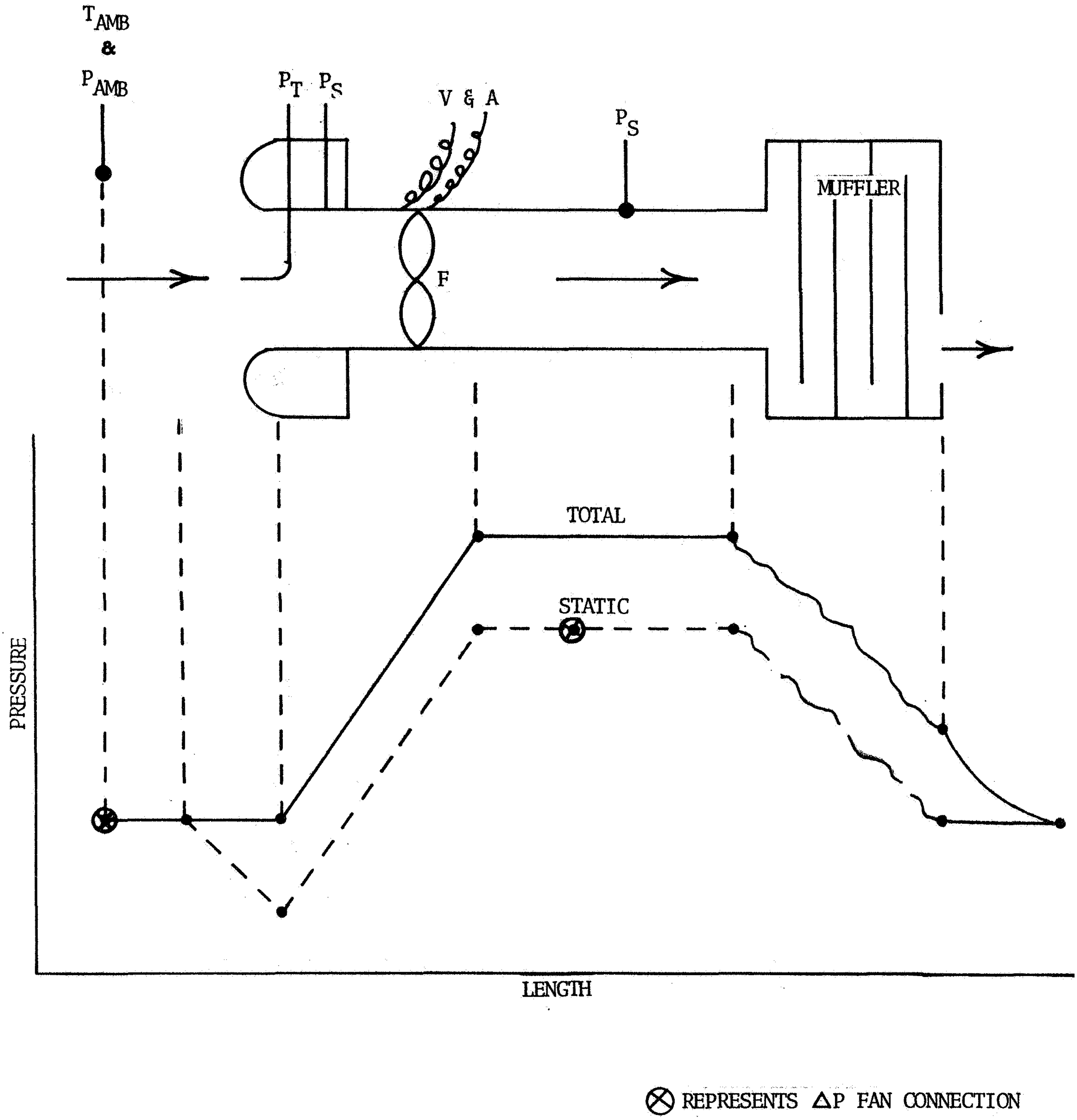
When changing the microphone location during acoustic testing, fan speed, fan pressure rise, and ambient temperature readings were taken. The ambient air temperature was measured at the fan entrance to eliminate any variation due to heating while passing over the motor. Voltage and current were monitored continuously in the control room at the power console.

Data Reduction

All the acoustic data was reduced using 1/3 octave band analysis. The data was then integrated to give 1/3 octave band PWL. Also, the 1/3 octave band PWL's were summed into full octave PWL's for comparison with estimated noise. The measured data from all the units is included in Appendix B. To evaluate the data in terms of the design objective of NC 30 at three feet, the 1/3 octave band SPL's from 50 to 10,000 Hz were summed into full octaves, then the NC value from each microphone location was calculated. The NC value of the item was then assumed to be the maximum NC value thus caculated.

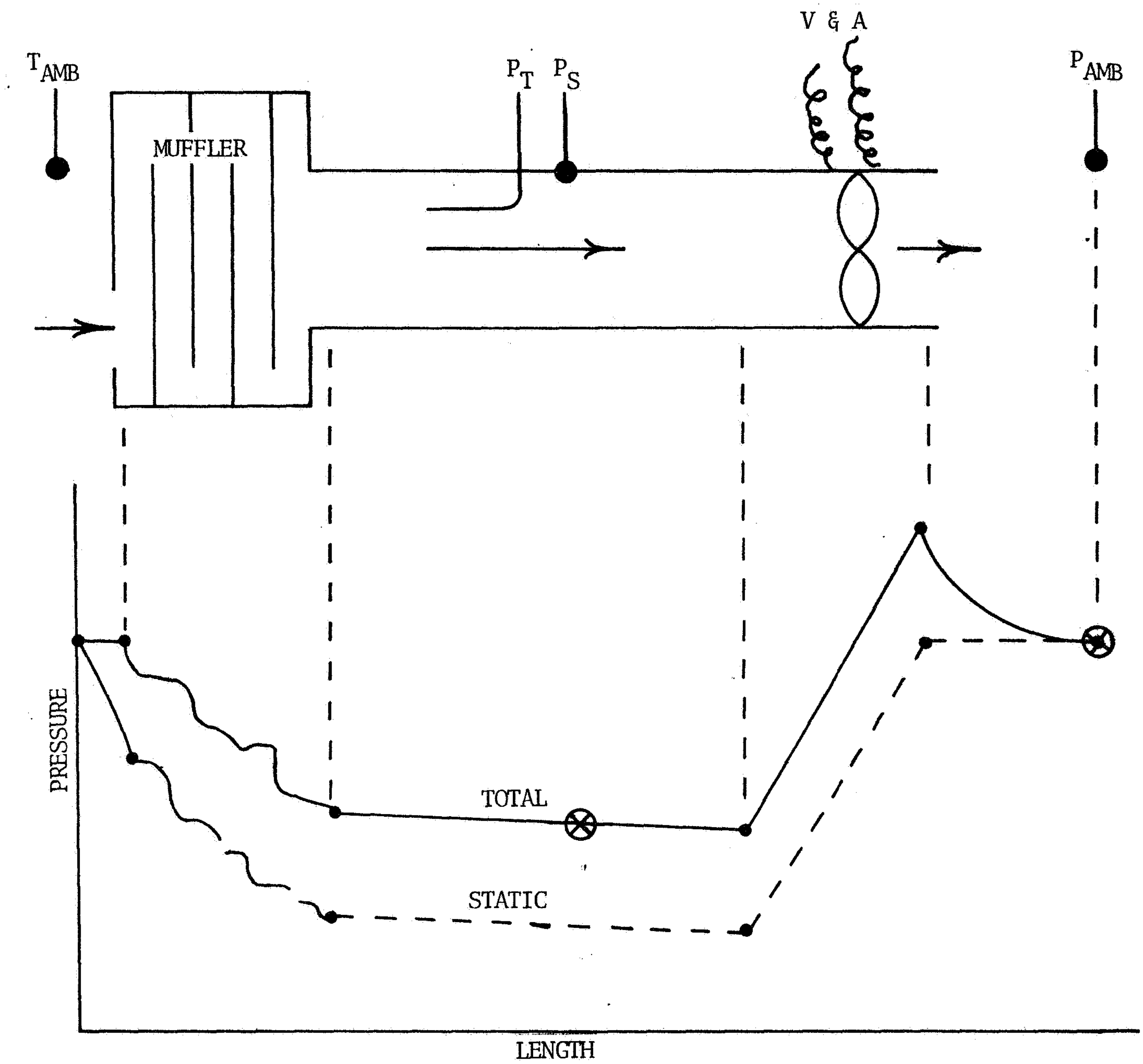
FIGURE 61

FLOW TEST SETUP IN ANECHOIC CHAMBER



FAN INLET NOISE MEASUREMENT FLOW SCHEMATIC

FIGURE 62



⊗ REPRESENTS ΔP FAN CONNECTION

FAN OUTLET NOISE MEASUREMENT FLOW SCHEMATIC

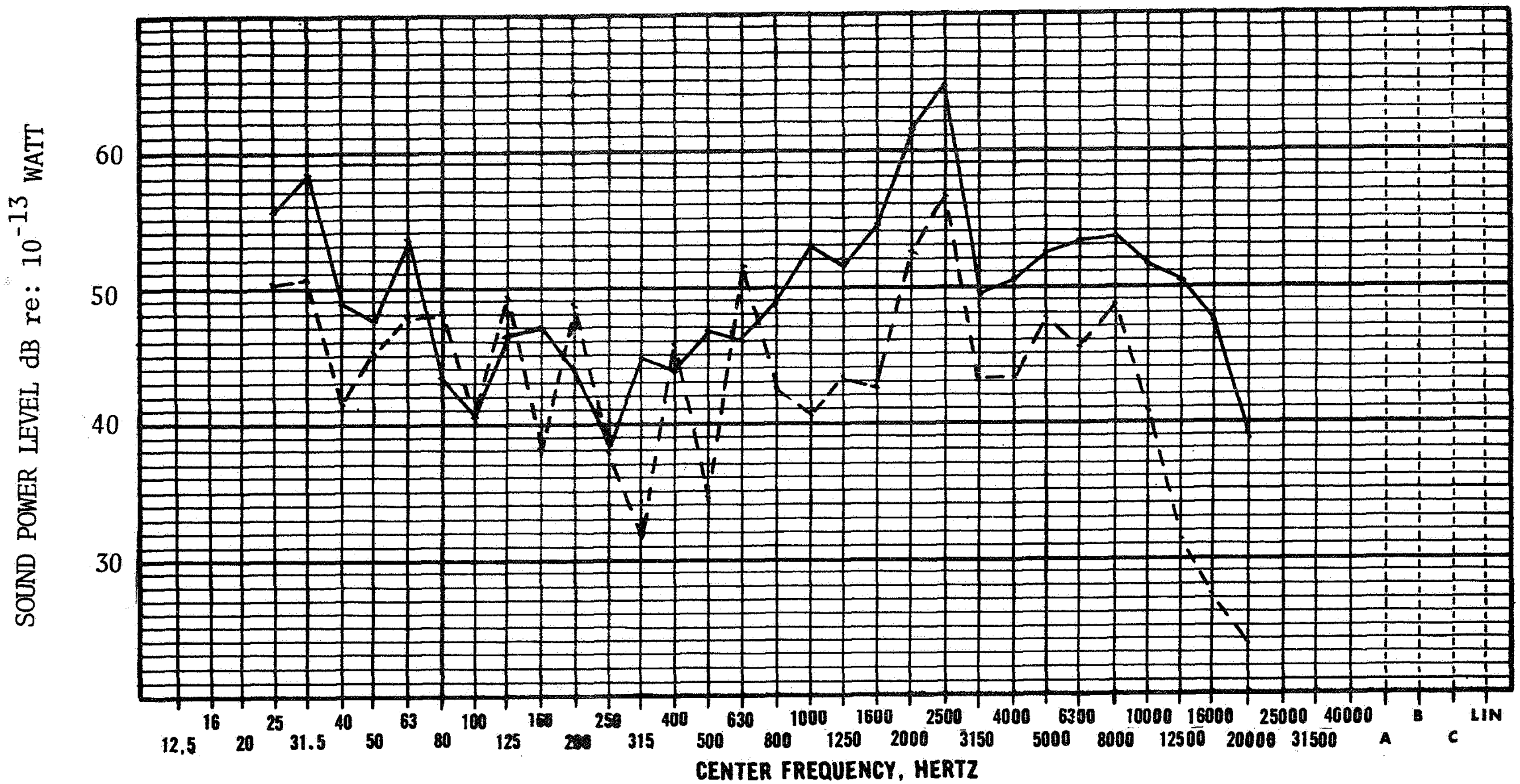
FIGURE 63

Discussion of Test Results

Pump Noise

Figure 64 shows the pump noise. The rotor passing frequency is seen in the 1000 Hz band. The large tone in the 2000 and 2500 Hz bands does not appear to be due to the pump, but rather is associated with the motor. Although this component, apparent in the motor-only spectrum, is not as strong for the motor noise, the motor noise measurements are not fully conclusive since the motor over-heated before a full set of measurements could be obtained. The available data on the pump's motor noise shows that the 2000 to 2500 Hz component is still increasing beyond 135 degrees azimuth, where the last measurement was made. In an AC motor, alternating current applied to the stator windings produces an electromagnetic field. The alternating current creates alternating magnetic forces within the stator and its laminations which tend to move the windings. The actual physical displacement is small, but produces the common "buzz" heard in motors. Since the voltage varies from plus to minus, this changes the direction of the force between windings twice per cycle. As such the electrical noise will be relatively high at both line and twice line frequency. Thus a tone at 2400 Hz is consistent with that expected from field lamination noise since for this 400 Hz, three-phase motor, the driving frequency is 2400 Hz (that is, 2 excitations per cycle x 400 Hz x 3 phases). Another possible source of motor noise is that from the bearings. The ball bearings used in this motor have seven 0.125 inch diameter balls. With a bearing race inside diameter of 0.25 inches and assuming an unloaded motor speed of 10,000 rpm, the fundamental "ball passing" frequency (equal to the motor shaft speed times the number of balls times the number of ball revolutions per shaft revolution) is 2333 Hz. It is therefore apparent that the peak seen in the 2500 Hz band in figure 64 is due either to motor lamination noise, bearing noise, or a combination of both. The broad hump centered on 8000 Hz is believed to be cavitation noise associated with inflow turbulence generated at the interface between the inlet coupling and the pump housing and at the sharp cornered inlet flange.

Figure 65 shows the octave band levels of the pump assembly for the maximum NC value. As this figure shows, the maximum penetration is into the NC-50 area, which gives it an NC value of 50 dB. The NC value is determined by the level of the 2000 Hz band, which is due mostly to motor noise components.



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE MICROPUMP REFERENCE TEST

Test Date ______ Run No. ______

Mic Location ______ Reel No. ______

Analysed By ______ Identification No. ______

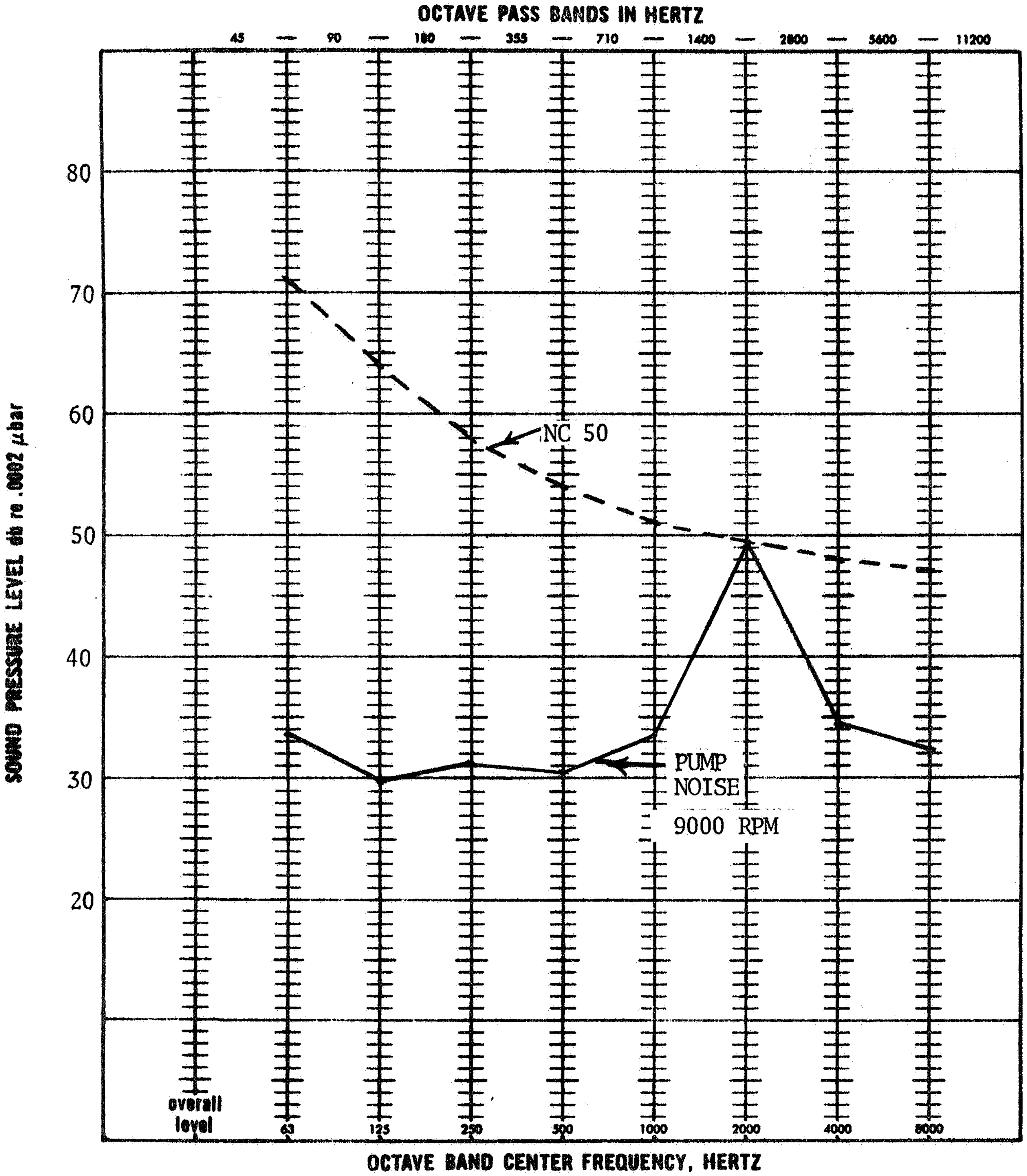
Analysis Method ______ Sheet ___ of ___

Comments, Sketches, Etc.

——— PUMP AND MOTOR - 9000 RPM

– – – MOTOR ONLY

FIGURE 64



Hamilton Standard
DIVISION OF UNITED AIRCRAFT CORP.
OCTAVE BAND ANALYSIS

PUMP NOISE LEVEL AT THE MAXIMUM
NC VALUE LOCATION

FIGURE 65

HSF-1677 3/68*

Axial Fan Noise

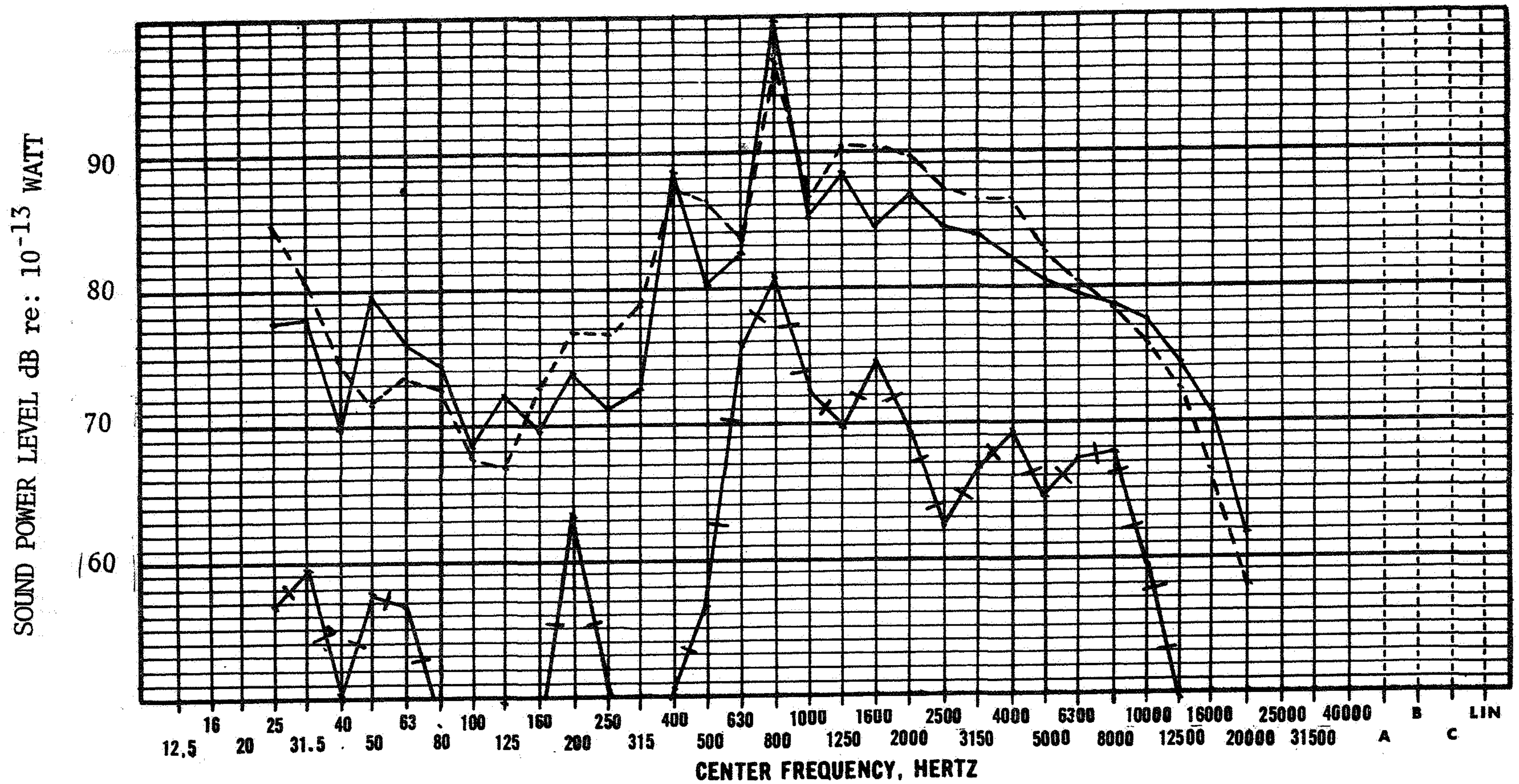
Figure 66 shows the noise of the two-bladed axial fan while figure 67 shows the noise of the three-bladed axial fan. These two sets of data are very similar. The dominant components are the tones at blade passing frequency and its harmonics. For the two-bladed fan running at 11,800 rpm the blade passing frequency is 393 Hz; for the three-bladed fan running at 9000 rpm, this frequency is 450 Hz. The two-bladed fan has the strongest tone at twice the blade passing frequency while the three-bladed fan is more conventional in that the strongest tone is at the fundamental blade passing frequency. These tones are believed to be due to rotor and stator interaction because the gap between the trailing edge of the rotor and the leading edge of the stator is small. Thus the rotor wakes are very strong at the stators. The stator vanes are not equally spaced and thus mode cancellation is inhibited. The modes, even those below cut-off, propagate.

Other sources of noise appear to be: 1) the peaked broad band centered on 2000 Hz in the inlet noise due to the large tip clearance of the rotor; 2) the broad hump centered around 1600 Hz in the exhaust noise from both fan configurations due to wake shedding from the stator trailing edges, which are very blunt and thick; 3) both tone and broad band noise levels accentuated by inlet flow distribution which is not entirely smooth, as is the case of the inlet data with a bellmouth.

It is seen in the figures that the motor noise is not a contributor to the total fan noise. However, reductions of 10 dB or more in the fan noise would bring the aerodynamic noise levels down to the point where the motor noise would result in a measurable increase in total fan noise. Also, the motor noise level of NC 65 requires significant quieting to achieve a total unit noise level meeting NC 30.

Figures 68 and 69 show the octave band spectra of the two-bladed and three-bladed fans, respectively, which correspond to the maximum NC values. It is seen from figure 68 that the maximum NC value is set at 1000 Hz band which corresponds to the second harmonic of blade passing frequency of 786 Hz. In the case of the three-bladed fan, in figure 69, the inlet noise NC value is set by the 1000 Hz band level, corresponding to the second harmonic of blade passing frequency, whereas the exhaust noise NC value is set by the 2000 Hz band level, corresponding to a higher harmonic of blade passing frequency and broad band peak.

The three-bladed fan is slightly quieter than the two-blade fan. Also, it has better aerodynamic characteristics. Thus the three-bladed fan is the better unit for further verification testing.



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE 2 BLADED AXIAL FAN NOISE

Test Date ______ **Run No.** ______

Mic Location ______ **Reel No.** ______

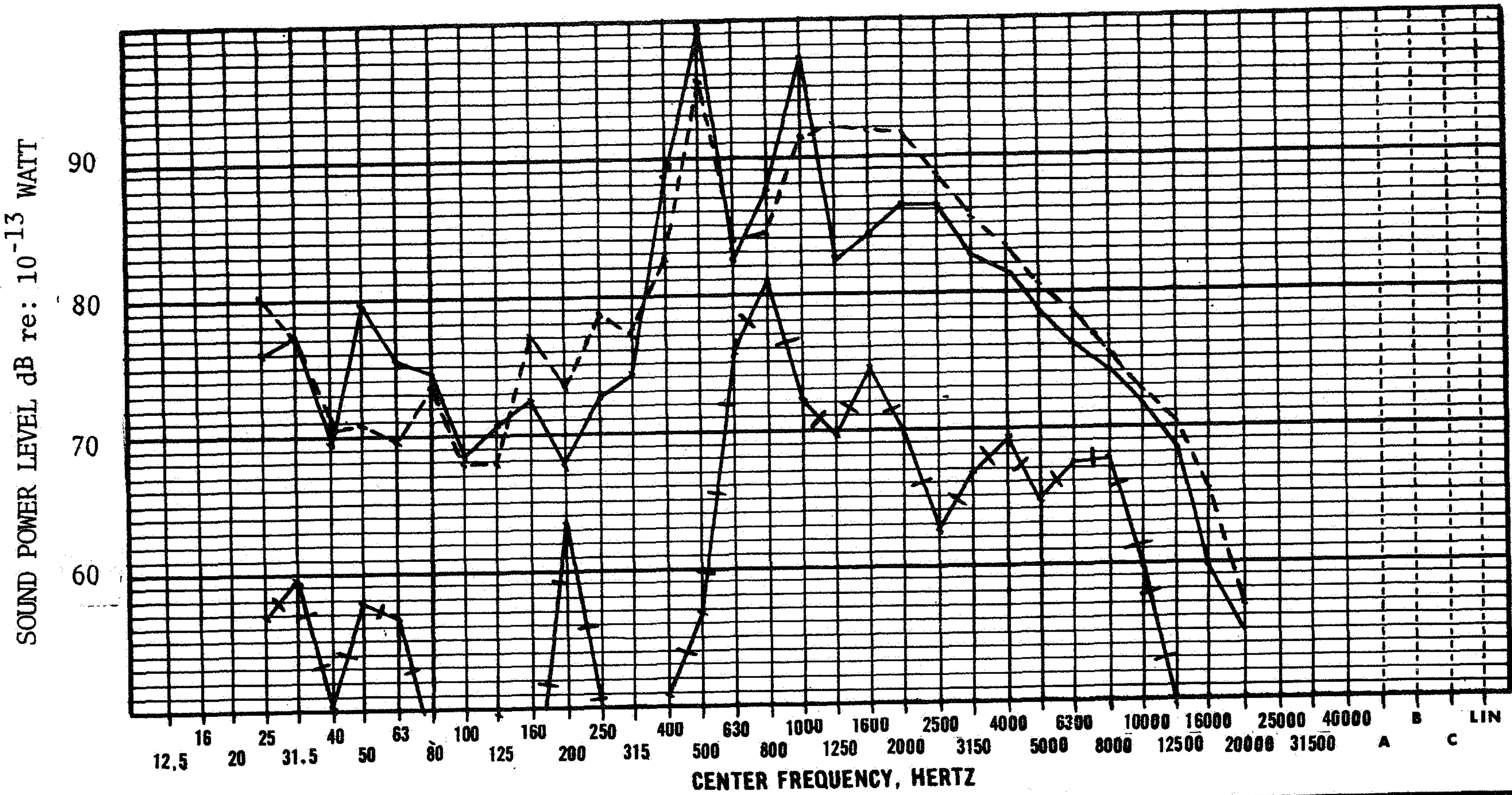
Analysed By ______ **Identification No.** ______

Analysis Method ______ **Sheet** ___ **of** ___

Comments, Sketches, Etc.

———	INLET NOISE	11800 RPM
– – – –	EXHAUST NOISE	11800 RPM
–+–+–	MOTOR NOISE	12,300 RPM

FIGURE 66



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE 3 BLADED AXIAL FAN NOISE

Test Date ______ Run No. ______

Mic Location ______ Reel No. ______

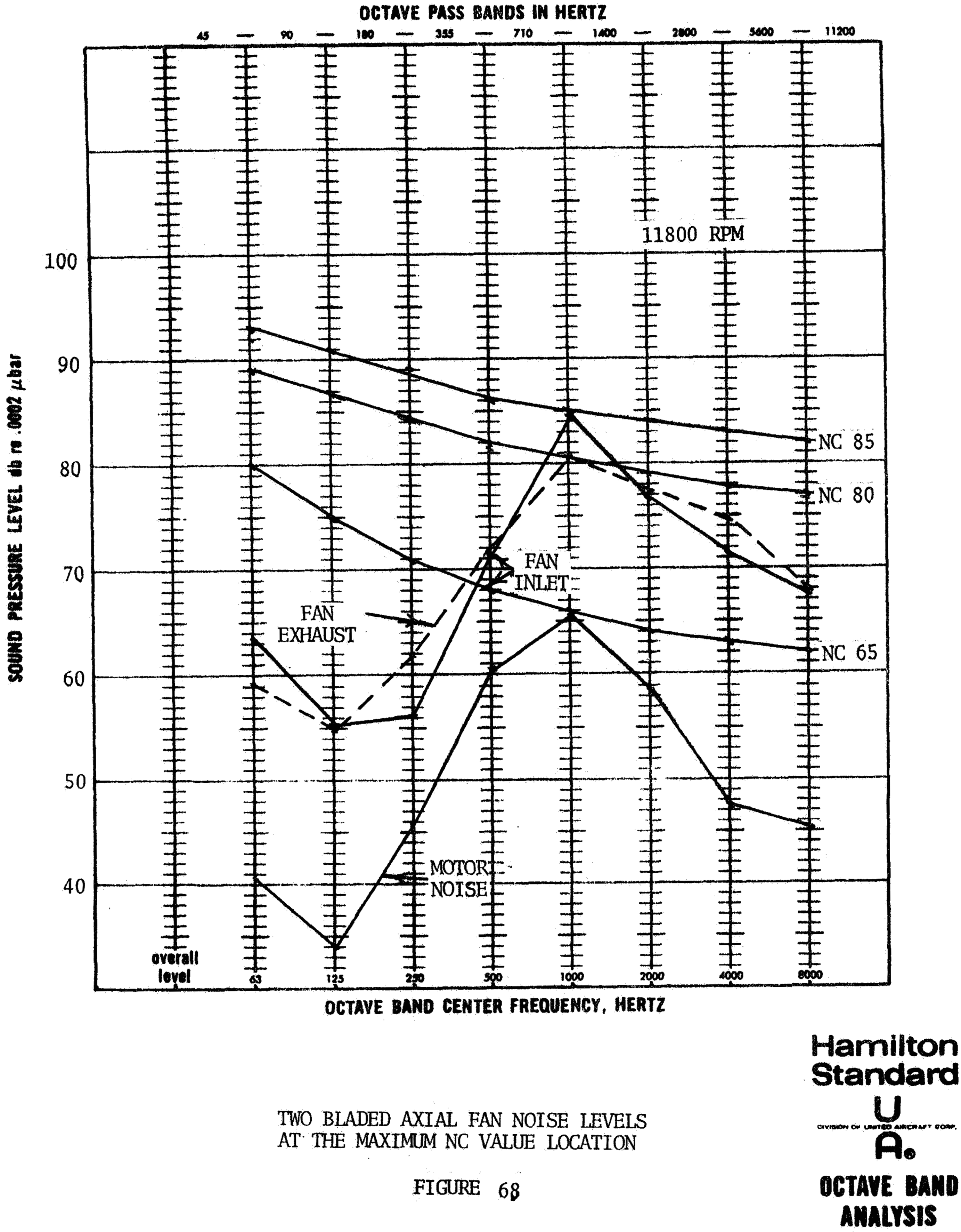
Analysed By ______ Identification No. ______

Analysis Method ______ Sheet ___ of ___

Comments, Sketches, Etc.

———	INLET NOISE	9150 RPM
— — —	EXHAUST NOISE	8900 RPM
—+—+—	MOTOR NOISE	12300 RPM

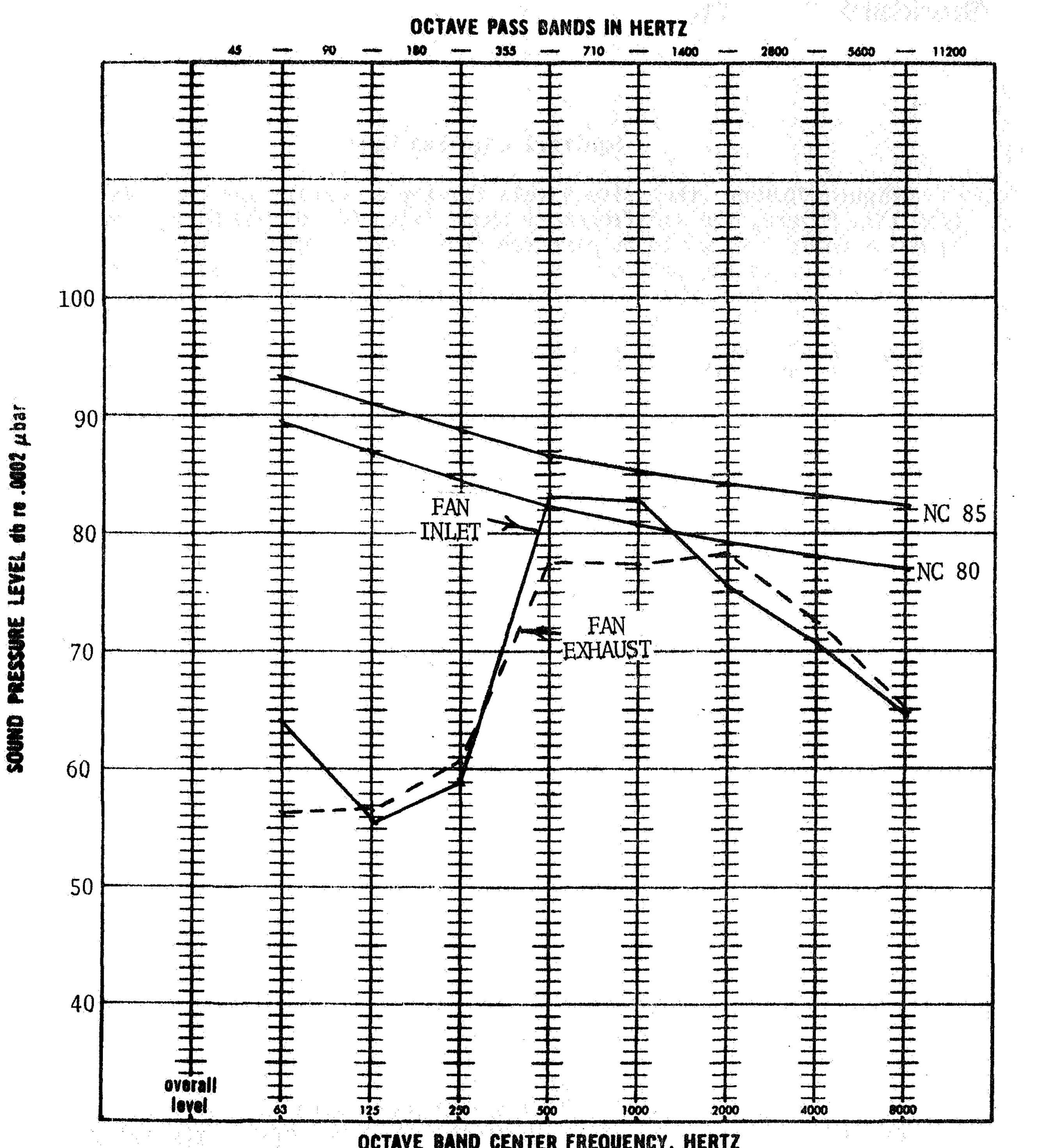
FIGURE 67



TWO BLADED AXIAL FAN NOISE LEVELS
AT THE MAXIMUM NC VALUE LOCATION

FIGURE 68

HSF-1677 3/68*



THREE BLADED AXIAL FAN NOISE LEVELS
AT THE MAXIMUM NC VALUE LOCATION

FIGURE 69

HSF-1677 3/68*

Squirrel Cage Fan Noise

Figure 70 shows the noise levels for the squirrel-cage fan. As seen from this figure, the mid-frequency bands from 800 to 8000 Hz are dominated by motor noise. As would be expected from a single phase, 400 Hz motor, field winding and lamination noise occurs at 800 Hz (that is, 2 excitations per cycle x 400 Hzxl phase). Several harmonics may also be seen in figure 70 at 1600 Hz, 2400 Hz, and 3150 Hz. Unfortunately, it is not possible to distinguish the fan noise because of the high levels of motor noise. Based on the speed and number of blades, the blade passing frequency of this unit is calculated to be at 1900 Hz. Thus, one might expect to see a tone in the 1600 or 2000 Hz band. However, due to the large gap between the cutwater and the rotor plus the low tip speed of this fan, the level of the tone can be very low and may not be apparent in the 1/3 octave band spectrum. This is especially true for the case where there are strong motor noise components in the same band.

It thus is possible to obtain only an approximation of the fan noise spectrum by smoothly fairing in a curve which eliminates the peaks due to motor noise as shown in figure 71.

It is apparent from figure 70 that the maximum NC value of the fan is set by the motor noise. However, based on the estimated levels for the fan noise, elimination of the motor noise reduces these levels by about 10 dB. Thus one would estimate a maximum NC value of approximately 67 to 69 dB for the fan alone.

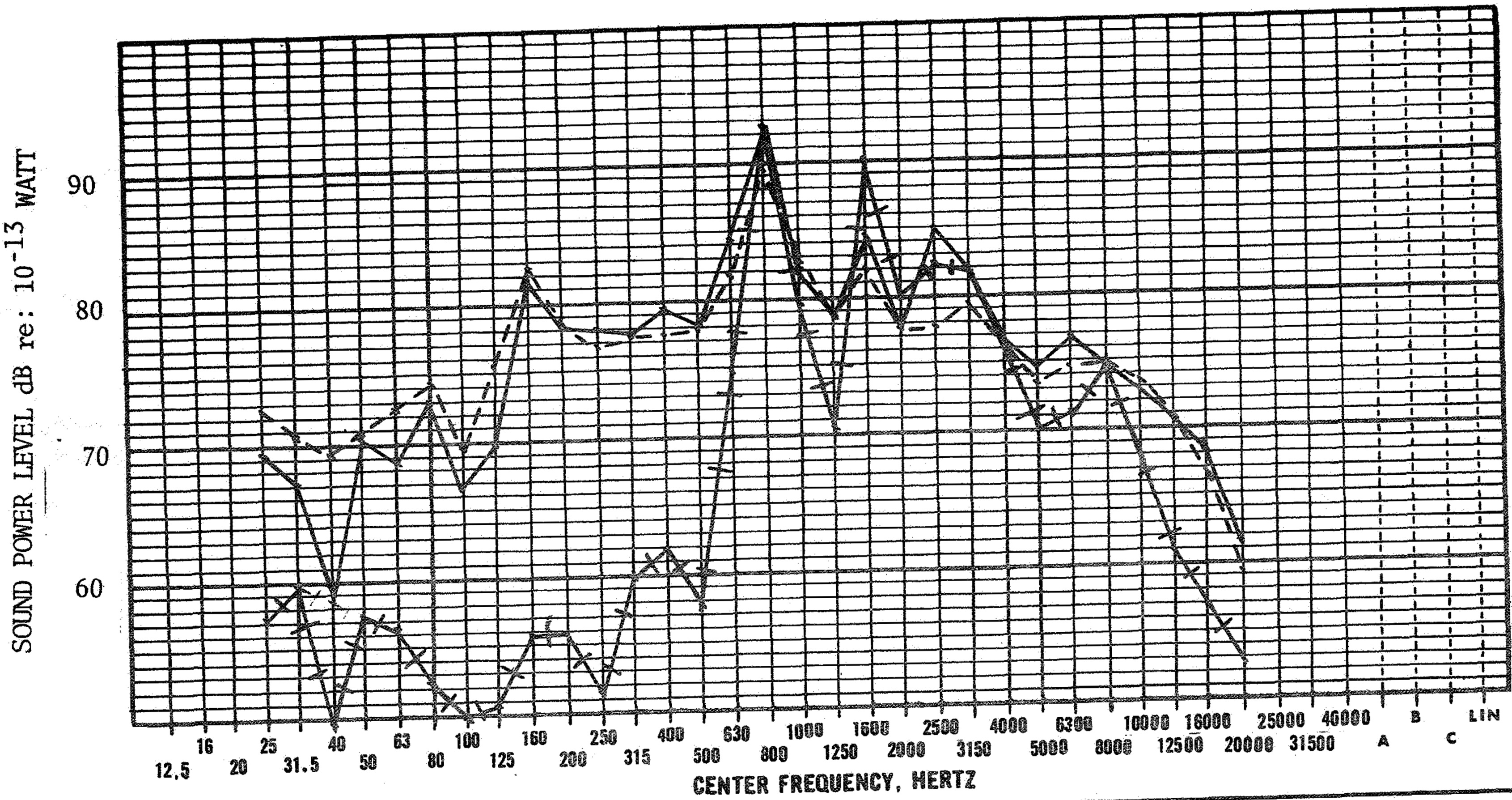
SELECTION OF NOISE REDUCTION METHODS

Pump Noise Reduction

Pump Noise Sources

The measured noise levels for this unit as received from the supplier are presented in figure 64. An analysis was made of the possible noise sources and a discussion of means for alleviating each of them follows.

The noise in the 4000 to 10000 Hz frequency band was believed to be caused by fluid cavitation. Cavitation is precipitated by sharp edges and non-uniform passages which may cause local fluid acceleration. An examination of the pump rotor showed desirable rounded leading edges on the blades, but there were also burrs and hooks at the blade outlet which could cause cavitation and therefore noise. The thrust plate adjacent to the rotor also had sharp corners which could become a source of cavitation unless rounded with a larger radius. Also, the pump inlet was threaded to accommodate a pipe fitting. The sharp edges of the threads also could be a source of cavitation. Finally, operating the pump at 4.0 psia inlet pressure enhanced the possibility of cavitation. Thus, subsequent testing was conducted at higher inlet pressures.



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • ONE THIRD OCTAVE BAND ANALYSIS

TITLE SQUIRREL CAGE FAN NOISE

Test Date ________ Run No. ________

Mic Location ________ Reel No. ________

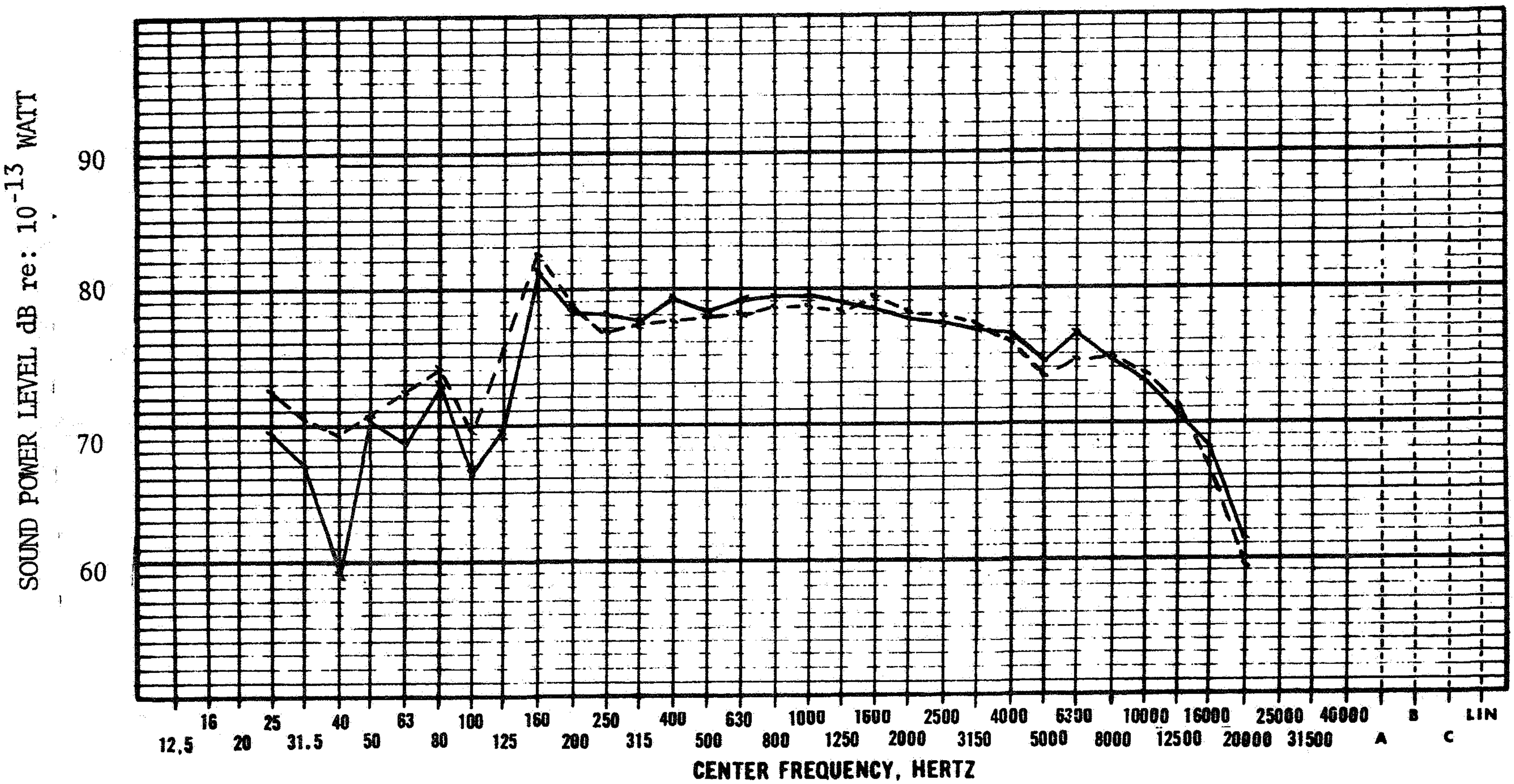
Analysed By ________ Identification No. ________

Analysis Method ________ Sheet ____ of ____

Comments, Sketches, Etc.

———	INLET NOISE	3870 RPM
– – –	EXHAUST NOISE	3840 RPM
—+—+—	MOTOR NOISE	4140 RPM

FIGURE 70



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP. • ONE THIRD OCTAVE BAND ANALYSIS

TITLE NOISE LEVELS FOR THE SQUIRREL CAGE FAN WITH NOISE PEAKS ELIMINATED

Test Date ______ Run No. ______

Mic Location ______ Reel No. ______

Analysed By ______ Identification No. ______

Analysis Method ______ Sheet ____ of ____

Comments, Sketches, Etc.

——— INLET NOISE
– – – EXHAUST NOISE

FIGURE 71

The slight noise peak in the 1000 Hz band coincides with the vane passing frequency. This noise component is a tone and is caused by the pressure pulse which is generated each time a vane passes by the cutwater. The amplitude of the pulse can be reduced by increasing the clearance between the vanes and the cutwater - with some loss in pumping efficiency - and also by changing the cutwater design.

Finally, the peak shown in the 2500 Hz band, believed to be due to motor lamination and bearing noise, can be reduced by potting the motor stator assembly to prevent the laminations and field windings from vibrating and by replacing the bearings with quieter types, such as sleeve bearings. The motor also has several surfaces, notably the aluminum back plate and motor housing, which may be good acoustic radiators. Thus, applying vibration dampening material to the vibrating surfaces and enclosing the motor housing with fiberglass and lead-impregnated vinyl should reduce these noise sources.

Pump Modifications

A number of the above mentioned causes and modifications of the various noise sources were selected as the most promising for achieving noise reductions within the scope of the present program.

The pump rotor was cleaned up by removing burrs and hooks and rounding its leading edges. The inflow passages were improved by providing a straight pipe inlet and filling in the pipe threads. The edge of the thrust plate was rounded to provide a more gradual transition into the rotor. The motor was reworked to eliminate apparent tones by replacing the ball bearings with sleeve bearings, and the motor radiated noise was dampened by enclosing radiating surfaces.

Axial Fan Noise Reduction

Fan Noise Sources

The measured noise levels of the three-bladed axial fan as received from the supplier are shown in figure 67. The following paragraphs summarize what were believed to be the major noise sources in this unit and the means for reducing the strength of these sources.

The major cause of noise was interaction tones between the rotor and stator assemblies. Since the five stator vanes were unevenly spaced, mode cancellation was inhibited and probably all the interaction modes propagated (see earlier discussion on interaction mode decay). Thus, to reduce this noise, it is common practice to increase the spacing between the rotor trailing edges and the stator leading edges by moving the entire stator assembly further downstream. Also, spacing the stators evenly promotes better cancellation of modes.

There were three important sources of broad band noise in this fan. The first of these, which would appear mostly in the exhaust noise, was caused by the shedding of turbulent wakes from the thick stator vane trailing edges. The second source was vortex shedding from the rotor blades. Both of these sources could be reduced by the use of airfoils with properly shaped leading and trailing edges to minimize the turbulent wakes. Finally, due to the large rotor tip clearance, it was possible to have a significant tip vortex, which could be reduced by reducing the rotor blade tip clearance.

Other broad band noise sources included various obstructions in the flow, such as screw heads, improper size matching between the stator and rotor center bodies, and duct wall roughness.

Another means for reducing the broad band noise from both rotor and stator vortex shedding is by use of porous materials. These materials are either attached to the blade or the blades can be made entirely or in part from the porous material.

Axial Flow Fan Modifications

The following noise reduction modifications were considered feasible within the scope of this program and were incorporated into the design of a reduced-noise axial flow fan.

The stator assembly was redesigned using proper airfoil sections. Five equally spaced vanes were located at a greatly increased distance downstream of the rotor. All the flow passages were cleaned up by machining the walls, countersinking bolt-heads, and matching center body diameters. The rotor blade tip clearance was reduced. Finally the rotor was reworked to include rounded leading and trailing edges and then was balanced in two planes to less than 700 micro ounce-inches.

Squirrel Cage Fan Noise Reduction

Fan Noise Sources

The measured noise levels for this unit are shown in figure 70. Since it is apparent that the noise was dominated by the motor noise, it was not possible to determine the aerodynamic noise sources from this fan from the measured noise spectra. A quieter motor was the first step in reducing the noise from this unit. In general, however, for this type of fan, the noise consists primarily of broadly peaked random noise, with several tones at blade passing frequency and its harmonics. The strengths of these tones are dependent primarily on the spacing between the blades and the cutwater. For this design, it was not believed that any significant tones from the fan itself existed since the blade-to-cutwater spacing was relatively large.

The broad band noise from this fan design can be reduced by the use of blades with cambered and twisted airfoils which have been matched to the airflow. Also, a conical section at the base of the blades could be helpful in turning the flow in to the blades.

Again, as for the axial flow fan, any discontinuities or obstructions in the airflow should be avoided. The use of porous materials on the cut-water might be a way to reduce the noise while maintaining a relatively small gap for better aerodynamic efficiency.

Squirrel Cage Fan Modifications

Since it was not possible to ascertain the actual noise characteristics of this fan, due to the masking noise of the motor, it was decided to obtain a quieter motor and retest the unit. The results of these tests are discussed in a subsequent section of the report.

MODIFIED HARDWARE

Description of Modifications

The details of the modifications to the verification hardware, including related technical comments, are summarized in this section.

Axial Fan

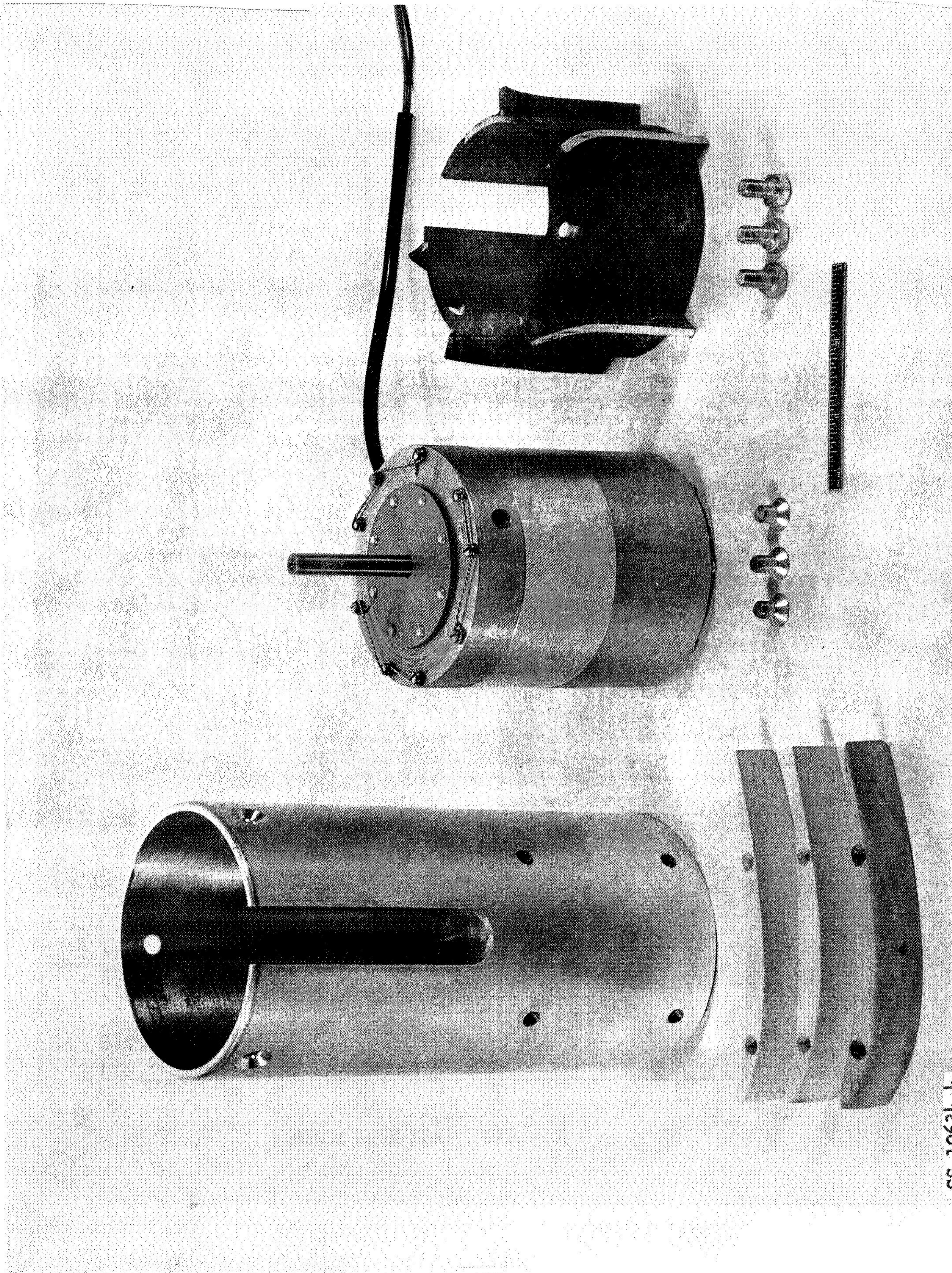
The modifications made to alleviate the noise sources described above are shown in figure 72 and 73. The rotor stator gap was increased to four inches (approximately one rotor chord length) by machining a new hub. The five unevenly spaced stators were replaced with five wooden airfoils having thin trailing edges. A full radius was machined on each of the rotor's leading edges. The rotor was then balanced to 611 μ oz in. The discontinuities were eliminated by countersinking the screws, rounding the hub inlet, placing a rubber filler in the hub to fill in the slot for the motor power cord, and machining the hub round to match the round fan rotor.

Large tip clearance results in a reduction of efficiency and the tip circulation causes noise producing vortices. The effect of tip clearance on rotor efficiency has been investigated by Howell [20], Ruden [21] and Kahane [22]. Their results are presented in figure 74, and show good agreement in the rate of efficiency change with clearance. On this basis a reduction

AXIAL FAN ROTOR AND HOUSING MODIFICATION

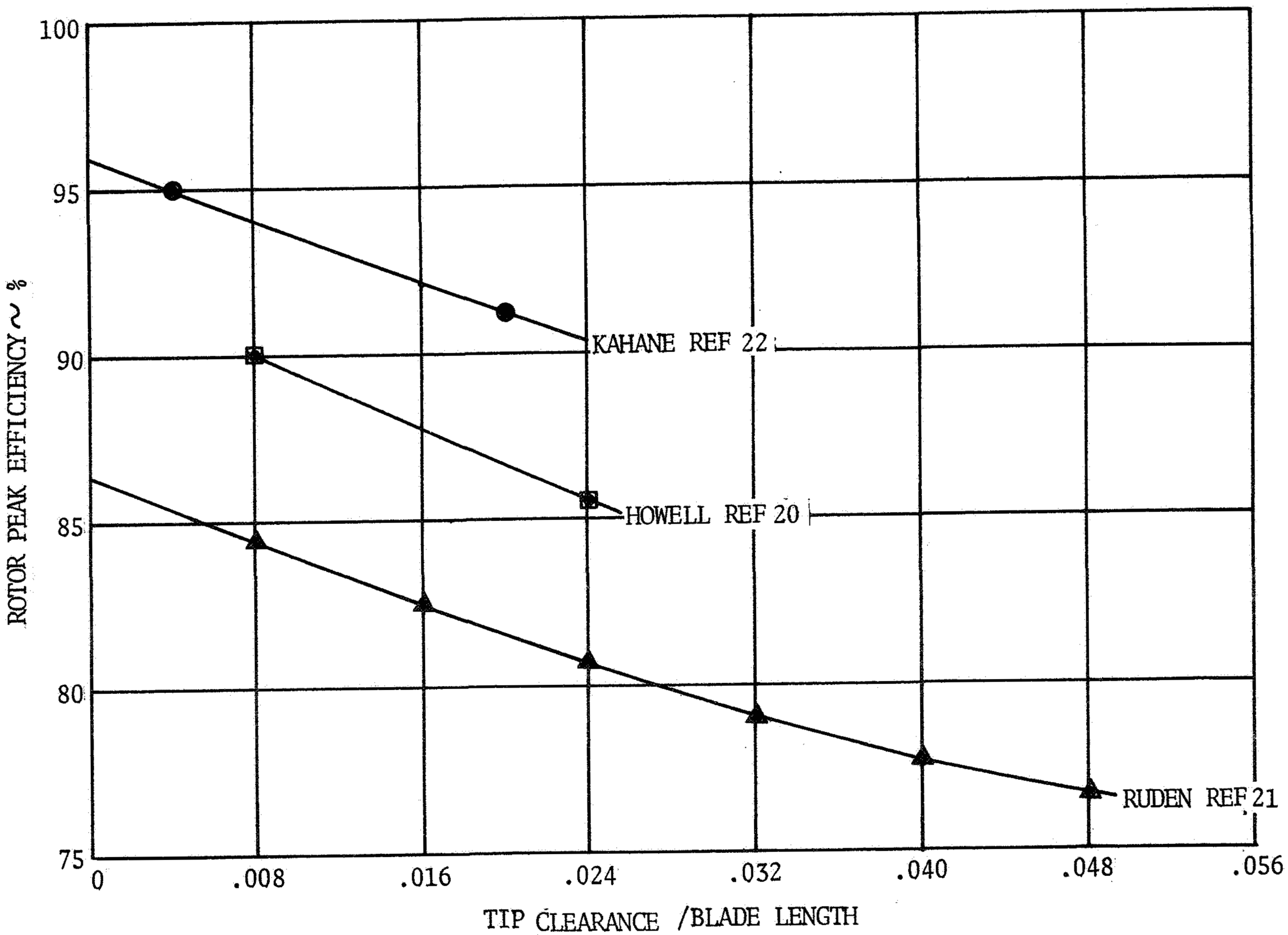
FIGURE 72

SS 10633-4



AXIAL FAN HUB AND STATOR MODIFICATION

FIGURE 73



EFFECT OF TIP CLEARANCE ON ROTOR EFFICIENCY

FIGURE 74

of tip clearance from 0.050 inches to 0.007 inches for the 1.125 inches mean blade height of the axial fan would yield an increase in fan rotor efficiency of approximately ten percent. The tip clearance was reduced from 0.050 inches to 0.006 - 0.008 inches, by machining a new 2.75 inch long outside housing.

Squirrel Cage Fan

The unit was tested to determine the angle of attack on the blades. These were found to be in an accepted 10° to 20° range. A new motor was purchased to reduce the prominent noise source. This was a 115 VAC, 60 Hz, one phase Dayton Model 5K684 unit, running at 3450 rpm. The cooling air fan was removed, temperature probes placed in the stator windings, and the motor rotating assembly balanced.

Centrifugal Pump

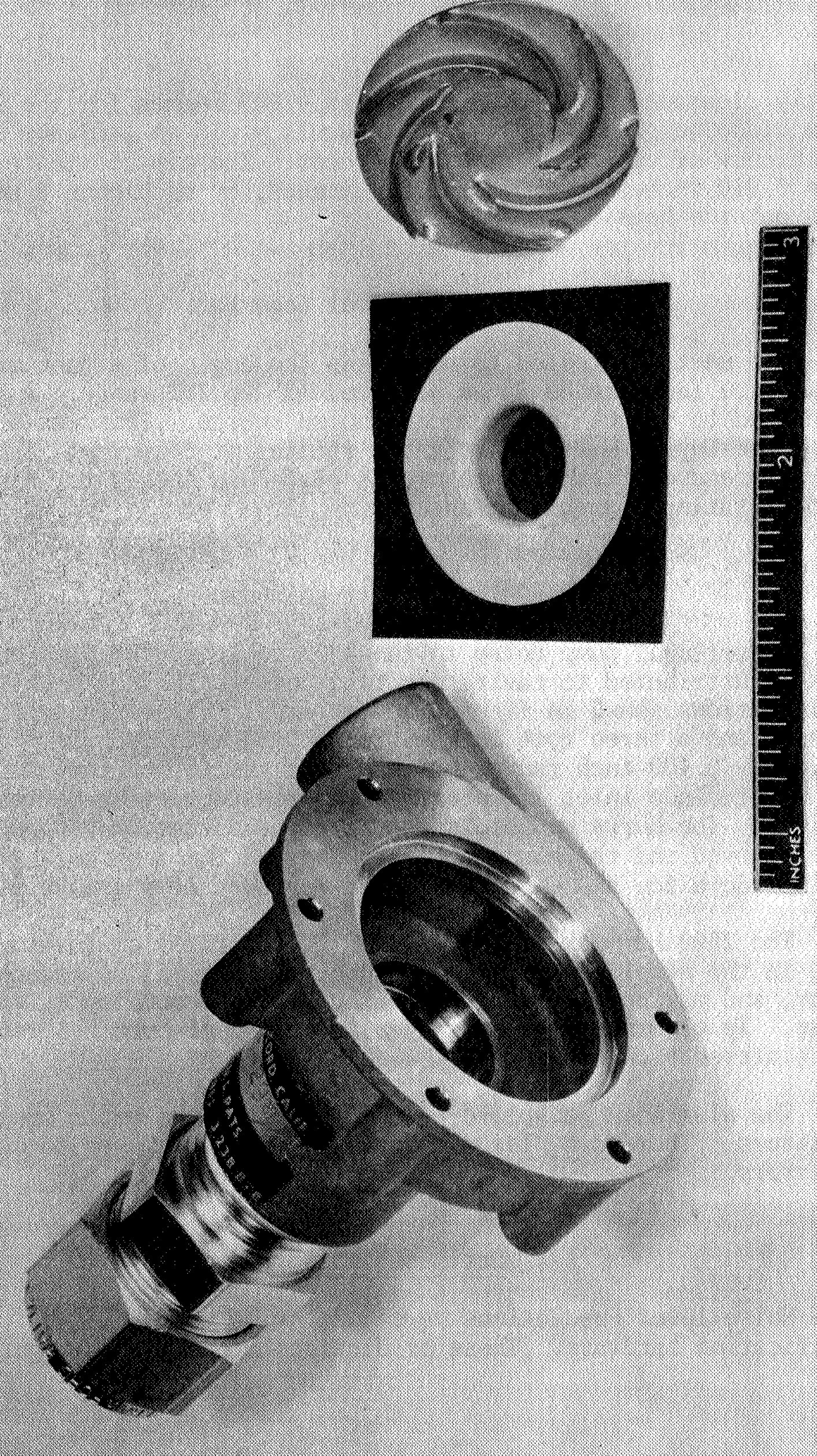
Centrifugal pump noise in the 4000 to 10,000 Hz frequency band is usually attributed to cavitation type noise. To reduce this the pump modifications shown in figure 75 were made. The entrance threads were removed and a three foot long entrance pipe extended from the smooth inlet. A 0.070 - 0.100 inch radius was added to the teflon thrust plate inlet port. The rotor blade inlet diameter was tapered to provide better entrance conditions. The burrs and hooks at the rotor outlet, as shown in figure 76, were removed and the blade outlet rounded. The test conditions were expanded to include a low and high pump inlet pressure of 9 and 26 psia, respectively.

The 2500 Hz peak is not related to the rotor or to flow since it occurs also in the motor test. It is probably structural resonance coming from the motor, and may be motor magnetic fluctuations, unbalance, and/or bearing noise. To eliminate the bearing noise the ball bearings were replaced with the sintered bronze bushings shown in figure 77.

The aluminum backplate of the motor and the motor housing are good radiators. Therefore, lead-impregnated vinyl was used to dampen these noise radiators.

Estimated Noise Reduction

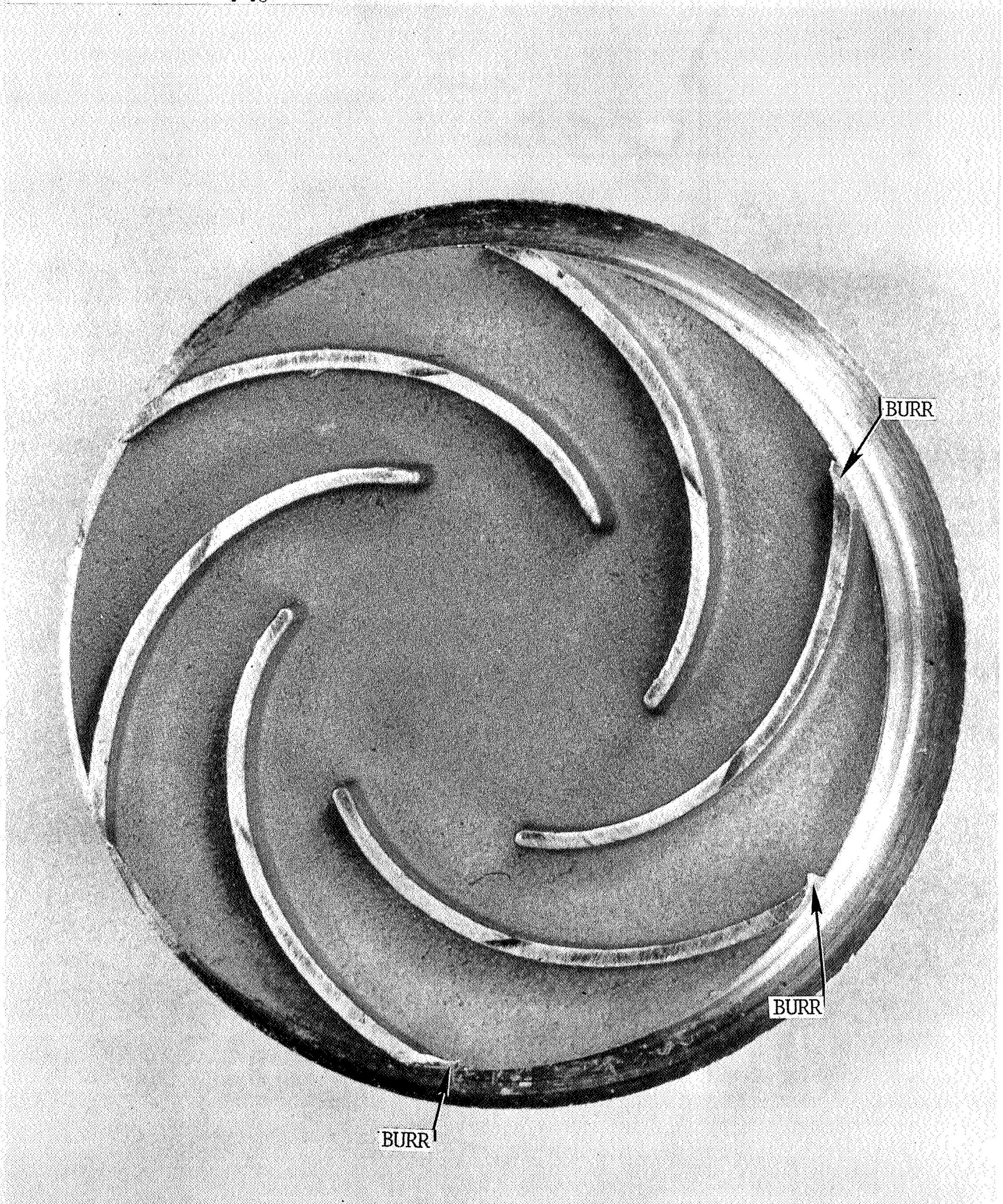
Noise level predictions were made prior to testing of the modified verification hardware. These predictions are shown in figure 78 and 79.



PUMP MODIFICATION

FIGURE 75

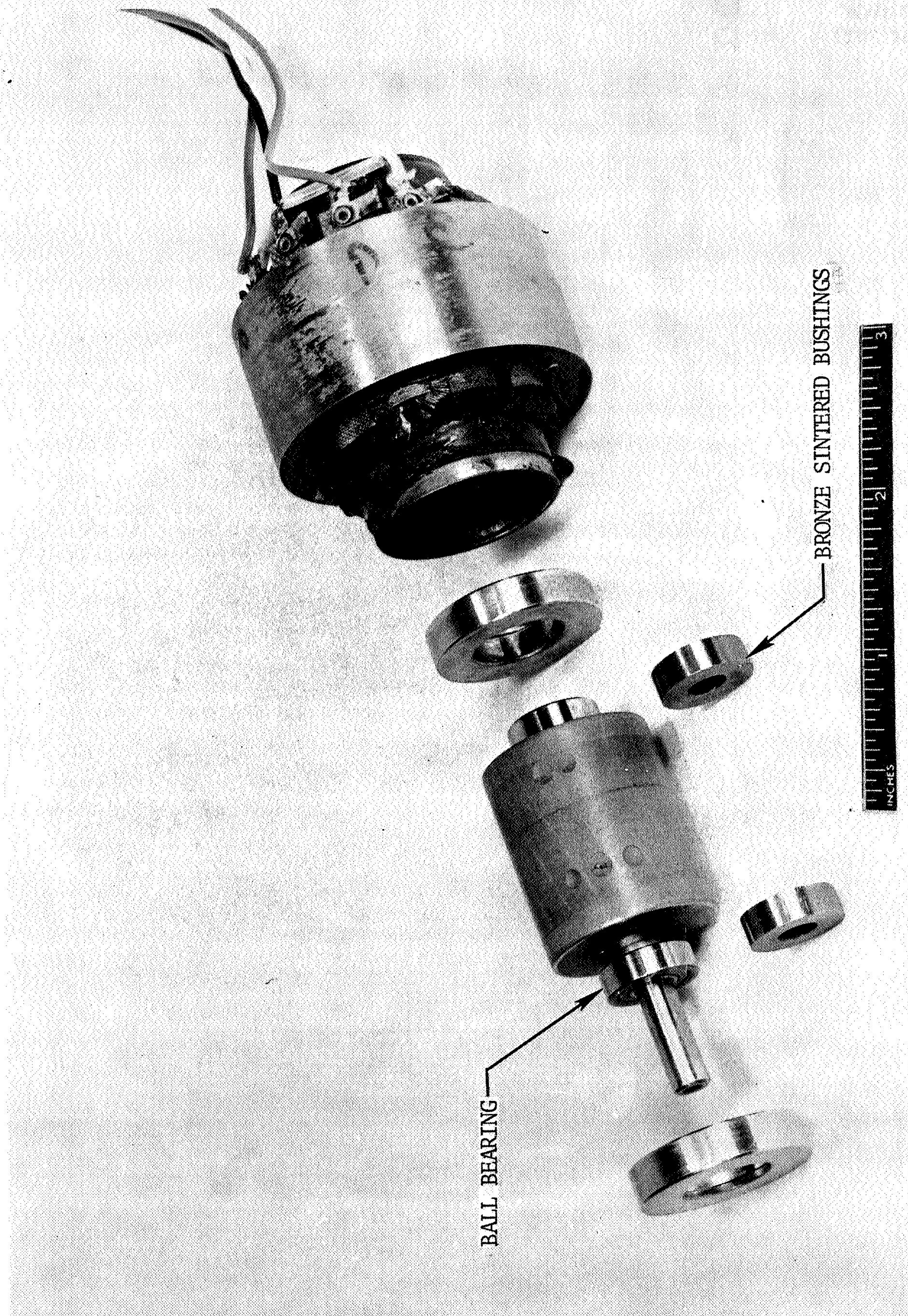
SS 10635-4



SS 10622-4

PUMP ROTOR BEFORE MODIFICATION

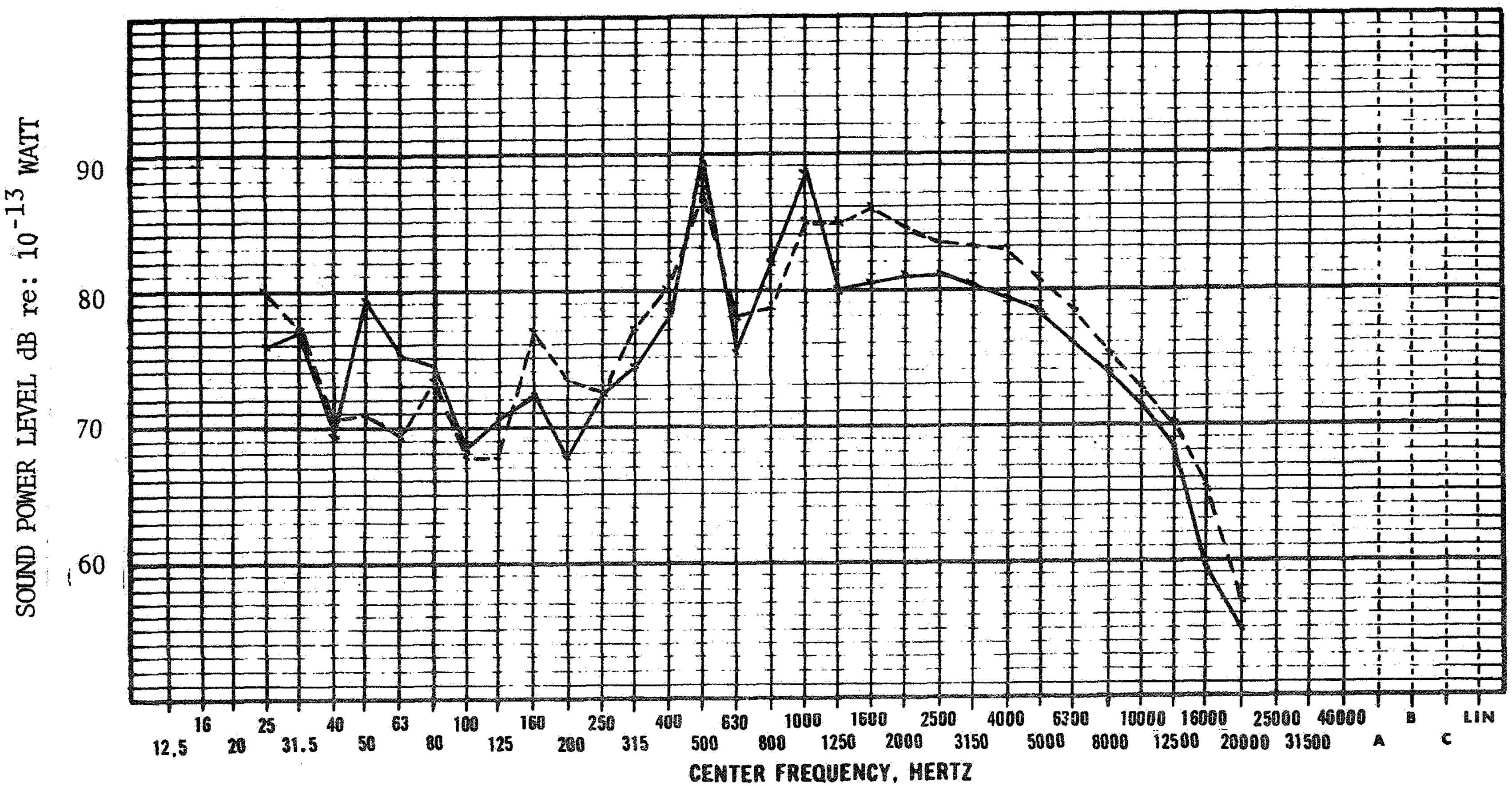
FIGURE 76



PUMP MOTOR BEARING MODIFICATION

FIGURE 77

SS 10662-4



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP. • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE ESTIMATED NOISE LEVELS FOR THE MODIFIED 3 BLADED AXIAL FAN

Test Date ______ **Run No.** ______

Mic Location ______ **Reel No.** ______

Analysed By ______ **Identification No.** ______

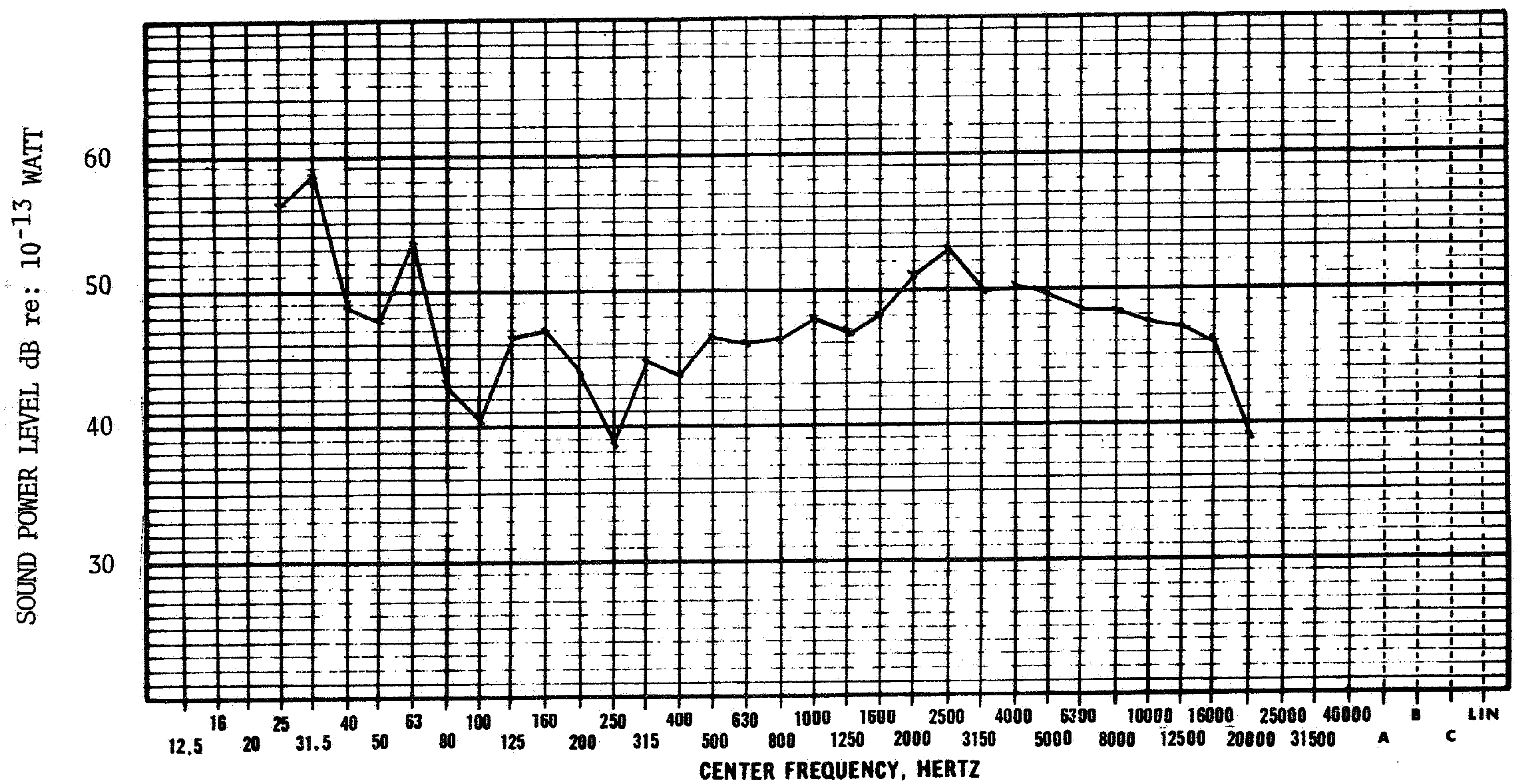
Analysis Method ______ **Sheet** ___ **of** ___

Comments, Sketches, Etc.

——— INLET NOISE

– – – EXHAUST NOISE

FIGURE 78



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP. • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE ESTIMATED NOISE LEVELS FOR THE MODIFIED PUMP

Test Date ______ **Run No.** ______

Mic Location ______ **Reel No.** ______

Analysed By ______ **Identification No.** ______

Analysis Method ______ **Sheet** ___ **of** ___

Comments, Sketches, Etc.

FIGURE 79

The axial fan was estimated to have lower tone noise levels since the rotor to stator distance was significantly increased. Based on rotor to stator gap studies conducted using the Hamilton Standard Axial Flow Fan Performance and Noise Calculation Computer Program, it is expected that the level of the fundamental drops by 10 dB and the level of the second harmonic drops by 8 dB. Since a combination of three blades and five stators places the third and higher harmonics above cutoff, these harmonics are not significantly affected. Remachining of the stators to an airfoil shape significantly reduces the vortex shedding noise. Thus, the wakes are decreased by a factor of approximately five,resulting in a reduction of 7 dB at the peak(that is, in the 100 Hz to 2500 Hz bands). Also, the reduced rotor tip clearance and smoothed leading edges result in approximately 5 dB less rotor vortex noise in the 2000 and 2500 Hz bands. The estimated noise levels for this three-bladed axial fan are shown in figure 78. These levels are estimated from the "as received" hardware test data (figure 67) with the above described reductions applied.

The estimated squirrel cage fan noise is shown in figure 71. As indicated earlier, this estimate was derived from figure 70 by eliminating the motor noise components.

Figure 79 shows the estimated pump noise. This estimate is based on a reduction of 5 dB of the blade passing frequency (at 1000 Hz) due to remachining of the blades, a reduction of 5 dB in the peak at 8000 Hz due to reduced cavitation noise by virtue of smooth inlet flow, and a reduction of 12 dB in the motor noise peak at 2500 Hz by improving the bearing noise characteristics.

MODIFIED HARDWARE TESTS

Test Description

The aerodynamic and acoustic testing of the modified hardware was conducted in a manner similar to that described for the Verification Hardware Testing.

Test Results

Tables XIX, XXI and XXII present the data taken on the modified verification hardware. When the axial fan results in Table XIX are compared with those in Table XVI for the three-bladed fan it can be seen that there is an increase in performance for the unit. The overall efficiency calculations in Table XX indicate an increase in overall fan/motor efficiency of approximately two percentage points, which would result in a 10 percent reduction in motor input power. Both the modified and "as received" fans had higher efficiencies when tested with the inlet noise set-up. This is attributed to the improved air inlet profile with the bellmouth attached to the fan. For outlet testing a duct provided the entrance to the fan.

TABLE XIX

MODIFIED 3 BLADED AXIAL FAN PERFORMANCE DATA
(400 Hz, 3 Phase Motor)

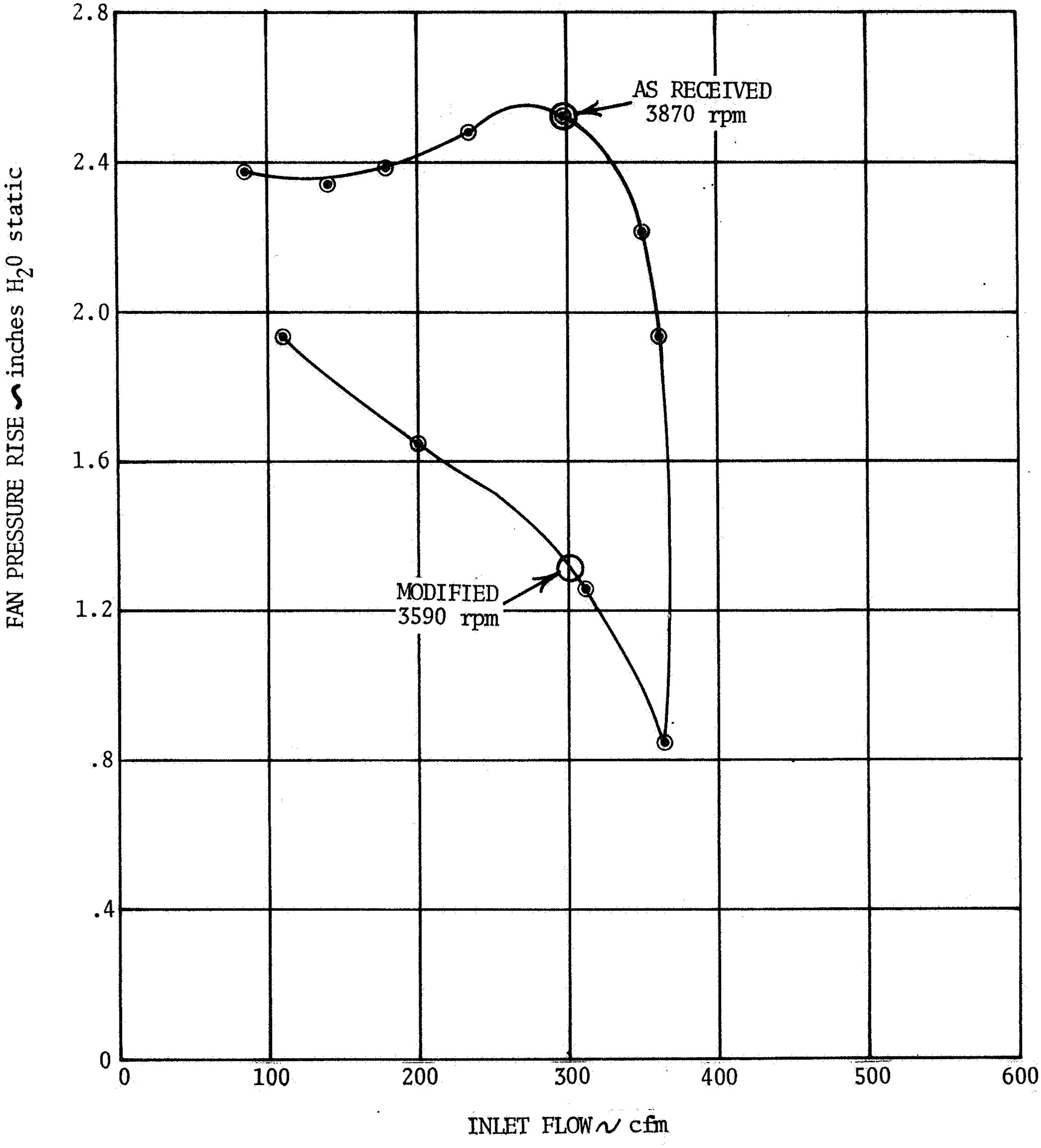
Noise Measurement Set-Up	Inlet	Outlet
cfm	470	460
$\Delta P''H_2O$	2.66	2.66
rpm	9050	9200
volts	132	136
amps/phase	3.06	3.0

TABLE XX

CALCULATED AXIAL FAN OVERALL EFFICIENCY
(Percent)

Noise Measurement Set-Up	"As Received" Fan	"Modified" Fan
Inlet	19.3	21.0
Outlet	18.4	20.4

Table XXI for the squirrel cage fan indicates operation at a lower pressure rise (1.27 inches of water) than was present with the "as received" unit. This difference is caused by the lower speed (3590 rpm) motor which replaced the "as received" (3870 rpm) motor. The difference in fan performance for these two motors is presented in figure 80. The "as received" fan was run with an overall fan/motor efficiency of 12%. The modified unit has only 4.5% overall efficiency. It is believed that this low efficiency is largely due to both a low motor efficiency and a reduced fan efficiency. Because the entire performance point could not be duplicated only the same volume flow was run in both tests.



SQUIRREL CAGE FAN PERFORMANCE

FIGURE 80

TABLE XXI

MODIFIED SQUIRREL CAGE FAN PERFORMANCE DATA
(60 Hz, 1 Phase Motor)

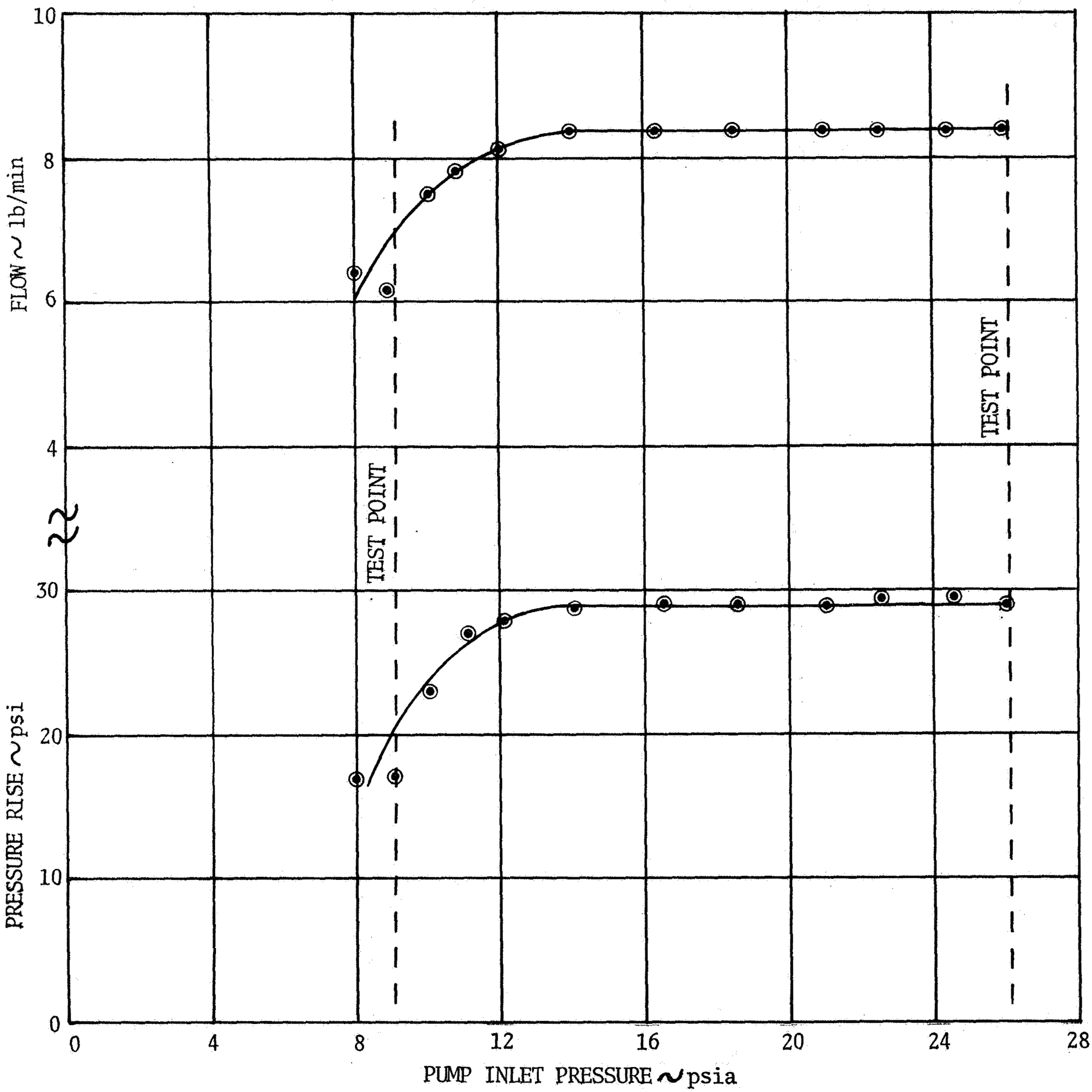
Noise Measurement Set-Up	Inlet	Outlet	Motor
cfm	310	310	-
$\Delta P"H_2O$	1.27	1.27	-
rpm	3590	3590	3600
Volts	106	104	115
Amps	9.7	10	9.1

Table XXII presents the pump test data. There is no appreciable difference in power when the motor was run with ball bearings or sintered bronze bushings. Using the sintered bronze bushings for added noise control, the reservoir pressure level was changed and the pump flow and pressure rise recorded as shown in figure 81. It can be seen that the pump cavitation decreases the flow and pressure rise of the pump at an inlet pressure of 12 psia and less. Inlet pressures of 26 psia and 9 psia were used to test for noise and performance. At 9 psia inlet pressure the unit is somewhat noisier and has only half the overall efficiency of that at 26 psia.

TABLE XXII

MODIFIED CENTRIFUGAL PUMP PERFORMANCE DATA
(400 Hz, 3 Phase Motor)

	UNIT		MOTOR	
	With Bronze Bushings		With Ball Bearings	With Bronze Bushings
Flow lbs/min	6.2	8.2	-	-
P_{in} psia	9	26	-	-
ΔP psi	17	28	-	-
rpm	- -	-	9000	9000
Volts	210	200	210	208
Amps/phase	.43 .50 .54	.41 .50 .53	.31 .33 .35	.30 .32 .34



MODIFIED CENTRIFUGAL PUMP PERFORMANCE

FIGURE 81

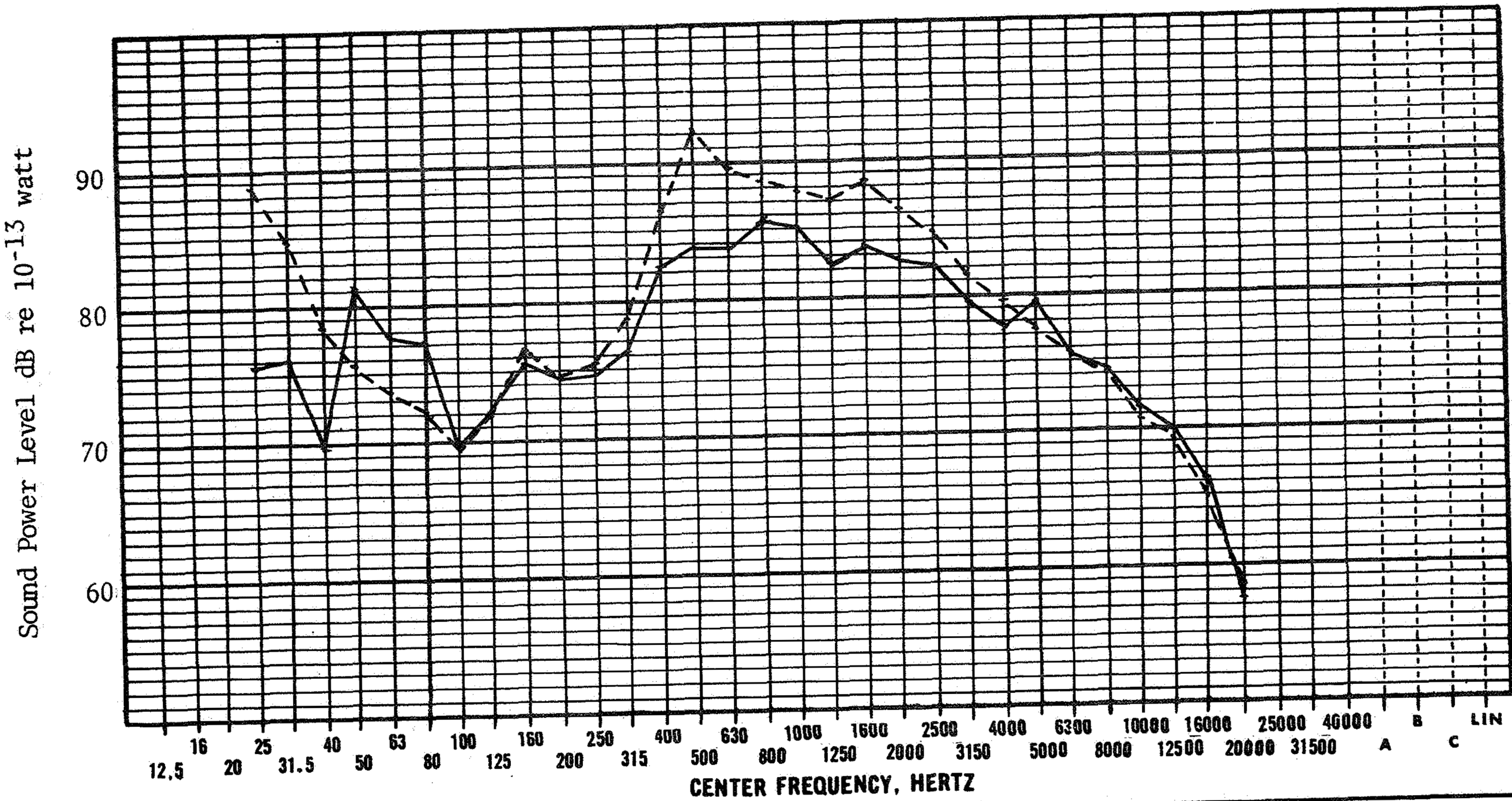
The 1/3 octave band sound power levels, based on measurements of the modified verification hardware tests, are shown in figures 82, 84, 86, 87 & 88 while the octave band levels at the maximum NC value location are shown in figures 83, 85, and 89. The measured 1/3 octave band SPL's are contained in Appendix B.

Figure 82 shows the PWL's for the axial fan. As may be seen in this figure, the tones have been virtually eliminated and are thus not distinguishable to the ear. Also, the mid-frequency broad band noise has been significantly reduced. Some evidence of the blade frequency fundamental tone is still evident in the exhaust noise. Although the mid-frequency broad band noise has been reduced, the achieved reduction of exhaust noise is not as dramatic as that of inlet noise. One possibility for the presence of the tone in the exhaust is that perhaps the decay rate of the tone was not high enough to be significantly affected by the short length of the fan housing. The octave band levels corresponding to the maximum NC values for the axial fan are shown in figure 83. The exhaust noise has maximum penetration into the NC curves at 500, 1000, and 2000 Hz so that to lower its NC level of 76 dB would require reducing the noise in those three bands covering the frequency range 350 to 2800 Hz. The NC value of 73 dB for the inlet noise is set by the level of the 2000 Hz band.

Figure 84 shows the measured squirrel cage fan noise levels for the "as received" fan with the new quiet Dayton motor. As is seen in this figure, the new motor noise levels are much lower than those of the original motor and do not contribute to the fan total noise. Figure 85 shows the octave band levels measured at the location of maximum NC value. Both the exhaust and inlet NC values are set by the level of the 2000 Hz band. The exhaust noise is at an NC value of 64 dB while the inlet noise is at an NC value of 67 dB. However, because of the reduced motor speed, it was not possible to achieve the same performance as before for this fan. Instead of 2.5 inches of water pressure rise, only 1.27 inches of water was achieved.

From the Hamilton Standard Empirical Fan Noise Estimating Procedure described in an earlier section, there is an adjustment for fan pressure rise given as Δ dB = 20 log Δ P. Thus an increase in noise of approximately 6 dB (i.e. 20 log $\frac{2.5}{1.27}$) would be expected for this fan due to increasing its pressure rise from 1.27 to 2.5 inches of water.

In both of these fans the motor noise does not contribute to the NC level. However, motor noise could be a problem in the fans if further quieting is required.



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE MODIFIED 3 BLADED AXIAL FAN NOISE

Test Date ______ **Run No.** ______

Mic Location ______ **Reel No.** ______

Analysed By ______ **Identification No.** ______

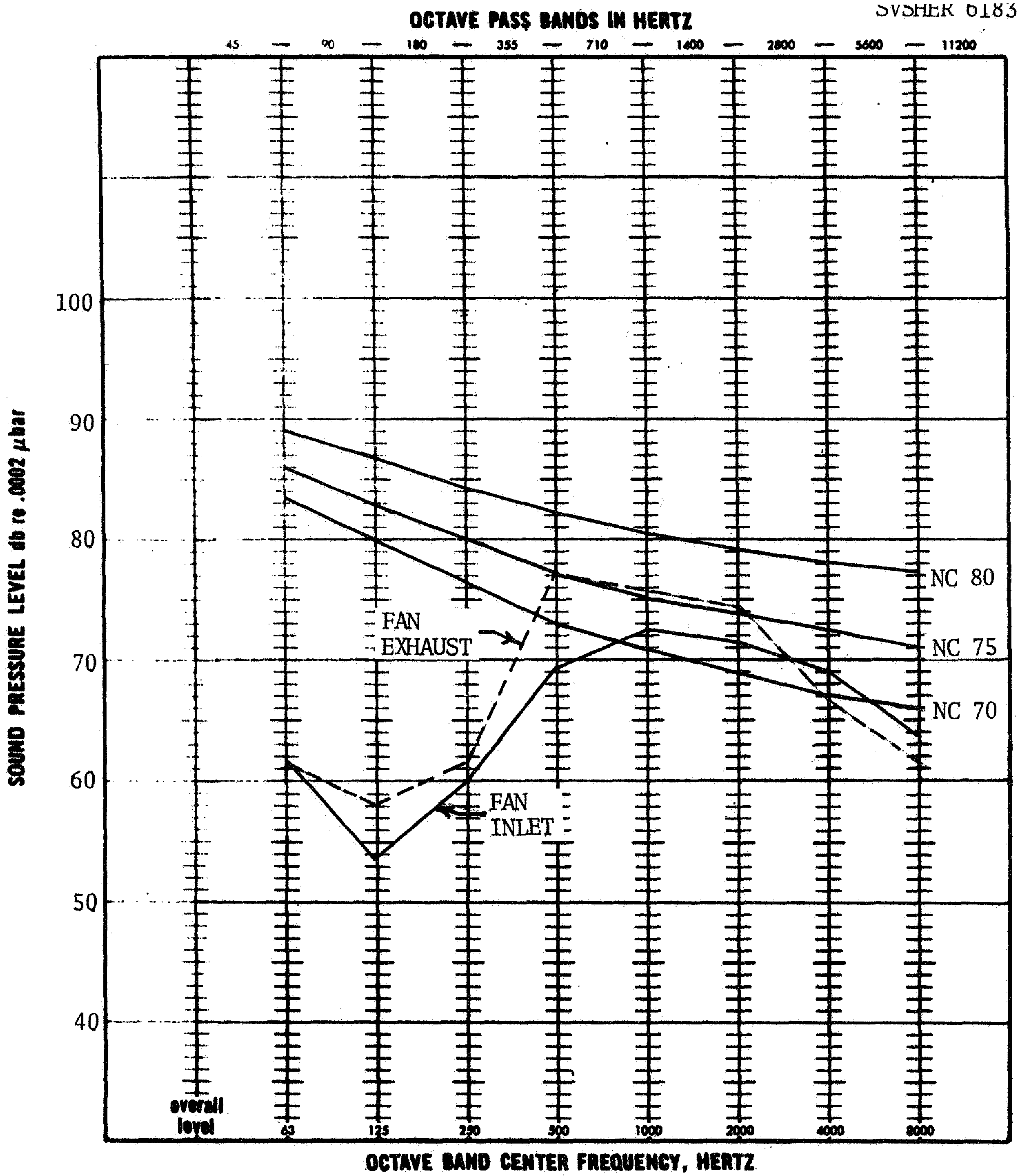
Analysis Method ______ **Sheet** ___ **of** ___

Comments, Sketches, Etc.

——— INLET NOISE 9050 RPM

– – – – EXHAUST NOISE 9200 RPM

FIGURE 82



Hamilton Standard

OCTAVE BAND ANALYSIS

MODIFIED AXIAL FAN NOISE LEVELS
AT THE MAXIMUM NC VALUE LOCATION

FIGURE 83

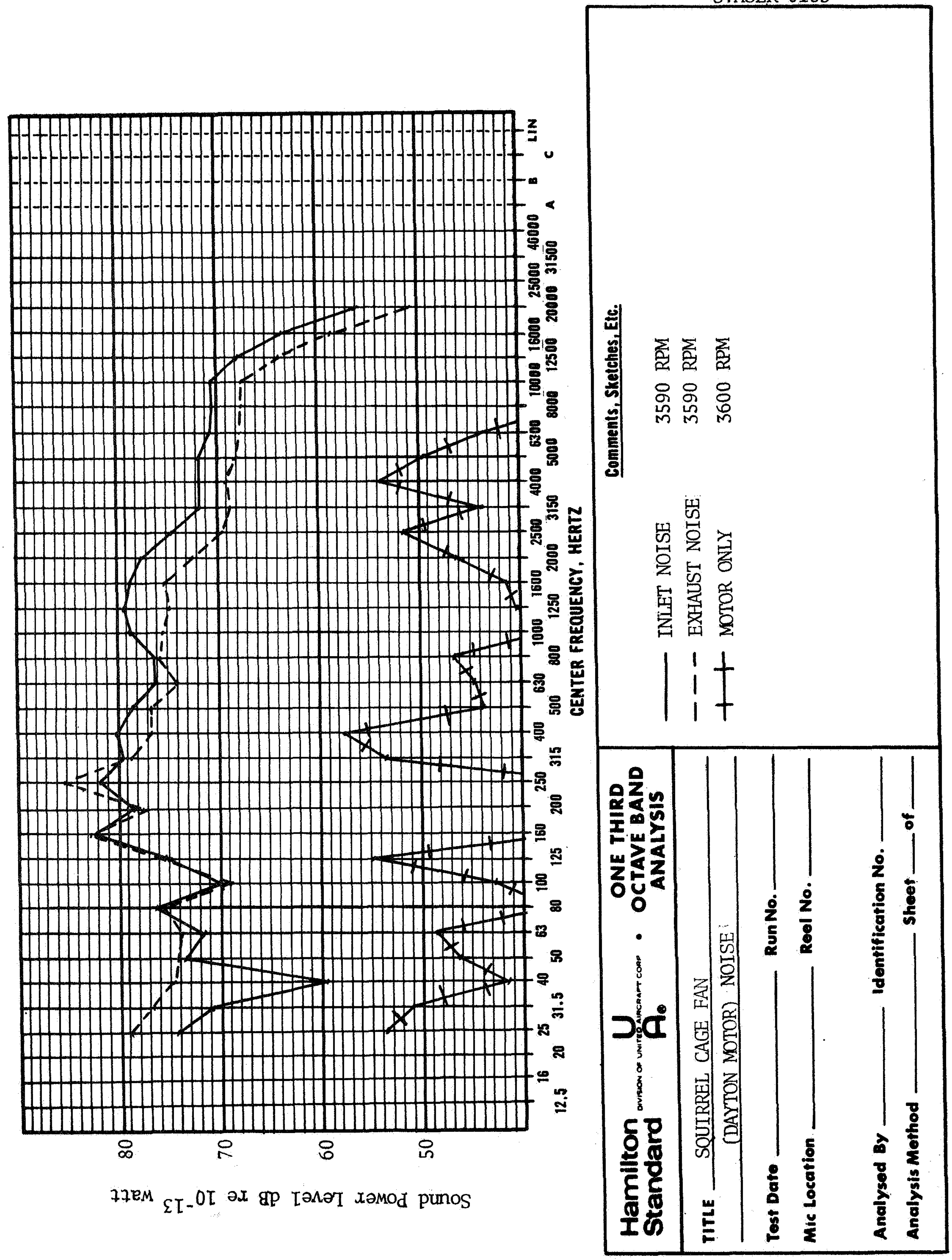
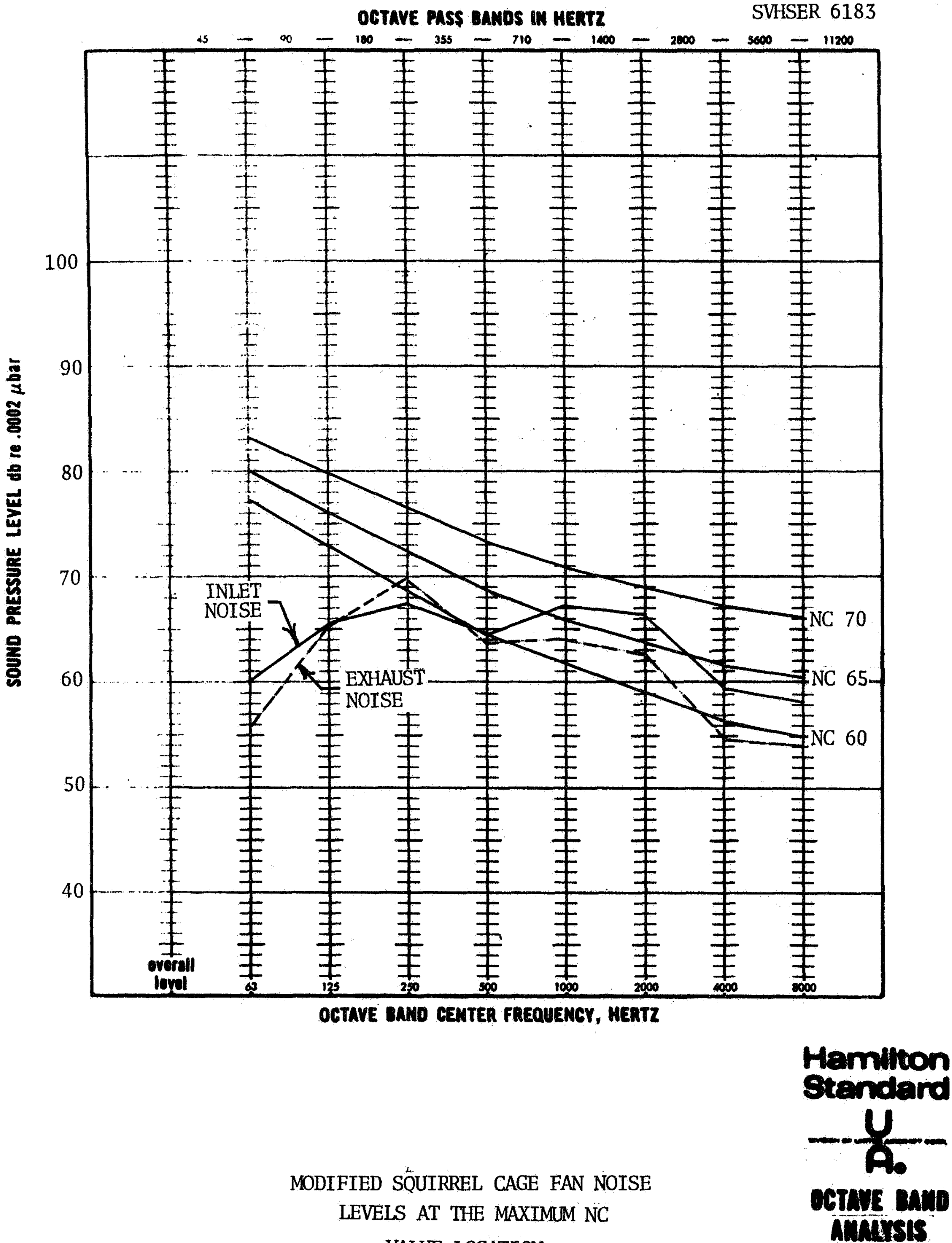

Sound Power Level dB re 10^{-13} watt
80
70
60
50
12.5
16
20
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
6300
8000
10000
12500
16000
20000
25000
31500
40000
A
B
C
LIN
CENTER FREQUENCY, HERTZ
Hamilton Standard
DIVISION OF UNITED AIRCRAFT CORP
ONE THIRD OCTAVE BAND ANALYSIS
TITLE SQUIRREL CAGE FAN
(DAYTON MOTOR) NOISE
Test Date
Run No.
Mic Location
Reel No.
Analysed By
Identification No.
Analysis Method
Sheet
of
Comments, Sketches, Etc.
INLET NOISE 3590 RPM
EXHAUST NOISE 3590 RPM
MOTOR ONLY 3600 RPM

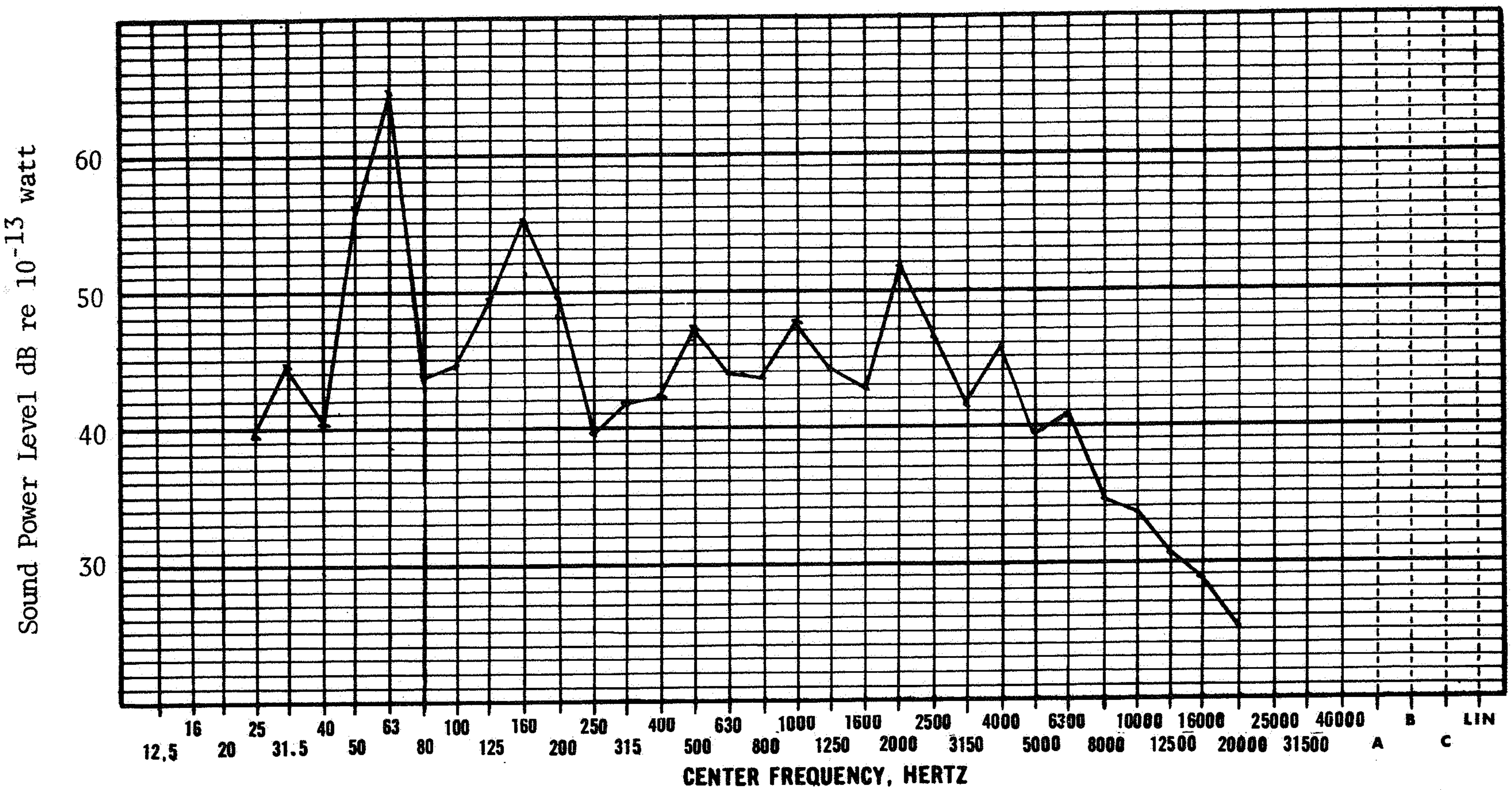
FIGURE 84



MODIFIED SQUIRREL CAGE FAN NOISE
LEVELS AT THE MAXIMUM NC
VALUE LOCATION

FIGURE 85

HSF-1677 3/68*



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE MODIFIED PUMP NOISE

Test Date ______ **Run No.** ______

Mic Location ______ **Reel No.** ______

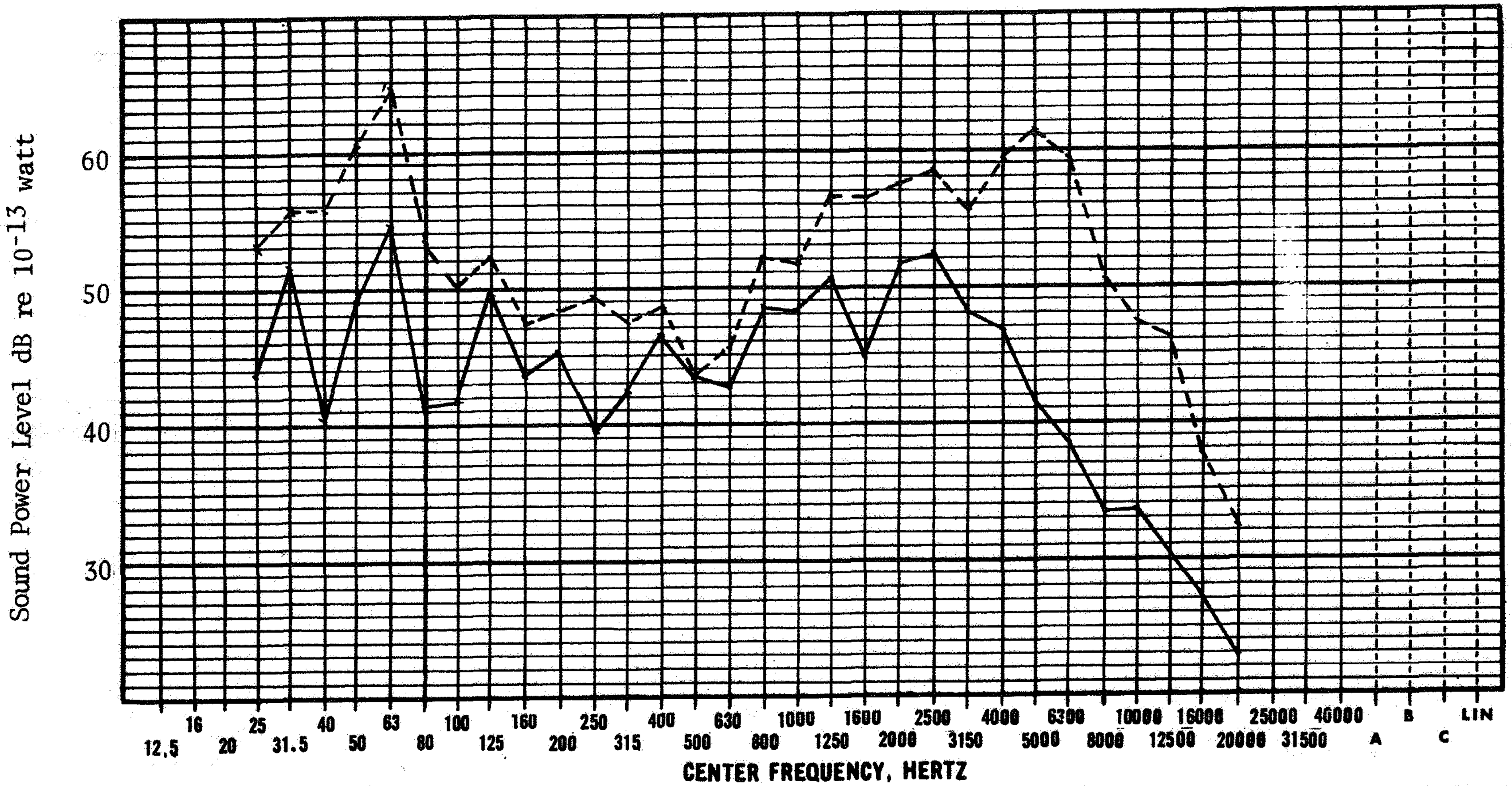
Analysed By ______ **Identification No.** ______

Analysis Method ______ **Sheet** ___ **of** ___

Comments, Sketches, Etc.

9000 RPM

FIGURE 86



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE MODIFIED MICROPUMP
CASE RADIATED NOISE

Test Date ______ **Run No.** ______

Mic Location ______ **Reel No.** ______

Analysed By ______ **Identification No.** ______

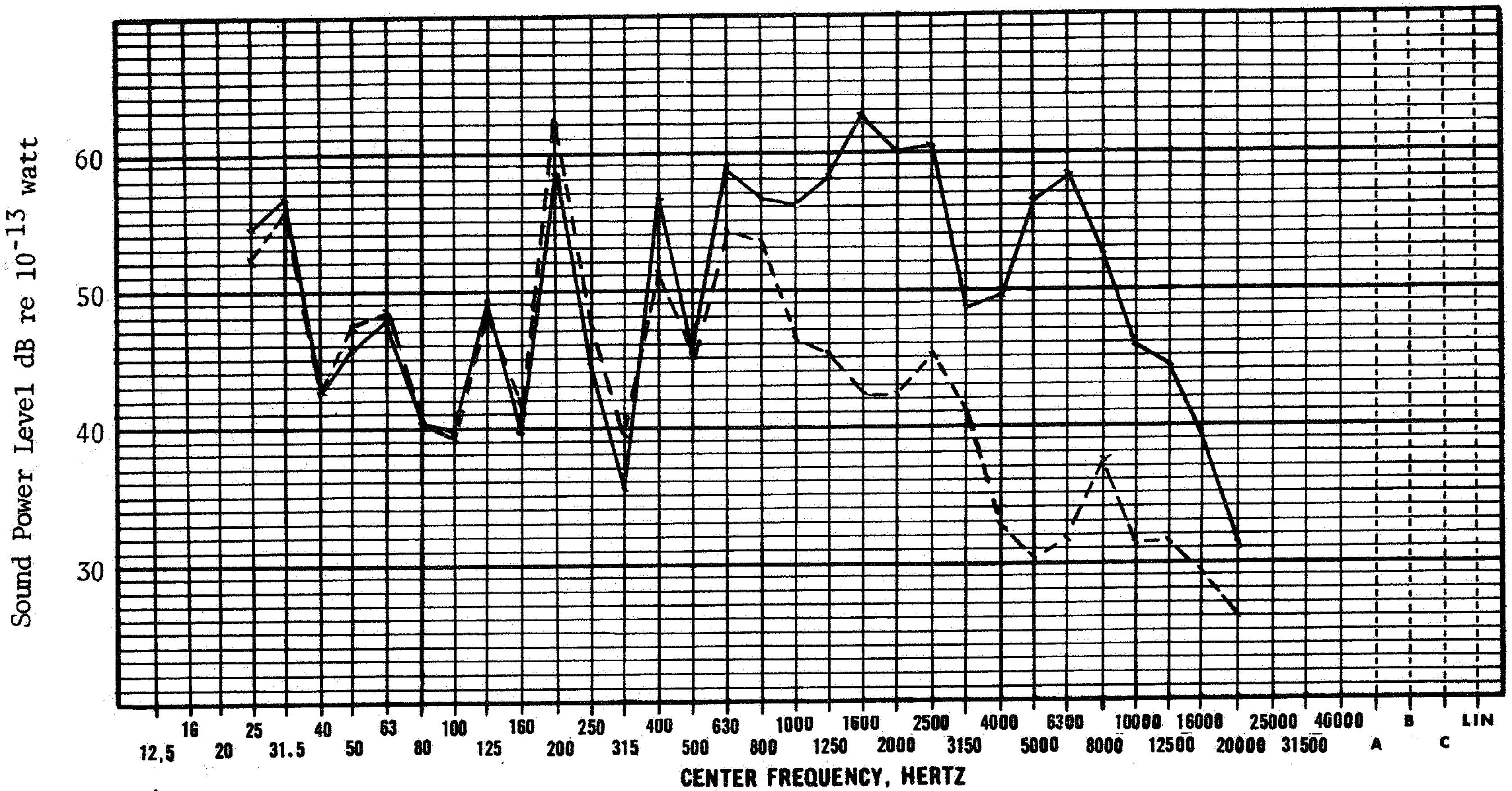
Analysis Method ______ **Sheet** ___ **of** ___

Comments, Sketches, Etc.

— — — 9 psia inlet

———— 26 psia inlet

FIGURE 87



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE PUMP MOTOR NOISE

Test Date ______ **Run No.** ______

Mic Location ______ **Reel No.** ______

Analysed By ______ **Identification No.** ______

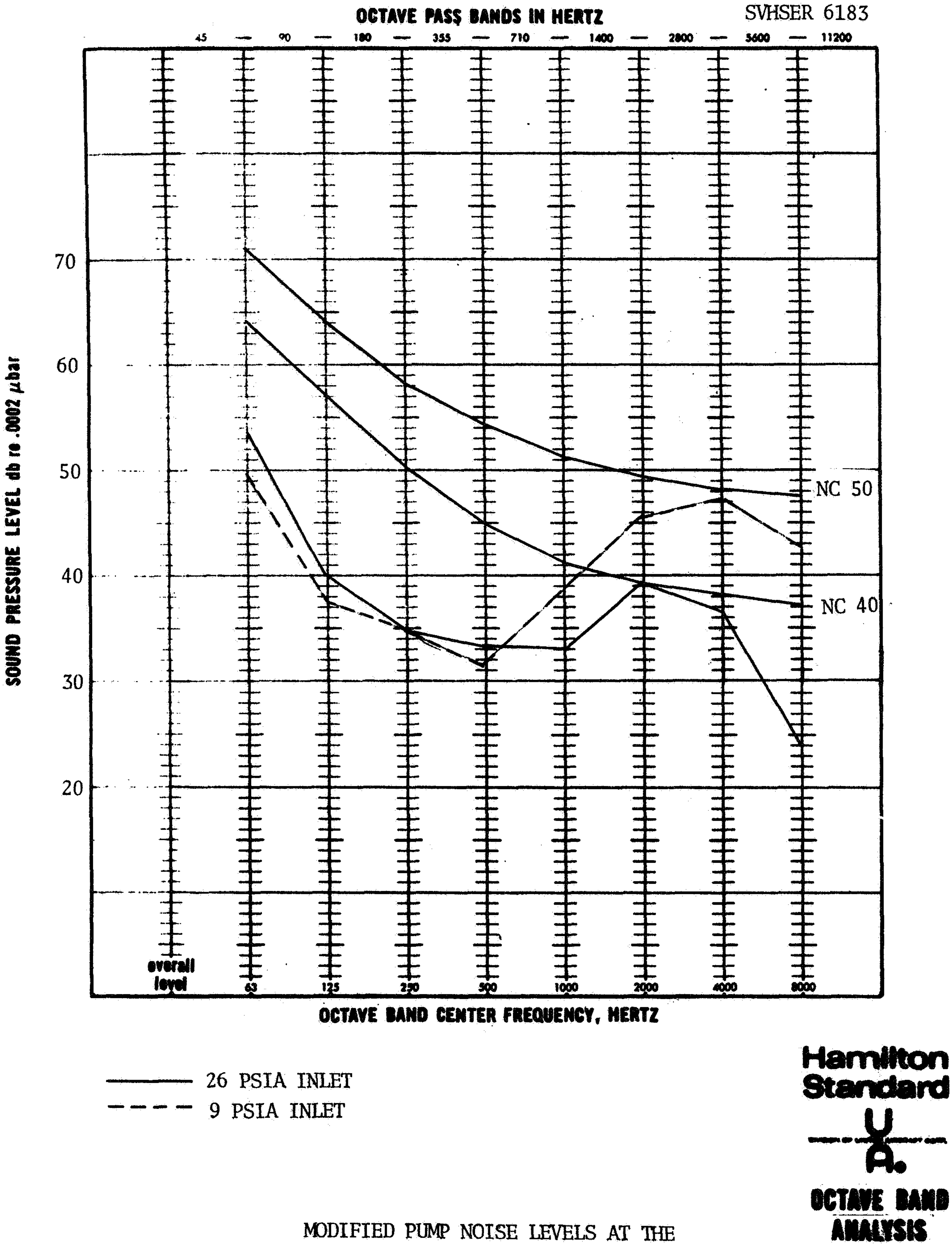
Analysis Method ______ **Sheet** ____ **of** ____

Comments, Sketches, Etc.

——— UNMODIFIED (ball bearings)

– – – MODIFIED (bronze bushings)

FIGURE 88



MODIFIED PUMP NOISE LEVELS AT THE

MAXIMUM NC VALUE LOCATION

FIGURE 89

Figure 86 shows the measured pump noise levels for an inlet pressure of 26 psia. The tones in the 63 and 160 Hz bands are due to the 60 Hz line frequency and are not part of the pump acoustic noise. As is seen from this figure, the high level tone in the 2000 Hz band has been significantly reduced as has the high frequency broad band noise. Figure 87 shows a second set of measurements which were made to evaluate the cavitation noise. This figure shows that at 9 psia inlet pressure, significant noise is generated in the 1000 to 20,000 Hz bands. It thus is important to maintain pump inlet pressures sufficiently high to avoid cavitation, which causes significant noise generation and will contribute to mechanical failure. Figure 88 shows the reduction in noise of the pump motor by replacing the original ball bearings with bronze bushings. Although the low frequency noise was unaffected - but is much lower when tested with the pump, perhaps because of load versus no load operation - there is a significant reduction in the mid- and high frequency noise levels, typically 15 dB. Figure 89 shows the octave band levels measured at the maximum NC value location. This figure shows that NC levels are 40 dB and 49 dB at 26 and 9 psia inlet pressures, respectively.

The achieved noise reductions are summarized in Table XXIII, which presents the maximum NC values measured at three feet.

TABLE XXIII

SUMMARY OF ACHIEVED NOISE REDUCTION

Unit	Measured dBNC Value at Three Feet	
	Unmodified	Modified
Axial Fan		
Inlet	83	73
Outlet	79	76
Squirrel Cage Fan		
Inlet	79	67
Outlet	77	64
Squirrel Cage Adjusted for Flow, and Pressure Rise		
Inlet	80	73
Outlet	78	70
Pump	50	40

Although only 3 dBNC reductions are indicated for the axial fan exhaust noise, it is believed that an additional 3 dBNC could be achieved with a longer exhaust duct to promote further decay of the rotor/stator interaction tones, resulting in an overall NC value reduction of 10 dBNC rather than the 7 dBNC shown. Although the squirrel cage fan noise reduction is indicated in the table to be 12 dBNC, this does not take into account the adjustment due to the lower performance of the modified fan. The actual noise reduction which was achieved is more like 7 dBNC, making the noise levels of the axial and squirrel cage fans approximately equal.

The pump noise reduction achieved was 10 dBNC.

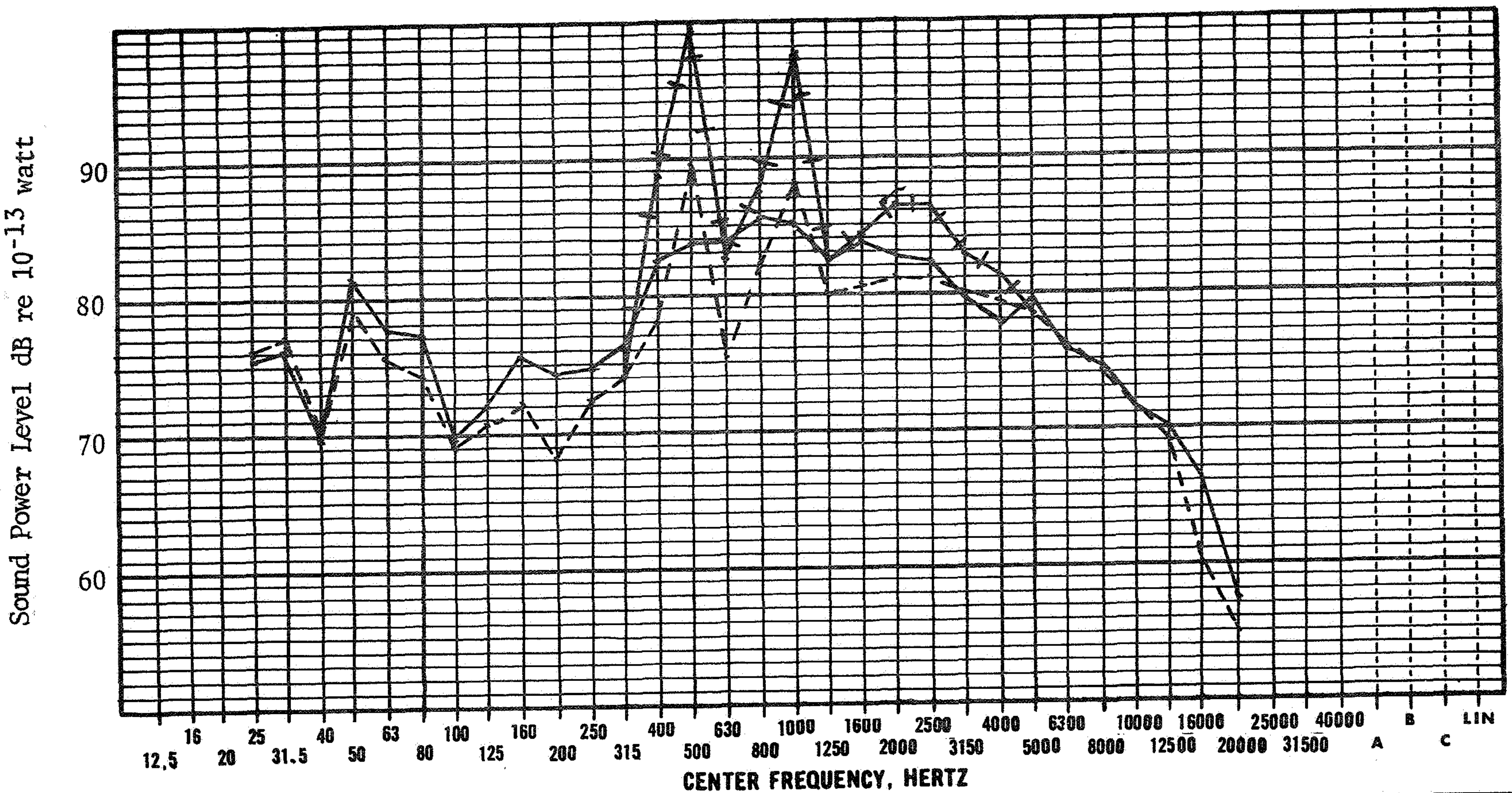
Comparison of Modified with Unmodified Hardware

Figures 90 and 91 show comparisons of the unmodified fan noise levels with those estimated and measured for the modified axial fan. In figure 90 the fan inlet noise levels are summarized. The reduction in the levels of the fundamental and second harmonic was slightly underestimated, as reductions of 16 dB and 12dB, respectively, were achieved compared to predicted reductions of 10 dB and 8 dB, respectively. The estimate was based on the reduction of the interaction noise by moving the stators further downstream from the rotor. However, cleaning up the blade leading and trailing edges could further reduce the strength of the wakes impinging on the stator assembly. The reduction of the mid-frequency noise was well predicted.

Figure 91 shows that although a reduction of 10 dB was predicted for the fundamental tone in the exhaust noise, only 3.5 dB was achieved. As previously mentioned, this is believed to be due to an insufficient length of duct to promote decay of the rotor-stator interaction field in the exhaust. Again, the agreement in the mid- and high frequency bands is good. Although a reduction of about 6 dBNC was anticipated for the modifications, only 3 dBNC was measured, due primarily to the high residual fundamental tone noise level.

Figures 92 and 93 show similar plots for the squirrel cage fan. Allowing for the 6 dB adjustment to the fan levels for the performance difference, the correlation is seen to be quite good.

Figure 94 shows the levels for the pump. The estimated and measured NC value set by the level of the 2500 Hz bands are very close. The very high frequency noise (above 4000 Hz), believed due to cavitation, was significantly reduced even more so than had been estimated by raising the inlet pressure.



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE MODIFIED AXIAL FAN
INLET NOISE

Test Date ______ **Run No.** ______

Mic Location ______ **Reel No.** ______

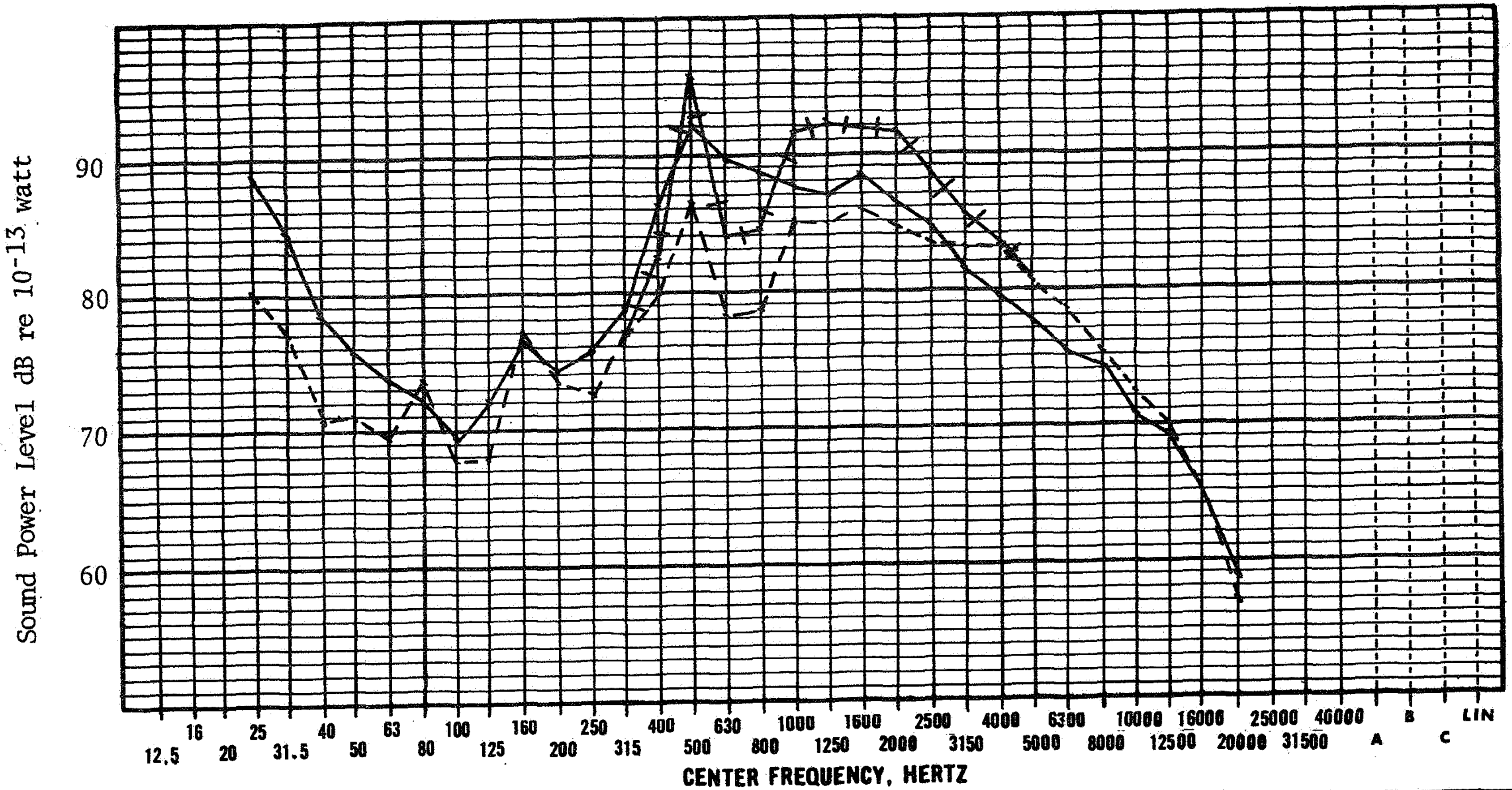
Analysed By ______ **Identification No.** ______

Analysis Method ______ **Sheet** ____ **of** ____

Comments, Sketches, Etc.

— — — ESTIMATED } MODIFIED FAN
——— MEASURED }
—+—+— UNMODIFIED FAN

FIGURE 90



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP. **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE MODIFIED AXIAL FAN
EXHAUST NOISE

Test Date ______ **Run No.** ______

Mic Location ______ **Reel No.** ______

Analysed By ______ **Identification No.** ______

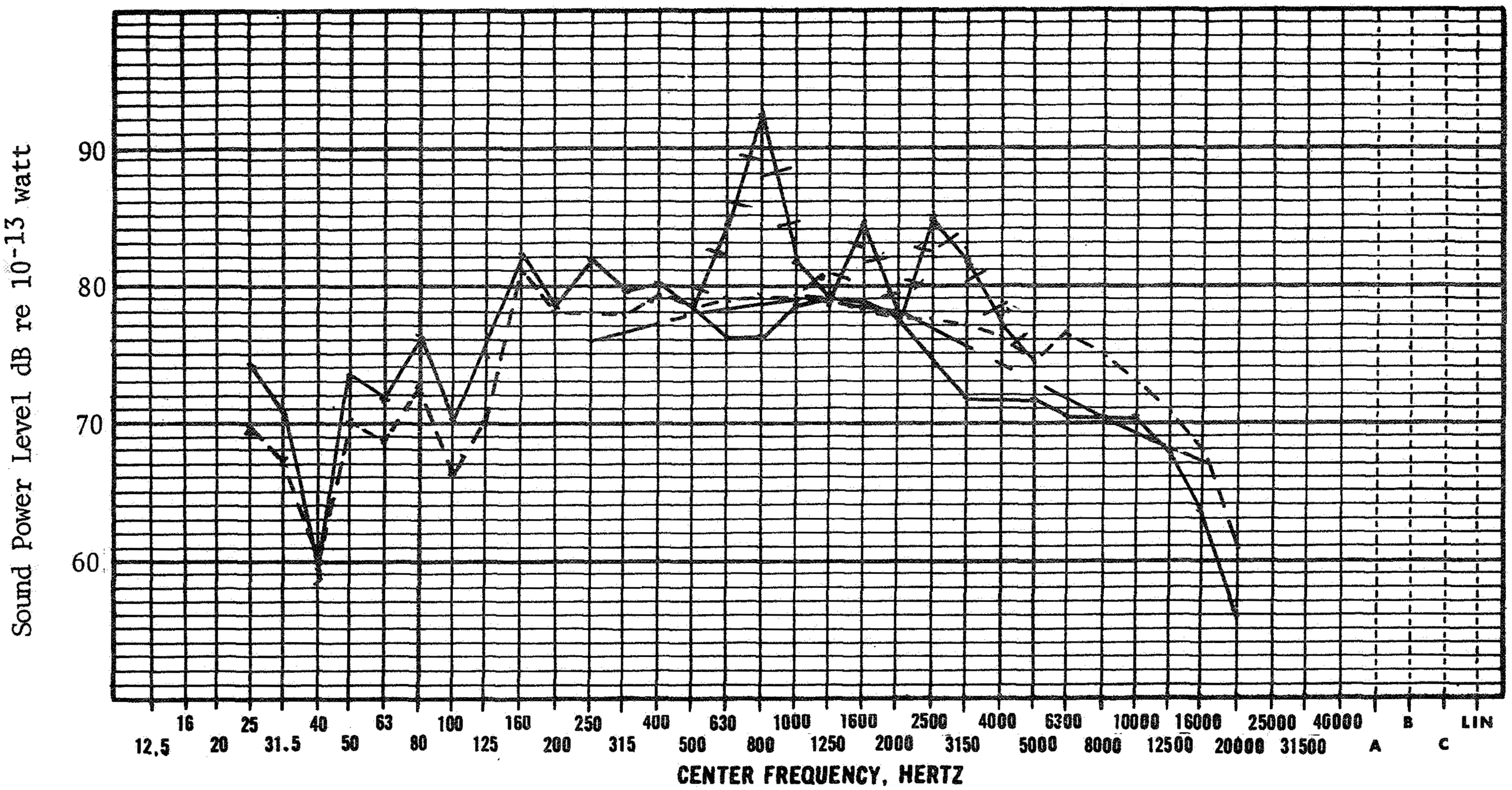
Analysis Method ______ **Sheet** ____ **of** ____

Comments, Sketches, Etc.

ESTIMATED } MODIFIED FAN
MEASURED }

UNMODIFIED FAN

FIGURE 91



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE SQUIRREL CAGE FAN
INLET NOISE

Test Date ______ **Run No.** ______

Mic Location ______ **Reel No.** ______

Analysed By ______ **Identification No.** ______

Analysis Method ______ **Sheet** ___ **of** ___

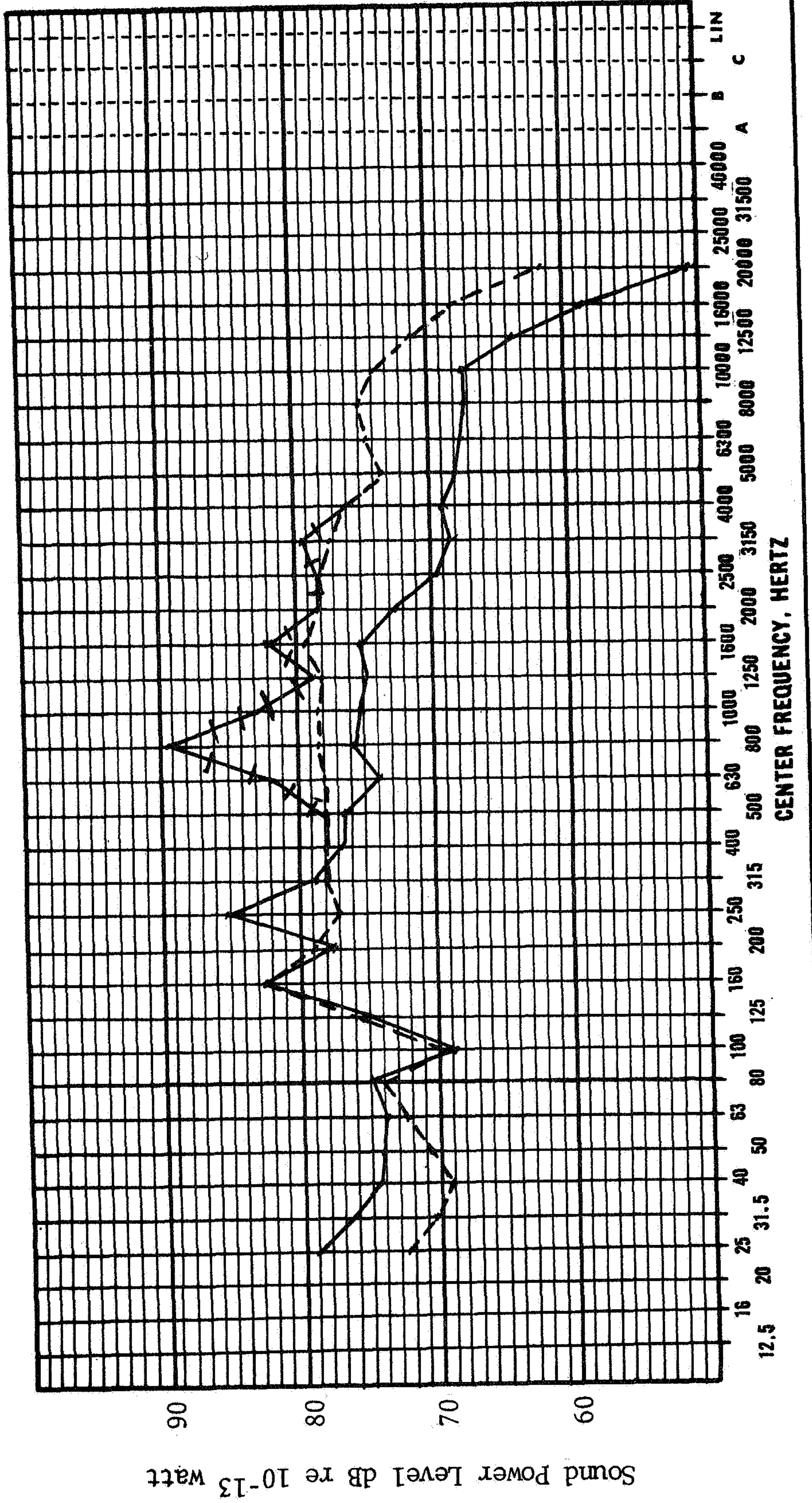
Comments, Sketches, Etc.

— - — PREDICTED (50% EFFIC.)
— — ESTIMATED
——— MEASURED

MODIFIED FAN

—+—+— UNMODIFIED FAN

FIGURE 92



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE SQUIRREL CAGE FAN EXHAUST NOISE

Test Date ______ Run No. ______

Mic Location ______ Reel No. ______

Analysed By ______ Identification No. ______

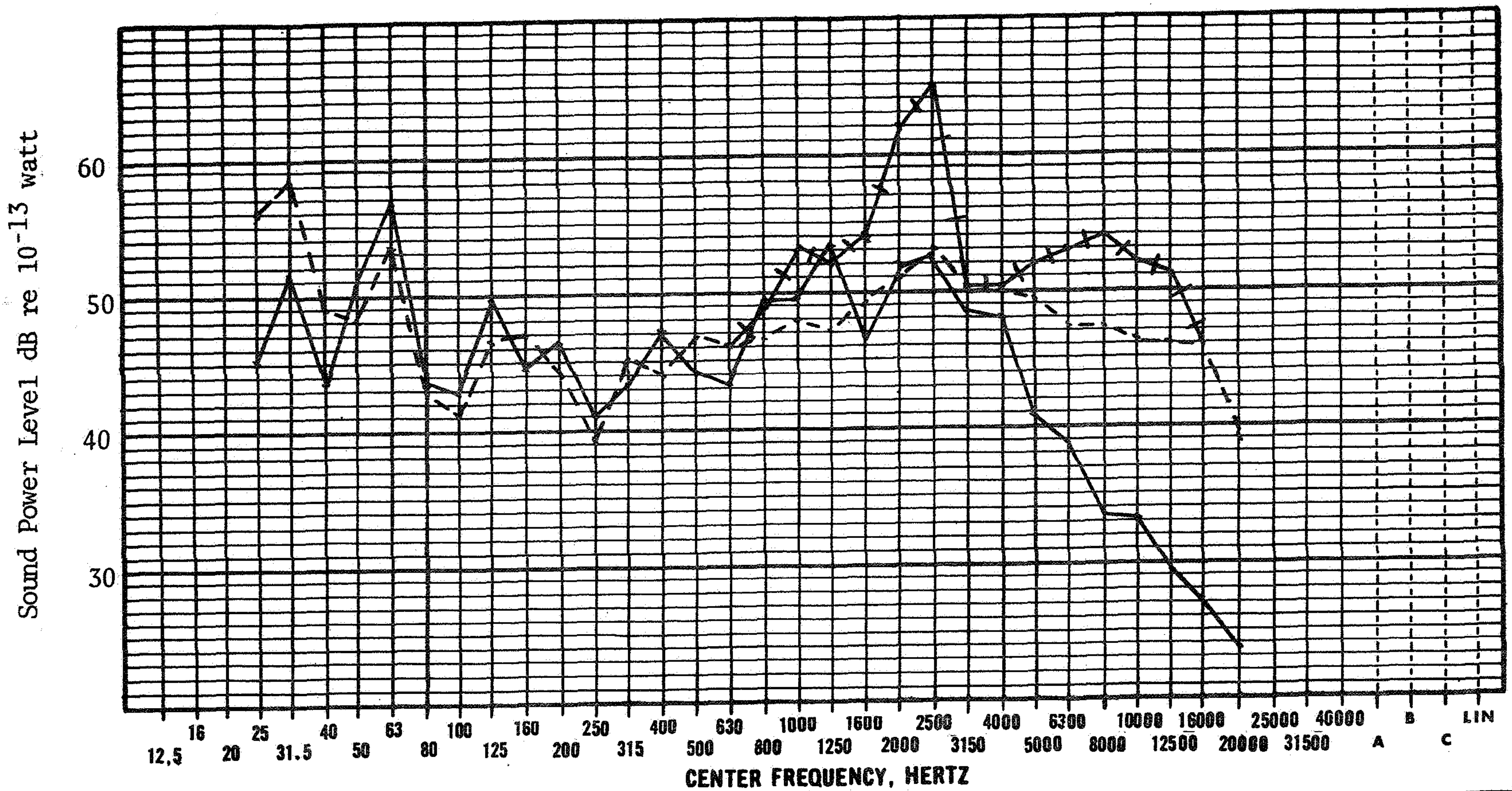
Analysis Method ______ Sheet ____ of ____

Comments, Sketches, Etc.

ESTIMATED, MEASURED: MODIFIED FAN

UNMODIFIED FAN

FIGURE 93



Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP • **ONE THIRD OCTAVE BAND ANALYSIS**

TITLE PUMP NOISE LEVELS

Test Date ______ **Run No.** ______

Mic Location ______ **Reel No.** ______

Analysed By ______ **Identification No.** ______

Analysis Method ______ **Sheet** ____ **of** ____

Comments, Sketches, Etc.

— — — ESTIMATED
——— MEASURED
} MODIFIED PUMP (AT 26 PSIA INLET PRESSURE)

—+—+— UNMODIFIED PUMP

FIGURE 94

Further Noise Reduction Potential

As previously mentioned, the axial fan exhaust noise can be reduced by the use of an exhaust duct. The fan inlet broad band noise might be reduced by the use of porous materials at the blade leading and trailing edges. The use of this material has been found to reduce the broad band noise by up to 15 dB (73). In addition, better designed and better aligned stator blades, requiring a detailed study of the axial and swirl components into the stators, could result in reduction of the stator noise. Porous surfaces also have been found to be of benefit in this application. Noise reduction also can be achieved by using screens or straightening tubes to reduce the inlet flow turbulence. This reduces both the tone and broad band noise and would result in a 5 dB improvement in the exhaust noise.

The squirrel cage fan has some noise reduction potential by optimizing the blade shapes, twist distribution and by the use of airfoil shapes. Porous blade surfaces are applicable to this fan also. In both the inlet and exhaust noise spectra may be seen a broad peak center at 1250 Hz. This frequency corresponds roughly to the turbulent boundary layer radiation frequency, assuming a boundary layer thickness of 0.015 inches. This noise mechanism could be reduced by the use of porous trailing edges. The reduction of this source would result in an NC value reduction of approximately 5 dB in the inlet and 4 dB in the exhaust.

The pump noise levels are quite low, at an NC value of 40 dB at three feet. Much of the residual noise is still due to the motor. Thus quieting this pump entails more careful motor design. A potted stator assembly, hydrodynamic bearings, and a heavier casing ostensibly could achieve a further reduction of 10 dBNC.

DEVELOPMENT OF DESIGN CRITERIA

This section summarizes the technical acoustical findings of this study. It includes general noise-to-performance relationships for several types of fans and compressors. These are intended to give a quick estimate of the anticipated noise level of a general, good aerodynamic design, but do not include any special low noise design characteristics. A more detailed discussion of the noise and performance parameters of axial fans is included. Finally, a compilation of guidelines, constraints, and rules of thumb, is included for general design and installation considerations of fans and pumps.

NOISE-TO-PERFORMANCE RELATIONSHIPS OF FANS

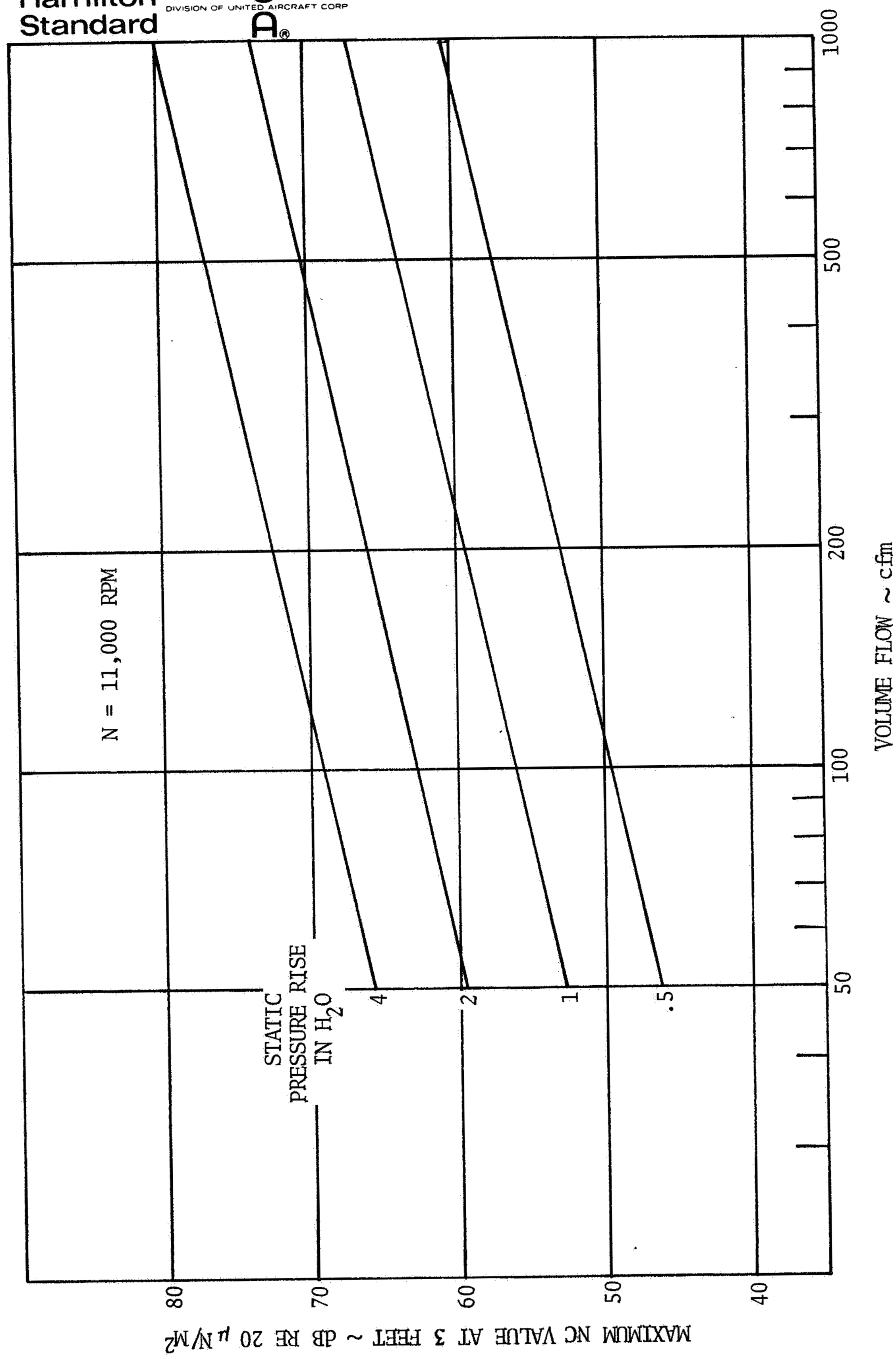
The noise levels, in terms of NC value at three feet, for axial, squirrel cage, and centrifugal fans are shown in figures 95, 96, and 97, respectively, as functions of volume flow and pressure rise. These curves were derived from the Empirical Fan Noise Estimating Procedure, which was used to calculate the octave band spectrum for these fans. The NC values then were calculated from the estimated spectra.

Figure 95 shows the noise-to-performance relationships of axial fans covering the flow range of 50 to 1000 cfm and the pressure rise range of 0.5 to 4 inches of water.

Figure 96 shows the noise-to-performance relationships of squirrel cage fans for the same range as the axial fan.

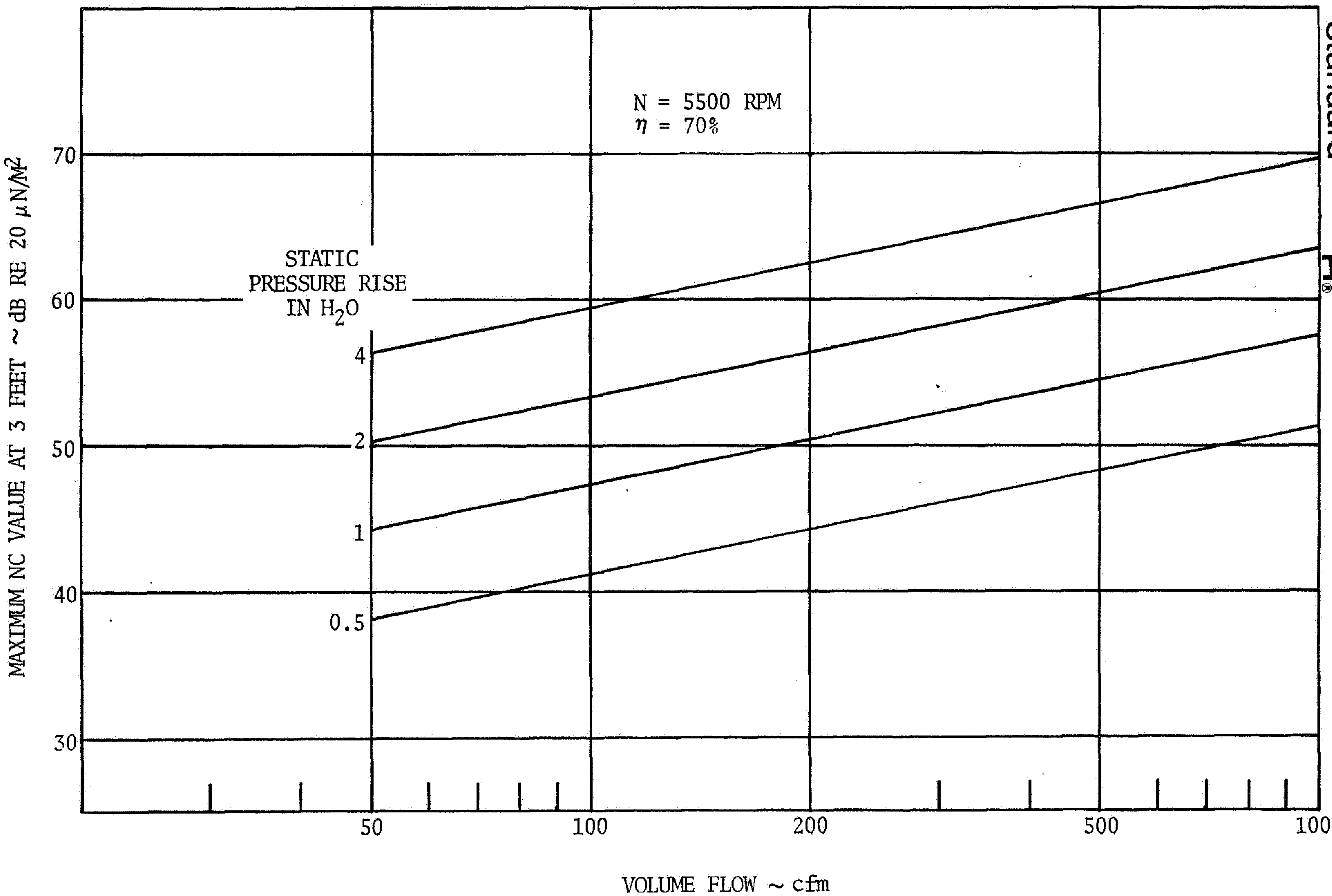
Figure 97 shows the relationships for centrifugal compressors.

As may be seen from these curves, the centrifugal fans are the noisiest units, while the squirrel cage fans are the quietest units.



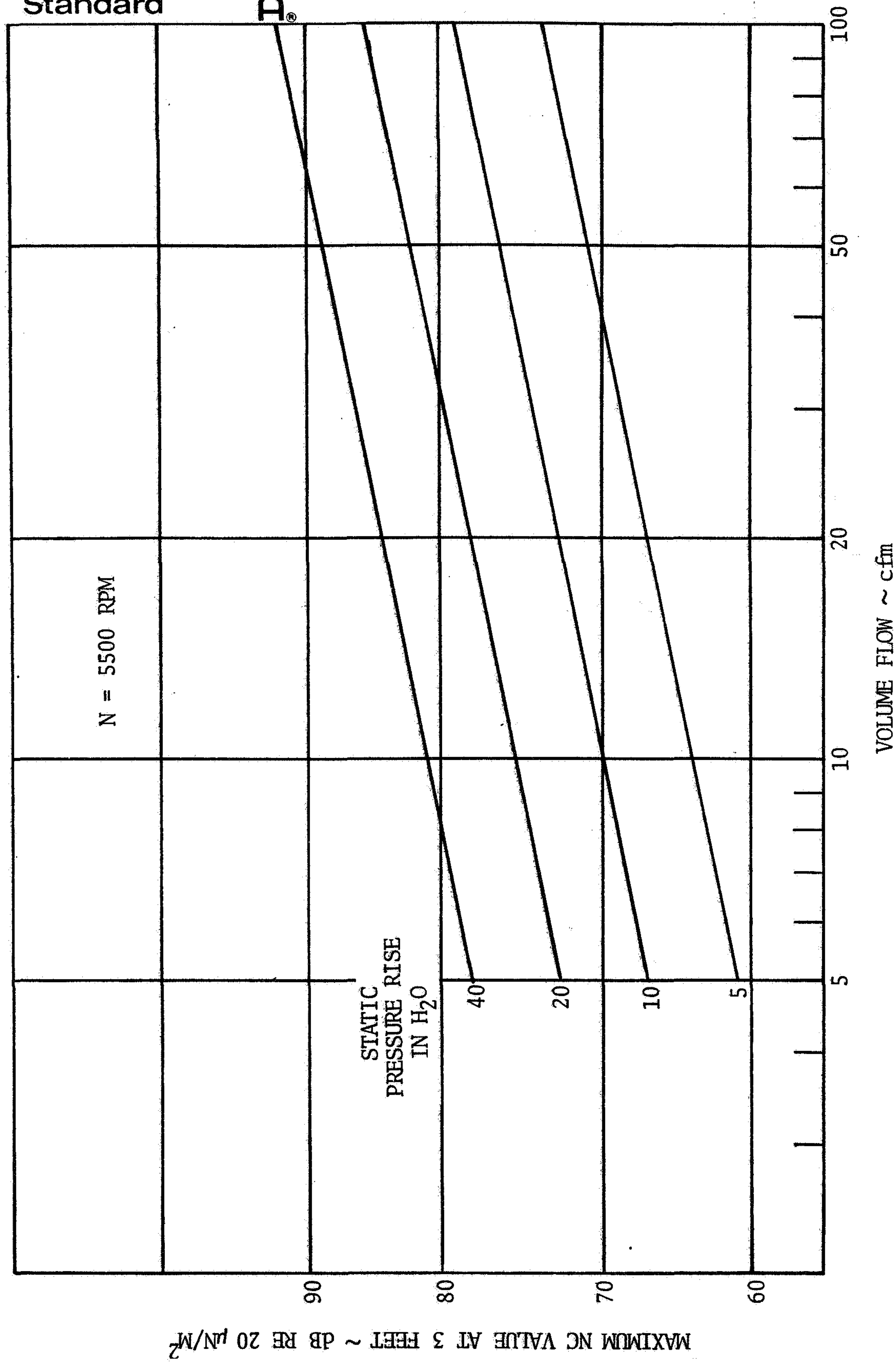
NOISE, PRESSURE RISE, AND FLOW RELATIONS FOR THE AXIAL FLOW FAN

FIGURE 95



NOISE, PRESSURE RISE, AND FLOW RELATIONS
FOR THE SQUIRREL CAGE FAN

FIGURE 96



NOISE, PRESSURE RISE, AND FLOW RELATIONS FOR THE CENTRIFUGAL FAN

FIGURE 97

AXIAL FAN PARAMETRIC MAPPING

Axial fan parametric noise mapping studies were made using the previously described Hamilton Standard Axial Flow Fan Performance and Noise Calculation Computer Procedure. Noise variations as a function of fan diameter, tip speed, number of blades, number of vanes and the blade-vane gap were investigated, all at the Space Shuttle design point of 400 cfm flow and 2.5 inches of water static pressure rise.

Fan Description

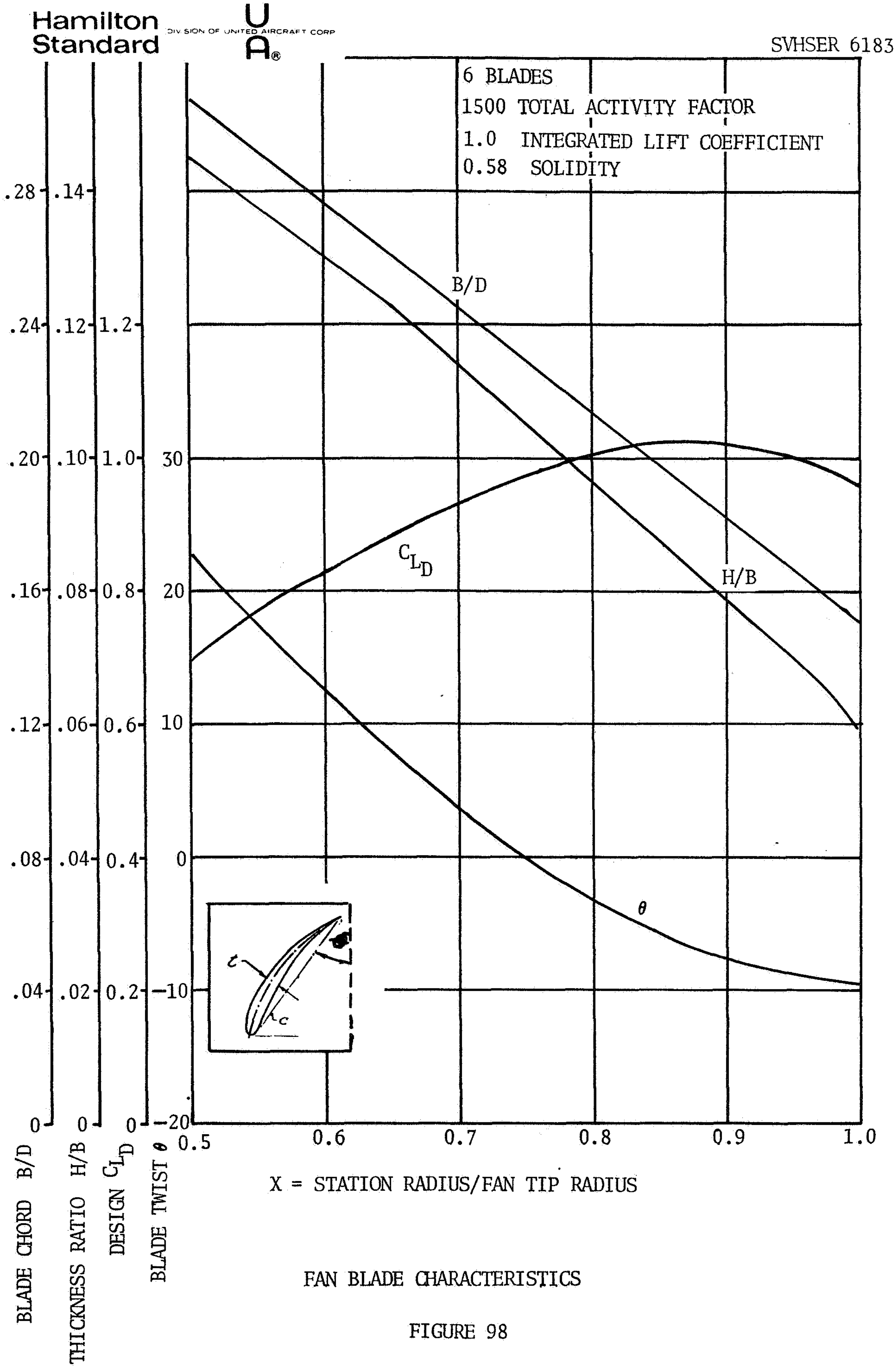
The basic fan design - that is the solidity, planform, twist, camber, twist distribution, and airfoil selection - chosen for this study is one which was originally designed as a lift fan for a Surface Effect Vehicle. The pressure rise and non-dimensional flow characteristics of this fan are well suited to the Space Shuttle requirement of 2.5 inches of water static pressure rise and 400 cfm flow.

A series 16 airfoil is used and the blade characteristics of this fan are summarized in figure 98. Note that the blade chords shown in this figure are for a six bladed fan. For constant aerodynamic performance blade chord should vary inversely as the number of blades to maintain constant total blade area. With a total activity factor of 1500, the fan has a solidity of 0.58 and an integrated lift coefficient of 1.0. The blade planform is very nearly trapezoidal with a 2 to 1 taper ratio, a thickness ratio of 0.06 at the tip and approximately 31.5 degrees of blade twist.

Performance Study Parameters

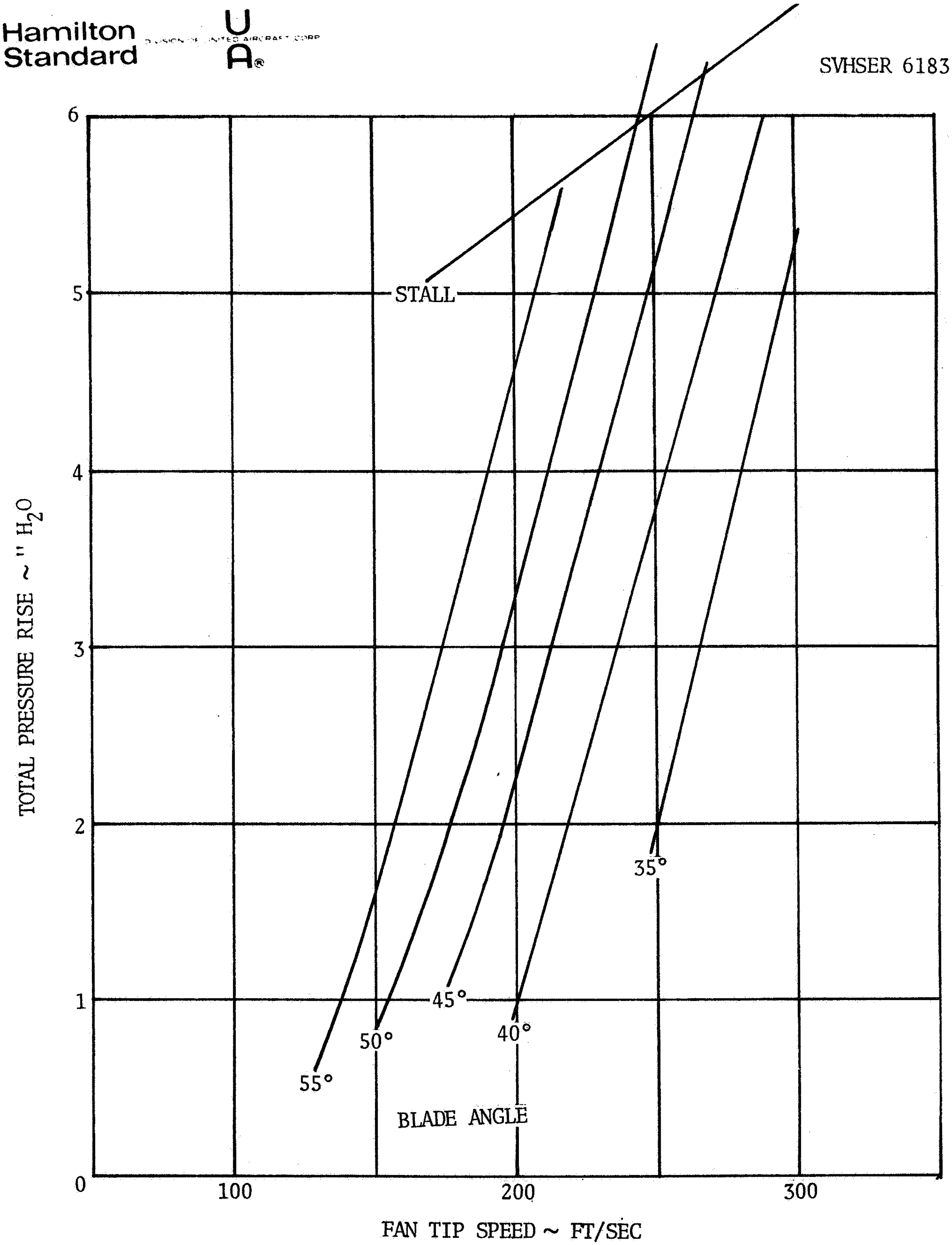
The Space Shuttle fan design point requires 400 cfm flow at 2.5 inches of water (13 psf) static pressure rise. Hamilton Standard's experience in previous designs indicates a fan diameter range of 3.5 to 6.5 inches with tip speed ranges of 100 to 300 ft/sec. To define the diameter, tip speed, and blade angle which gave the desired pressure rise at the desired flow 250 different fans were designed. These designs included the combinations of five diameters (3.5, 4.25, 5, 5.75, and 6.5 inches), five tip speeds (100, 150, 200, 250, 300 ft/sec), and ten blade angles (from 10 to 55 degrees in 5 degree increments).

The fans were designed using a Hamilton Standard axial flow fan performance calculation computer program which calculates, among other things, the blade section angles of attack, the fan stagnation pressure rise, and the fan rotor efficiency. The data from these computations first were plotted as pressure rise versus tip speed and blade angle for each diameter fan. These are shown in figures 99 through 103 for the five fan diameters. Also shown on



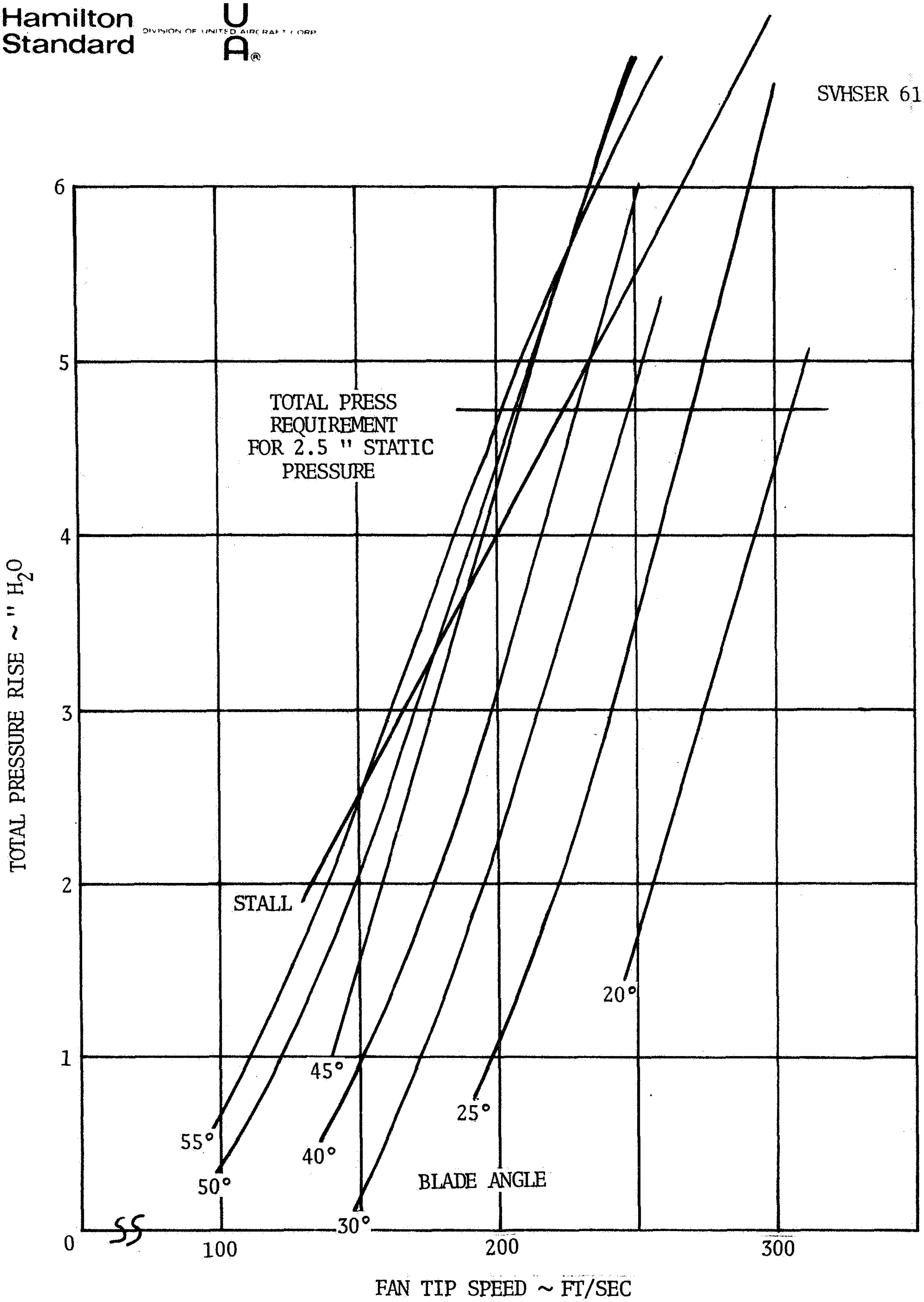
FAN BLADE CHARACTERISTICS

FIGURE 98



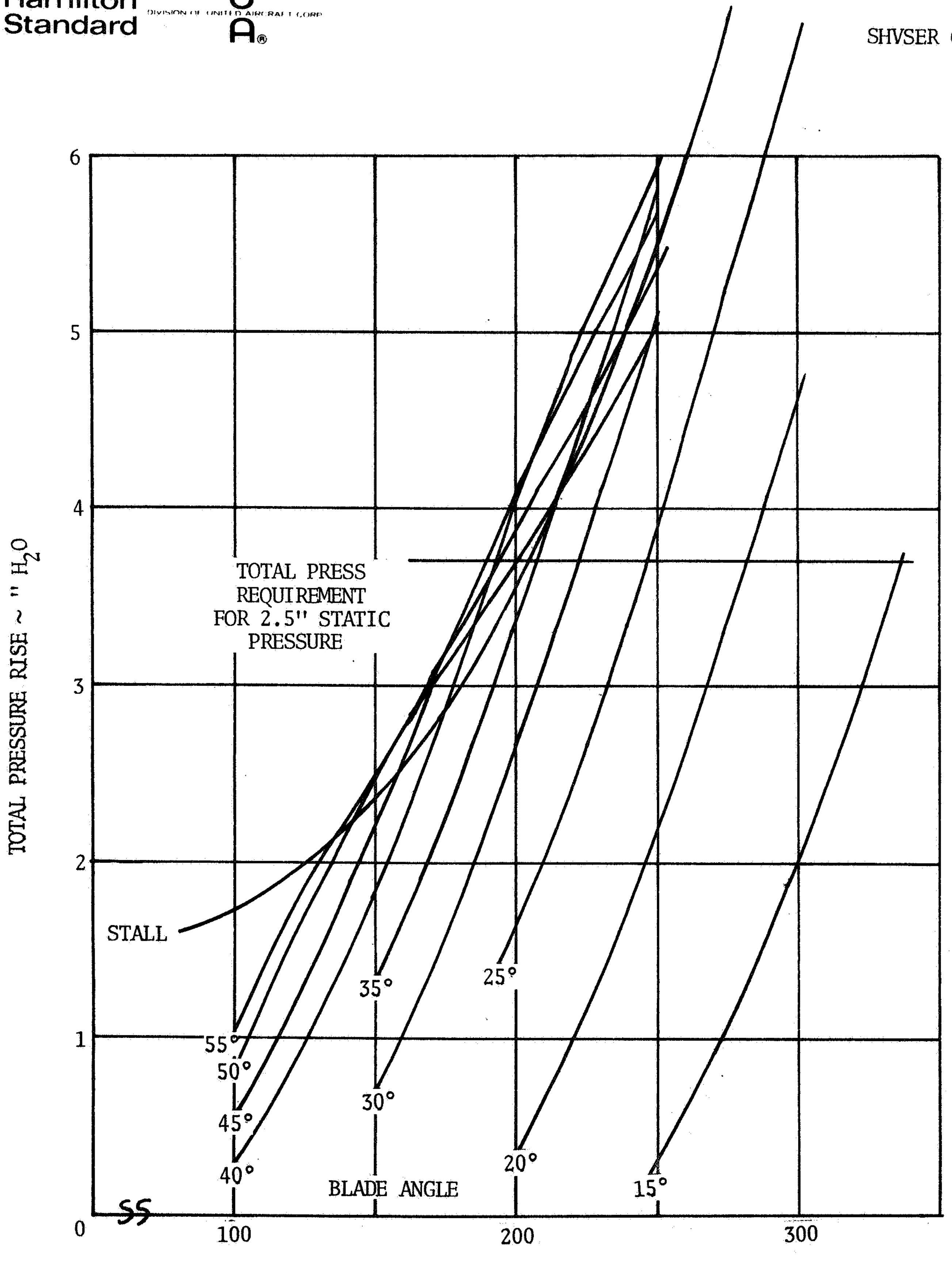
PRESSURE RISE/TIP SPEED RELATIONSHIPS
FOR THE 3.5 INCH DIAMETER FAN

FIGURE 99



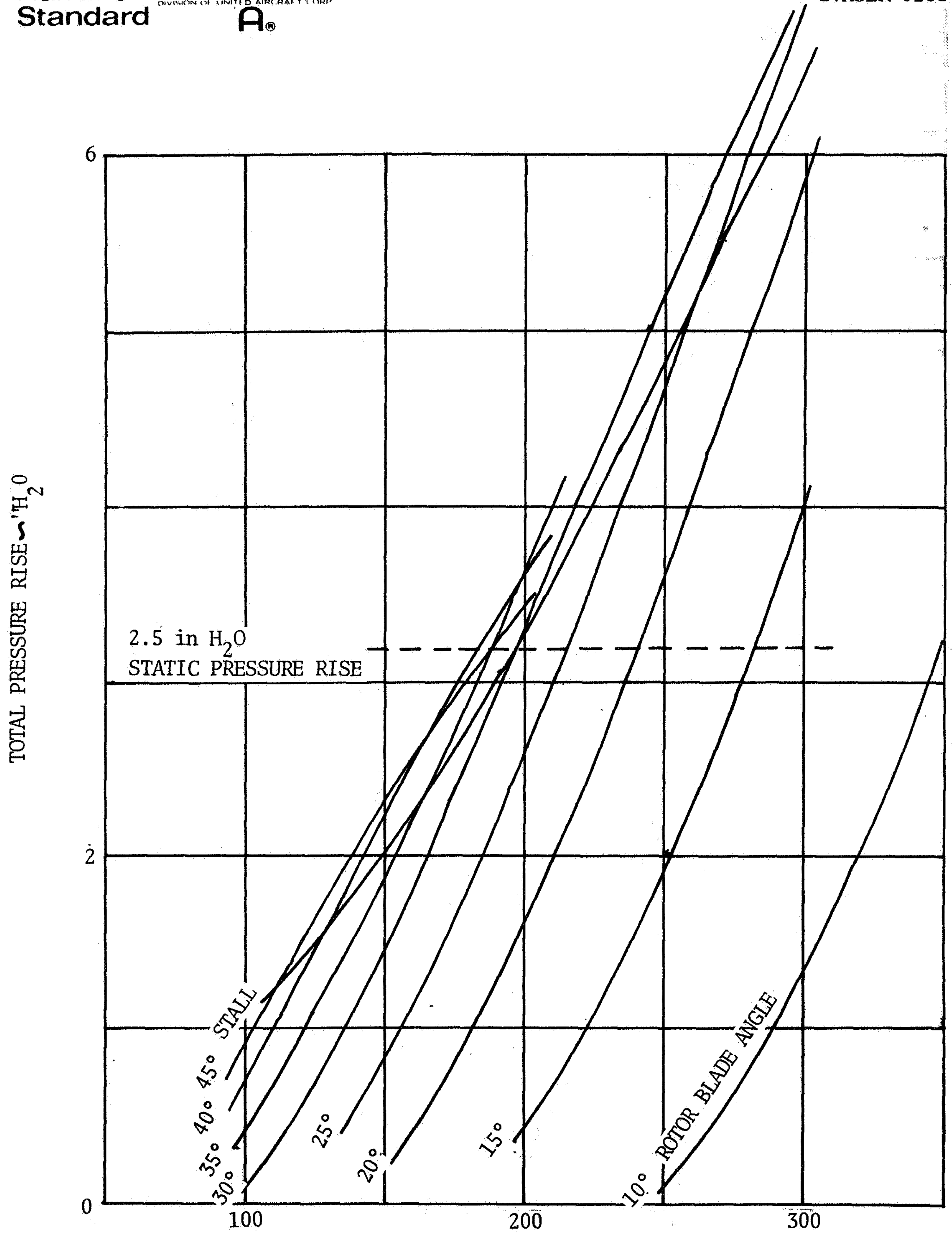
PRESSURE RISE/TIP SPEED RELATIONSHIPS
FOR THE 4.25 INCH DIAMETER FAN

FIGURE 100



PRESSURE RISE/TIP SPEED RELATIONSHIPS
FOR THE 5.0 INCH DIAMETER FAN

FIGURE 101

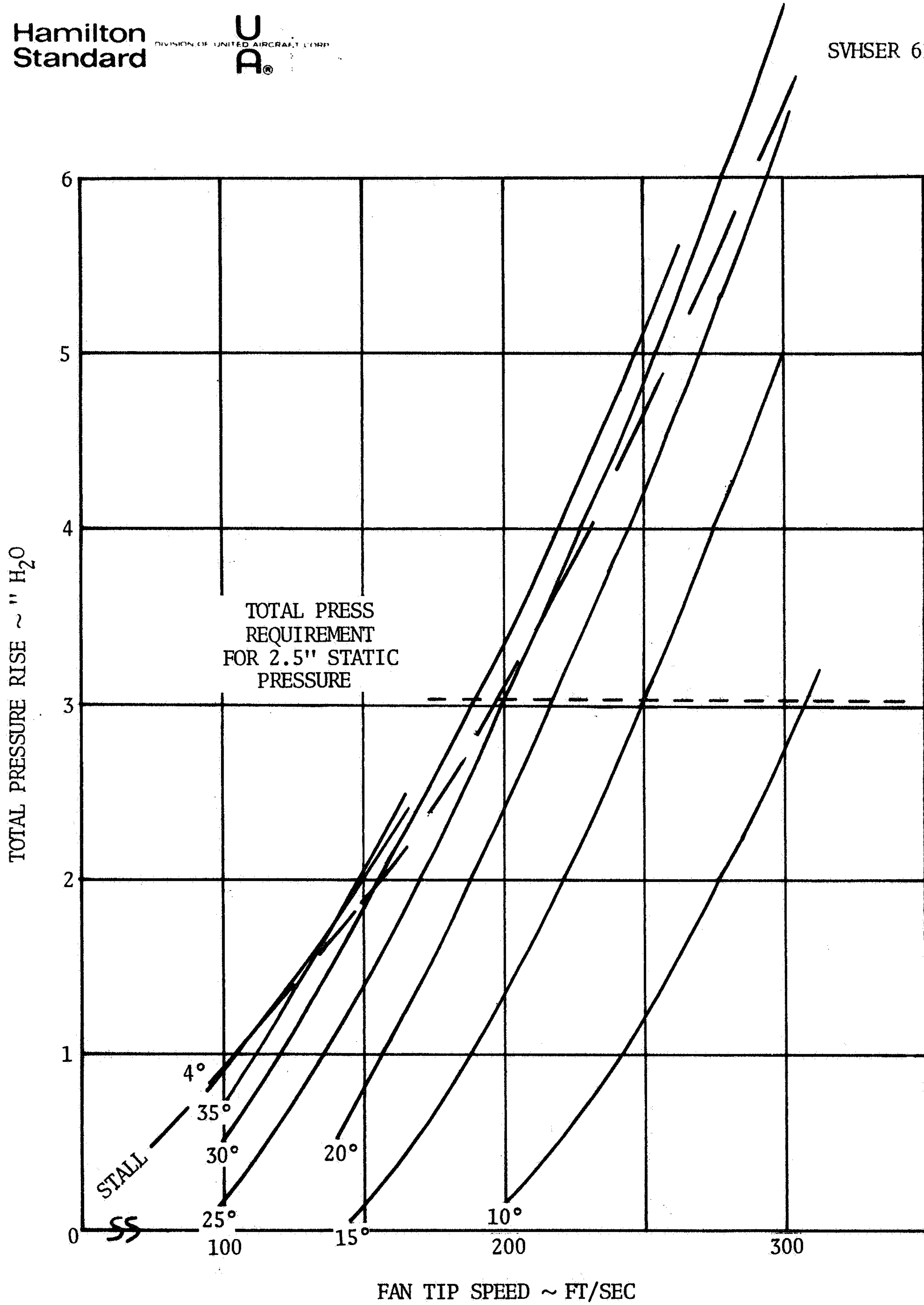


TIP SPEED ~ FT/SEC

PRESSURE RISE/TIP SPEED RELATIONSHIPS

FOR THE 5.75 INCH DIAMETER FAN

FIGURE 102



PRESSURE RISE/TIP SPEED RELATIONSHIPS
FOR THE 6.5 INCH DIAMETER FAN

FIGURE 103

the curves are the stall margin lines, based on the blade section angle of attack exceeding seven degrees. These are indicated because operating a fan beyond this line increases the possibility of fan surge.

Assuming that swirl recovery can be accomplished with good diffuser efficiency, the fan total pressure rise requirement will vary with fan diameter. Since the axial velocity component will vary with fan size, the required stagnation pressure of the fan will then vary with diameter as follows:

Fan Diameter (inches)	Axial Velocity (ft/sec)	Total Pressure (inches H_2O)
3.5	133.5	7.0
4.25	89.5	4.6
5.0	64.8	3.6
5.75	49.0	3.1
6.5	39.3	2.9

As may be seen from figure 99, the 3.5 inch diameter fan would operate in the surge region and is too small to meet the requirement. It thus was eliminated from this study. From figures 100 through 103 it now is possible to establish the blade angle to tip speed relationship which gives the required pressure rise. The tip speed at which each blade angle gives the required pressure rise yields the crossplot of figure 104.

To insure that the fan designs were reasonably efficient, the fan efficiency for each diameter was plotted versus tip speed and blade angle. These are shown in figures 105 through 108. For a given blade angle, the fan shows highest efficiency at a given tip speed with reduced efficiency on either side. An efficiency of 80 percent was considered a reasonable lower limit for the fan concept. The relationships plotted in figure 104 are limited at the high blade angle end by stall limits. Efficiency and tip speed limit the low blade angles. The tip speed range is thus narrowed to 200 to 300 ft/sec.

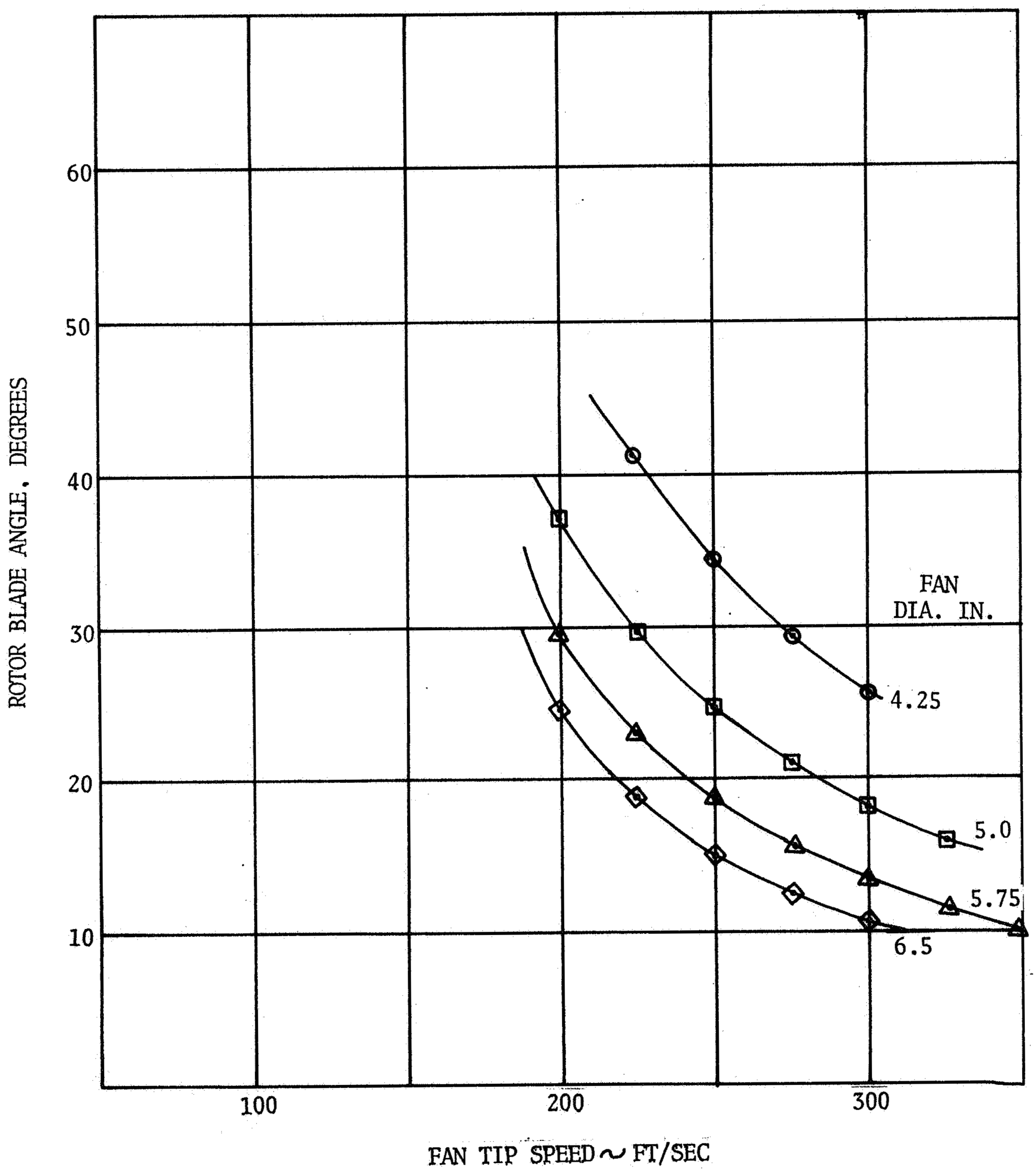
Figure 109 shows the fan efficiency as a function of diameter and tip speed at the required flow and pressure rise. Three fans achieve about 91 percent efficiency, whereas the 6.5 inch diameter fan appears to be oversized, achieving a peak efficiency of only 86 percent.

Noise Study Parameters

The fan designs defined by the circled points in figure 104 were used to perform a noise study which included variations in diameter, tip speed, number of blades, blade-vane gap size, and number of vanes. The noise calculations were made using the Hamilton Standard Axial Flow Fan Performance and Noise Calculation Computer Program with adjusted coefficients based on the correlation with the Apollo fan noise measurements. For this study, the SPL at three feet was calculated from which the NC values were determined.

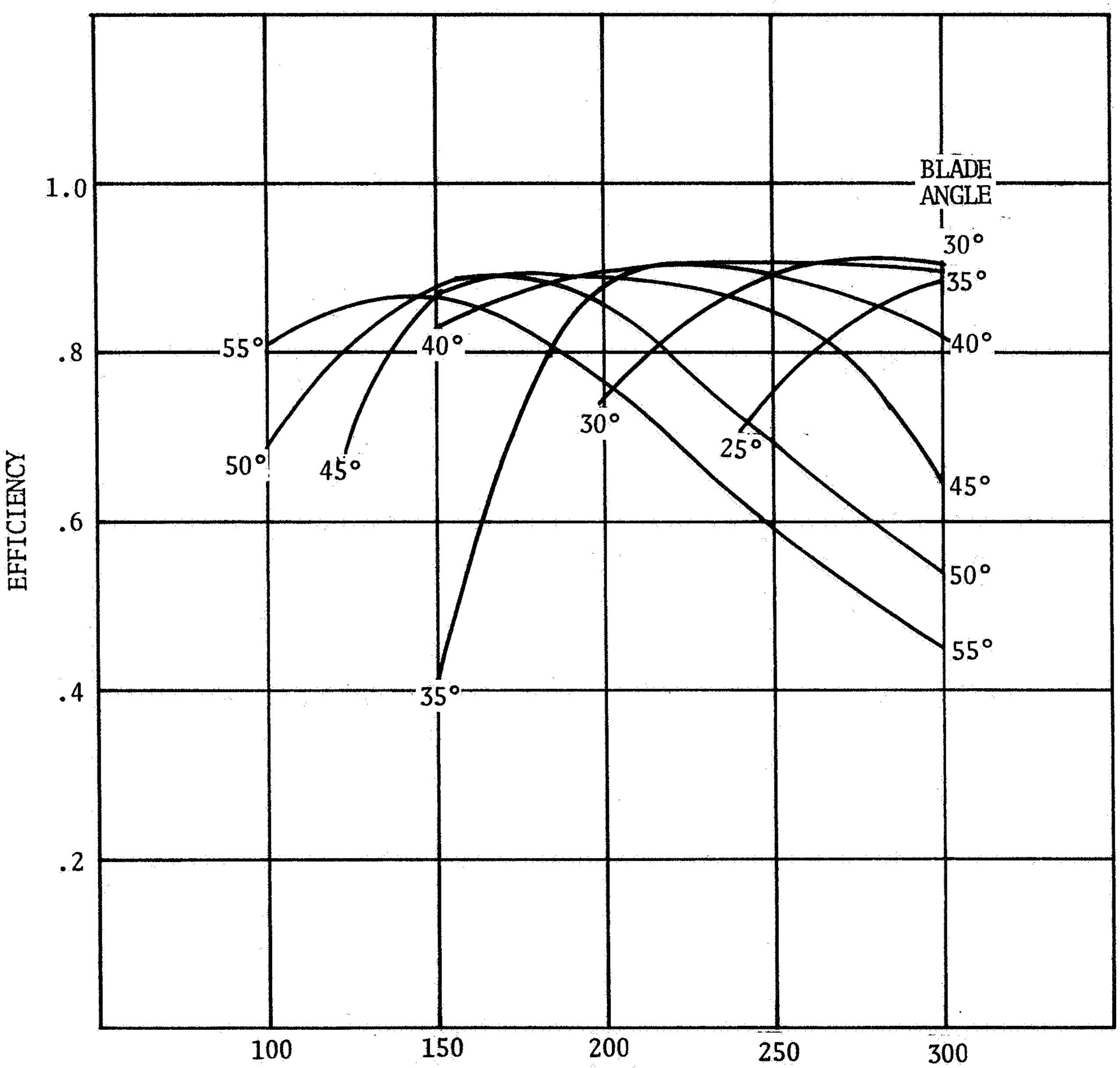
DESIGN POINT

STATIC PRESSURE RISE = 2.5 in H_2O
FLOW 400 cfm
MINIMUM EFFICIENCY 80%



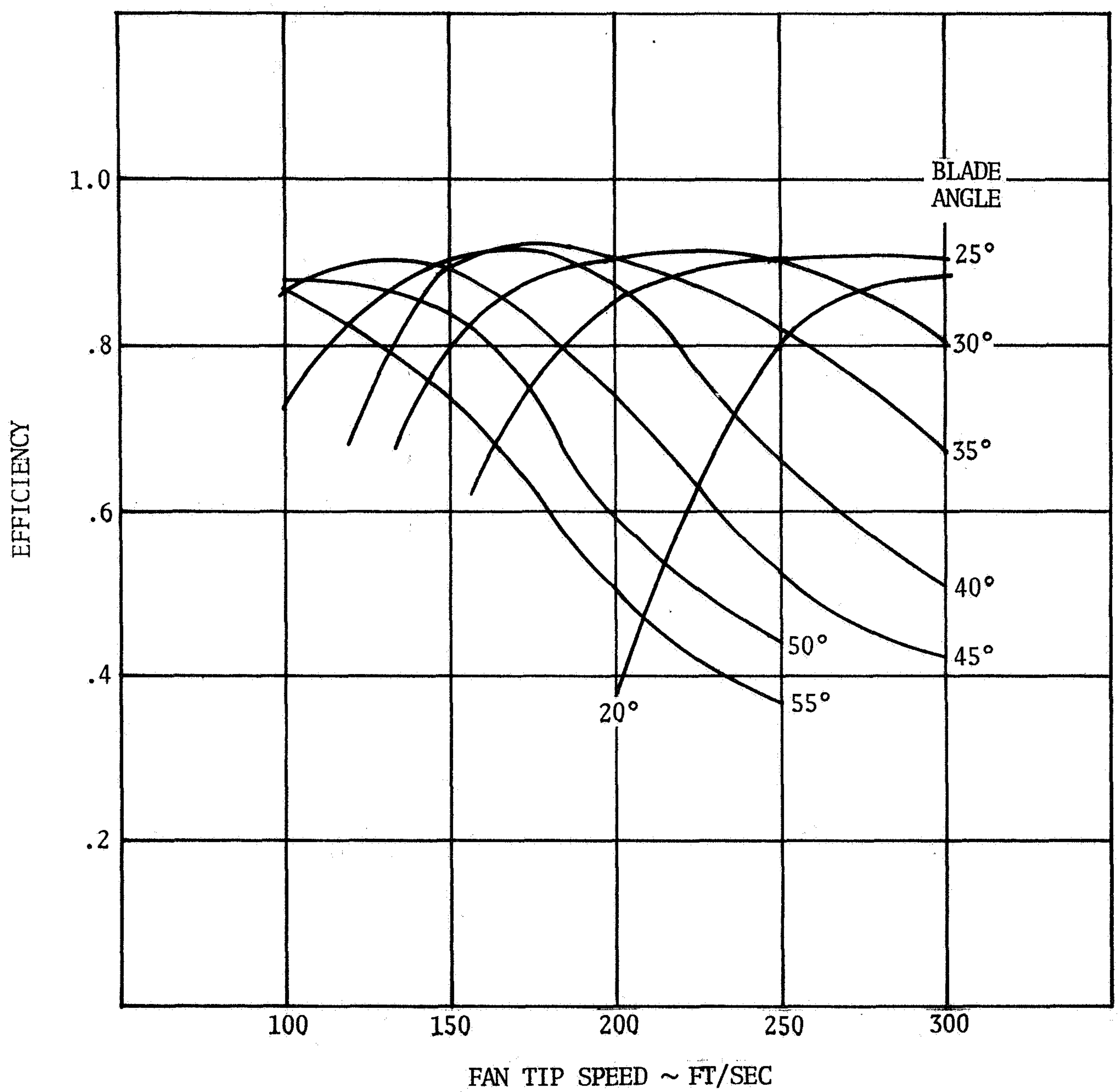
AXIAL FAN, ROTOR BLADE ANGLE vs FAN TIP SPEED

FIGURE 104



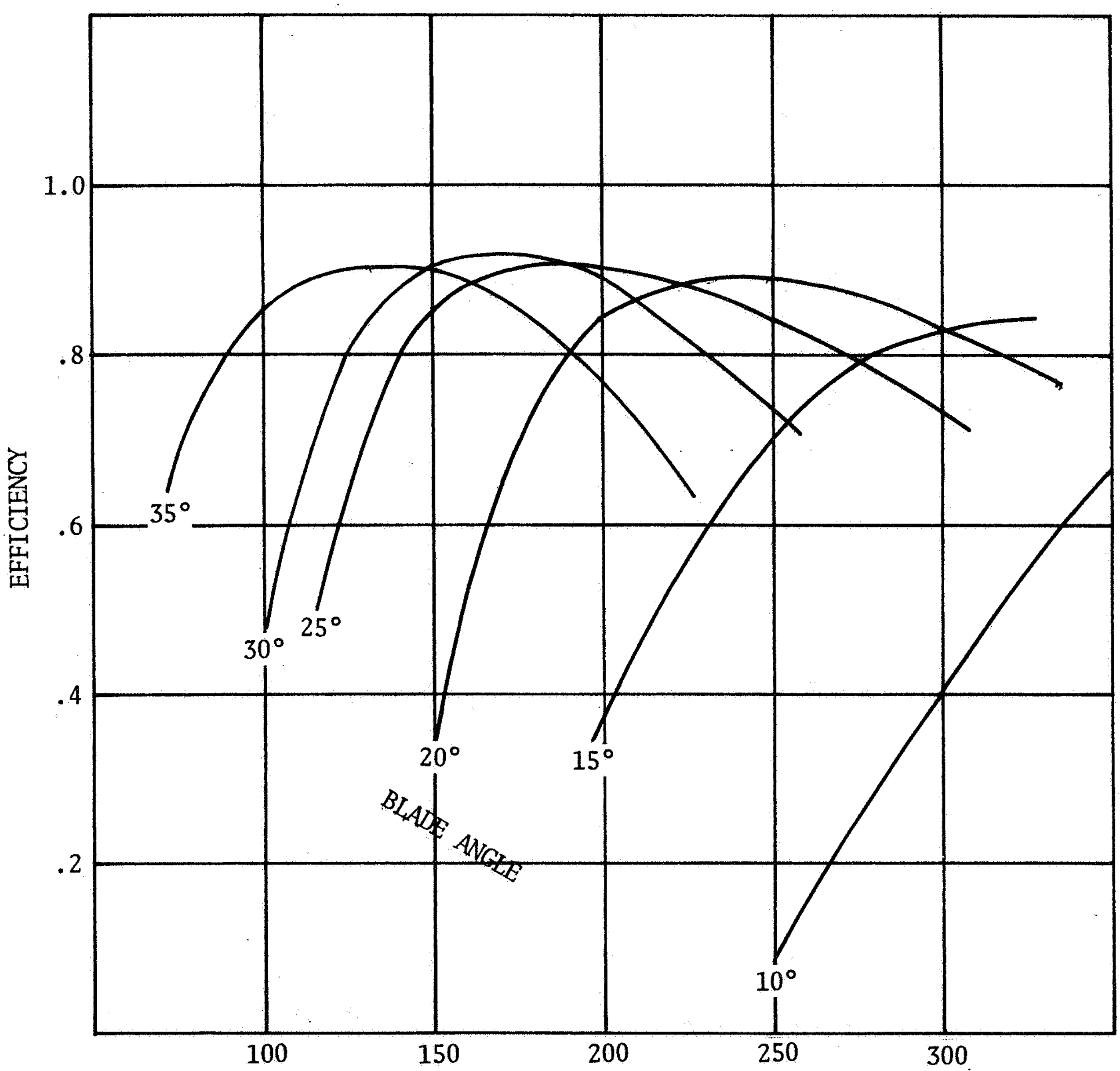
EFFICIENCY OF THE 4.25 INCH DIAMETER FAN

FIGURE 105



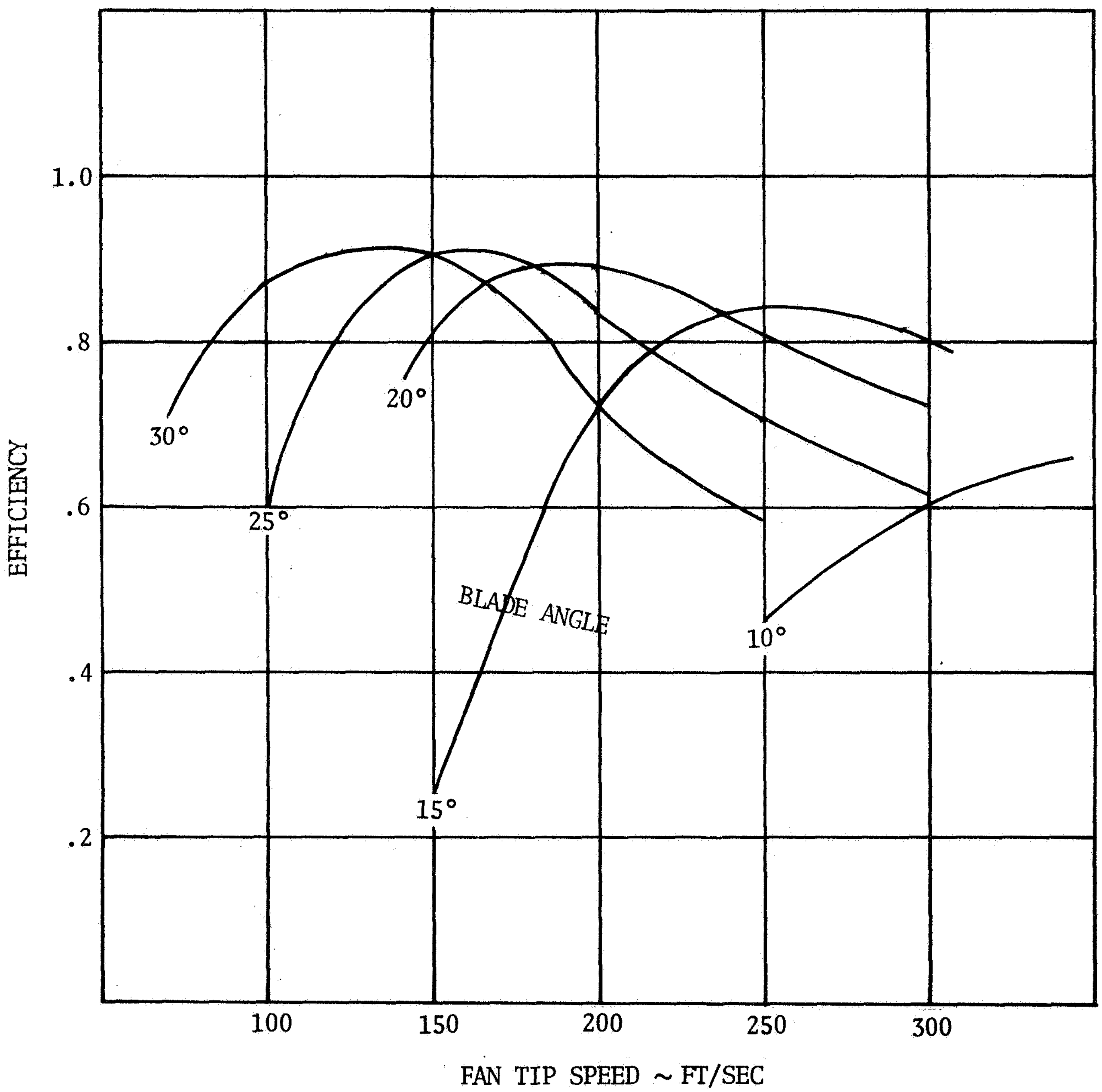
EFFICIENCY OF THE 5 INCH DIAMETER FAN

FIGURE 106



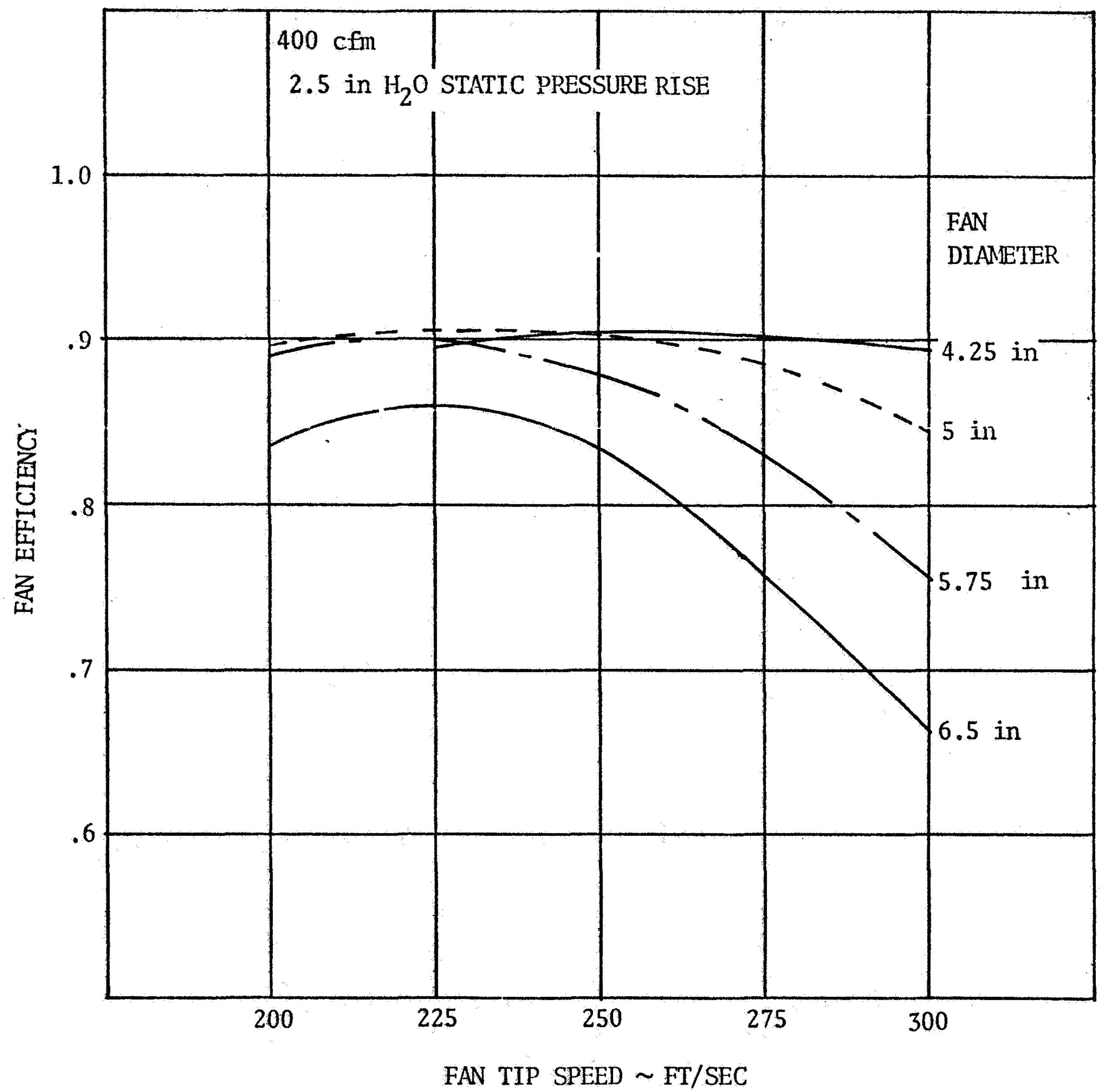
EFFICIENCY OF THE 5.75 INCH DIAMETER FAN

FIGURE 107



EFFICIENCY OF THE 6.5 INCH DIAMETER FAN

FIGURE 108



FAN EFFICIENCY VS TIP SPEED AND DIAMETER

FIGURE 109

The 19 points of figure 104 determined variations in tip speed from 200 to 300 ft/sec for fan diameters of 4.25, 5, 5.75, and 6.5 inches. Each fan at each tip speed was then estimated for two, three, four, five and six rotor blades, for three, five and seven stator vanes and blade-vane gaps of 0.5, 1, 1.5, and 2 times the blade chords.

Noise Versus Performance Trade-Off Study

Number of Blades Variation

In all cases the number of rotor blades having the lowest noise level was found to be three. Figure 110 shows a plot of the dBNC variation with blade count for the four fan diameters. The highest noise level occurs for the two bladed smallest fan. Then, the noise decreases rapidly to a minimum of three blades and increases slowly to five blades where it then levels off. Thus, for this size axial fan, three blades is optimum.

Tip Speed and Diameter Variation

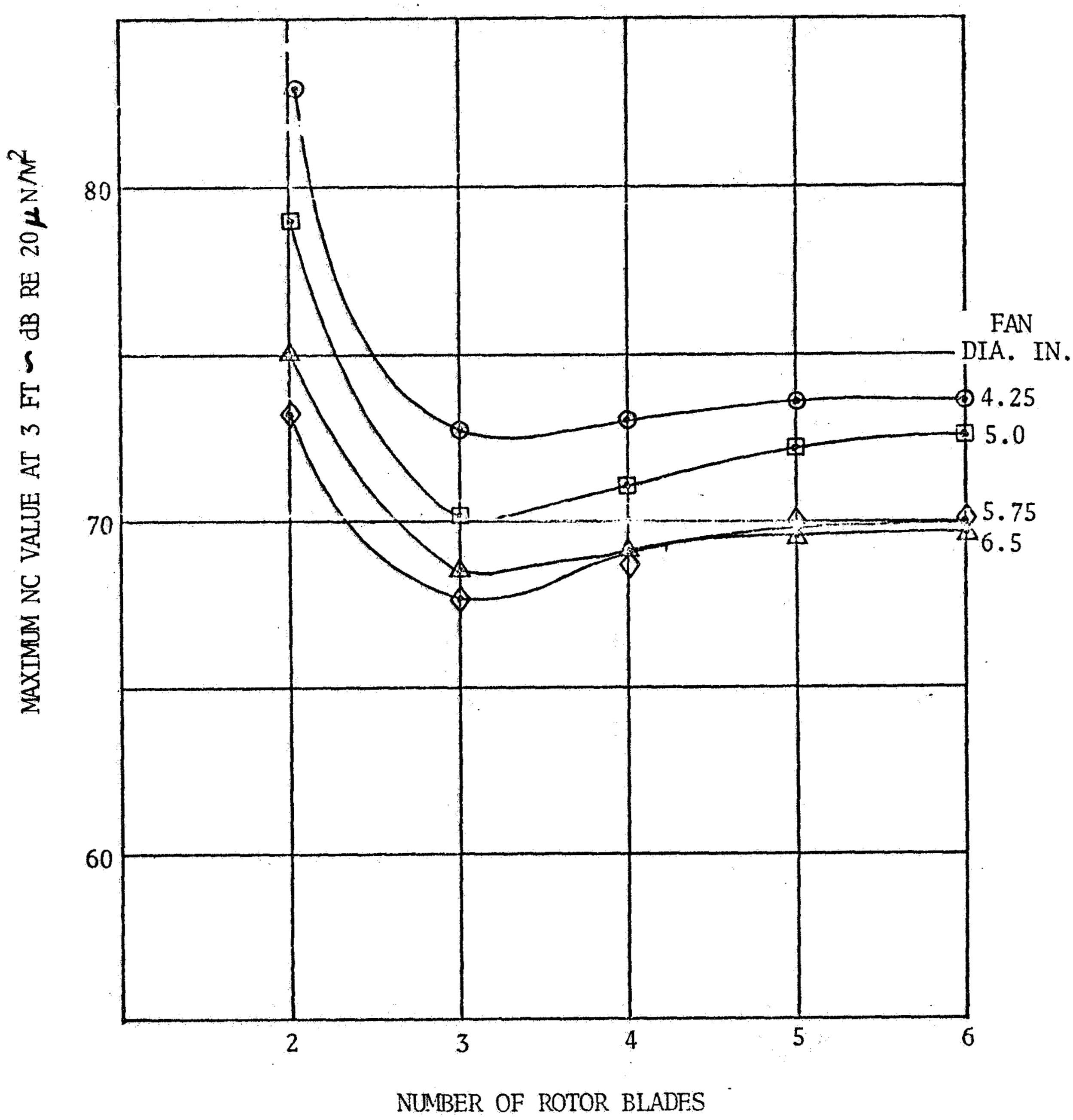
Figure 111 shows the dBNC noise dependence on tip speed for three bladed fans. In all cases, the minimum noise is seen to occur in the vicinity of 250 ft/sec.

The noise variation with fan diameter shows the 6.5 inch diameter fan to be the quietest at about 67.5 dBNC at 270 ft/sec tip speed. The 5.75 inch and 5 inch diameter fans are fairly close behind at 68.5 and 69 dBNC, respectively.

Blade Vane Gap

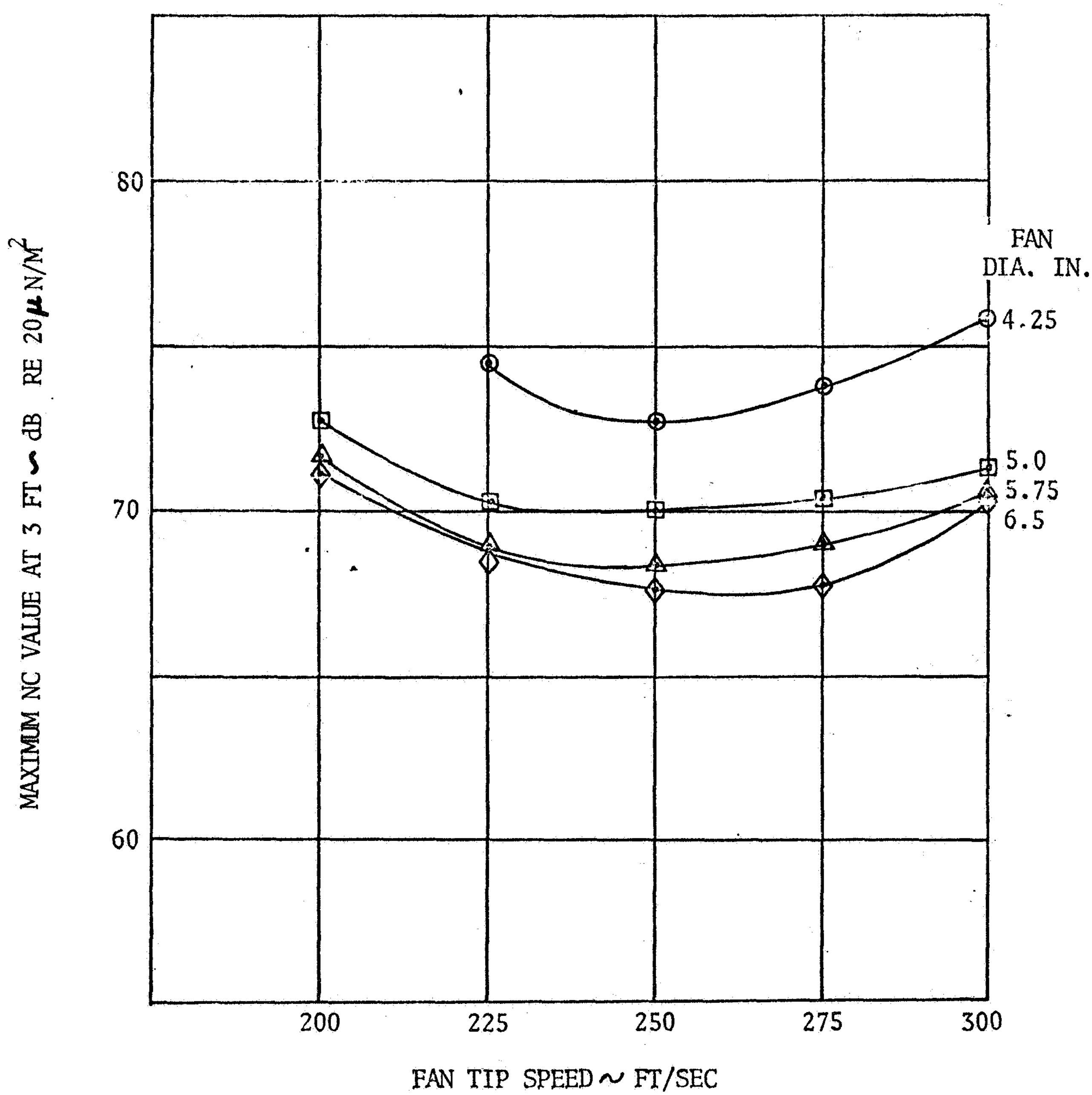
The variation of fan noise with blade-vane gap is shown in figures 112 through 115 for the four diameters being analyzed. These figures show clearly that increasing the gap causes a significant decrease in the fan noise.

Figure 116 summarizes this variation for a tip speed of 250 ft/sec. The greatest change occurs for small gaps. Approximately 3 dB decrease in noise occurs for a gap change from 0.5 to 1.0 blade chords, whereas only a 2 dB change occurs for a gap change of 1 to 1.5 blade chords, and approximately 1 dB for a gap change of 1.5 to 2.0 blade chords. It thus is apparent that as the gap is increased further, the reduction in noise becomes small. Because a large gap results in a large fan, a good compromise appears to be at a gap of 1.5 to 2.0 blade chords, since the slopes of the curves in figure 116 indicate that negligible reduction in noise occurs beyond this gap size.



MAXIMUM NC VALUE VS NUMBER OF ROTOR BLADES FOR
AXIAL FAN WITH 5 VANES AND 250 FT/SEC TIP SPEED

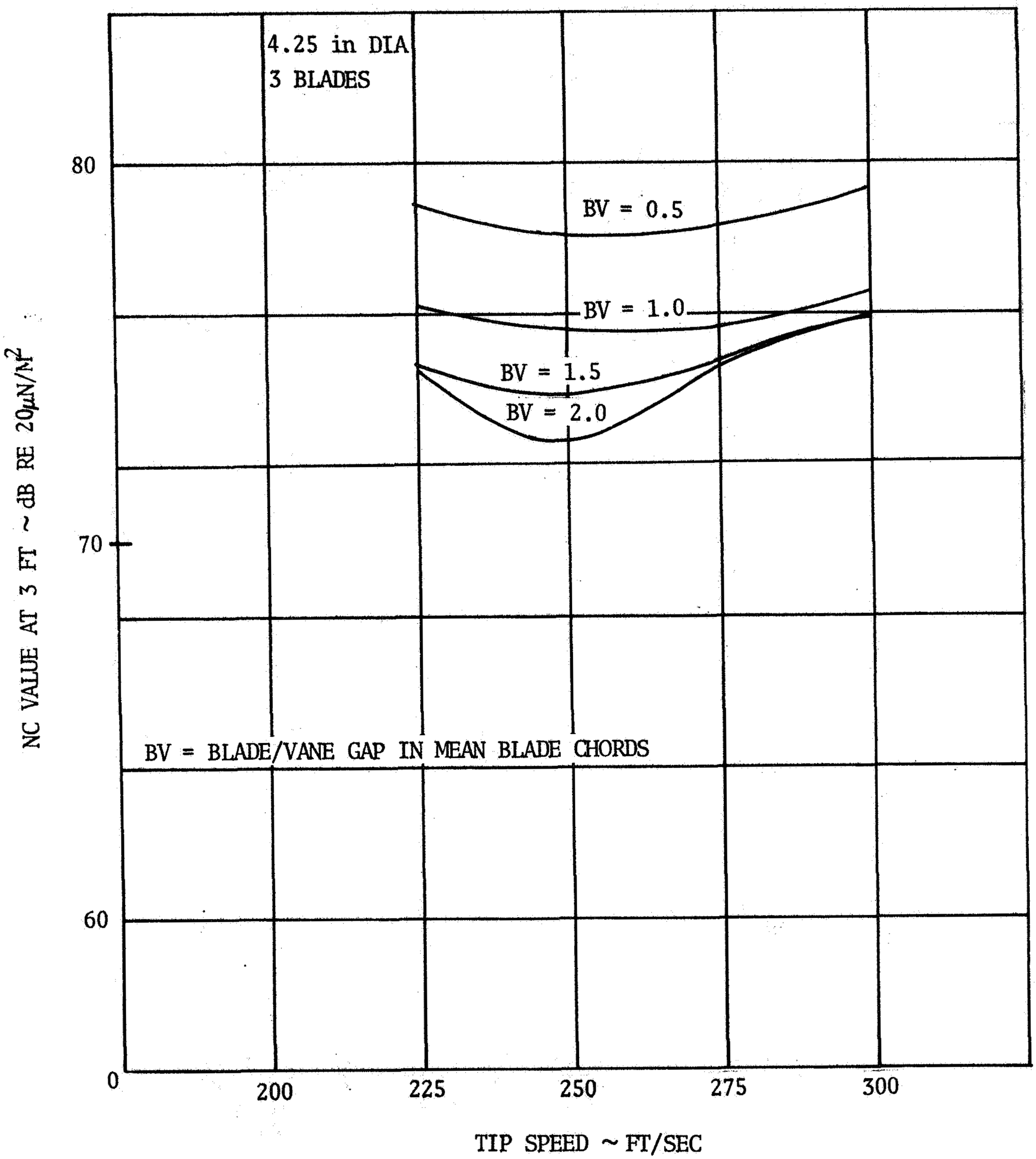
FIGURE 110



MAXIMUM NC VALUE VS FAN TIP SPEED FOR

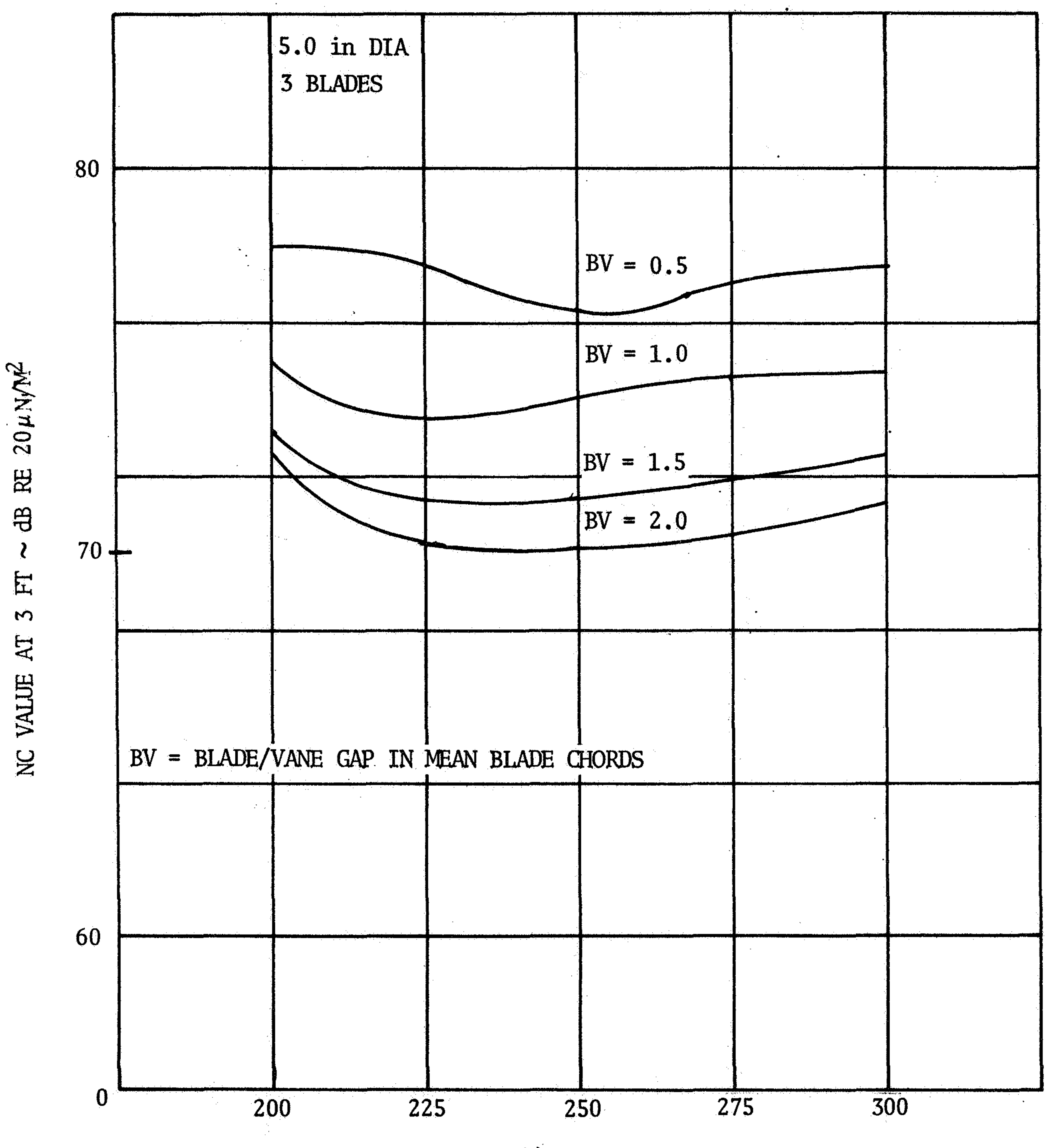
AXIAL FAN WITH 3 BLADES

FIGURE 111



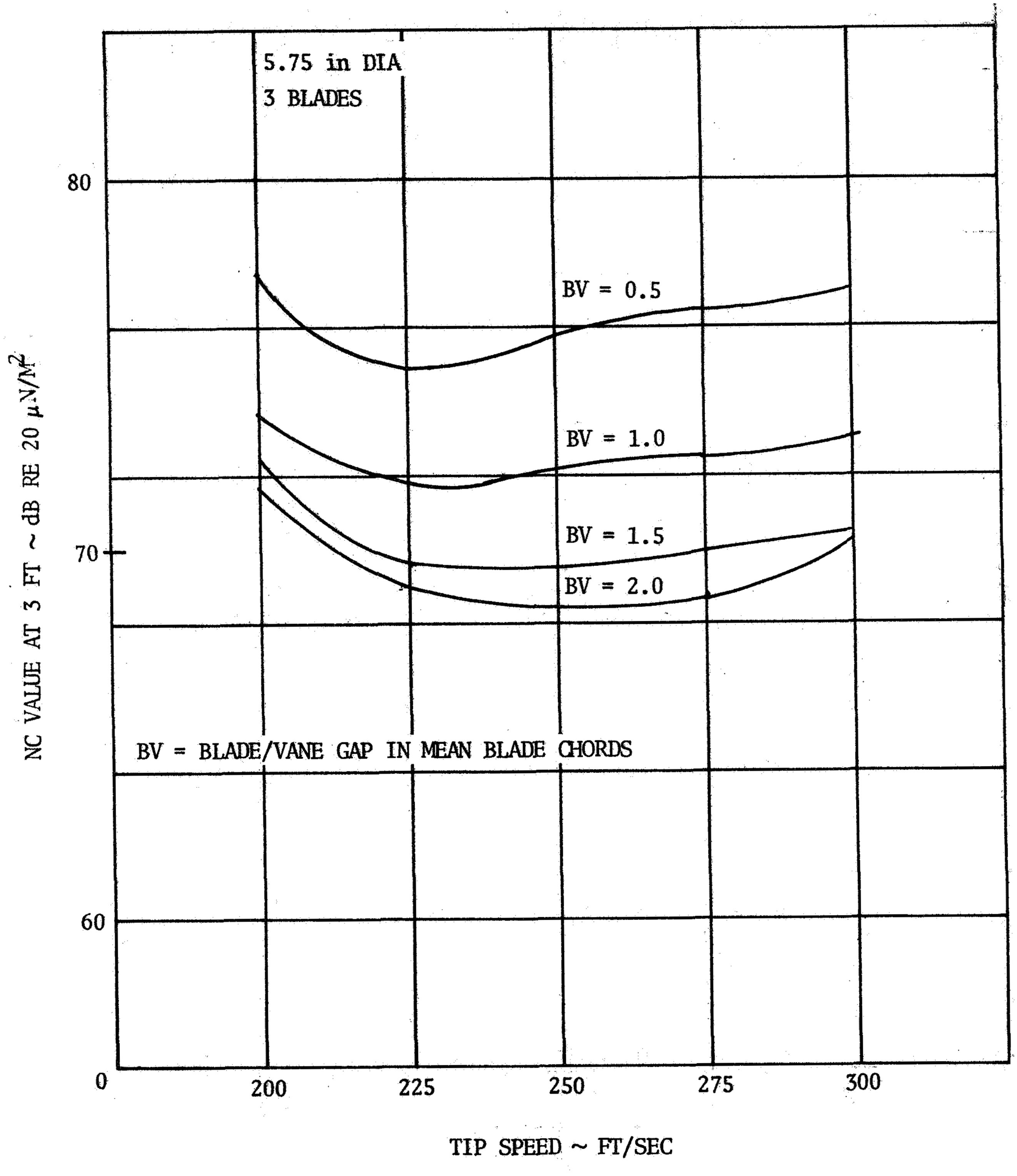
FAN NOISE VARIATION WITH BLADE-VANE GAP
FOR THE 4.25 INCH DIAMETER FAN

FIGURE 112



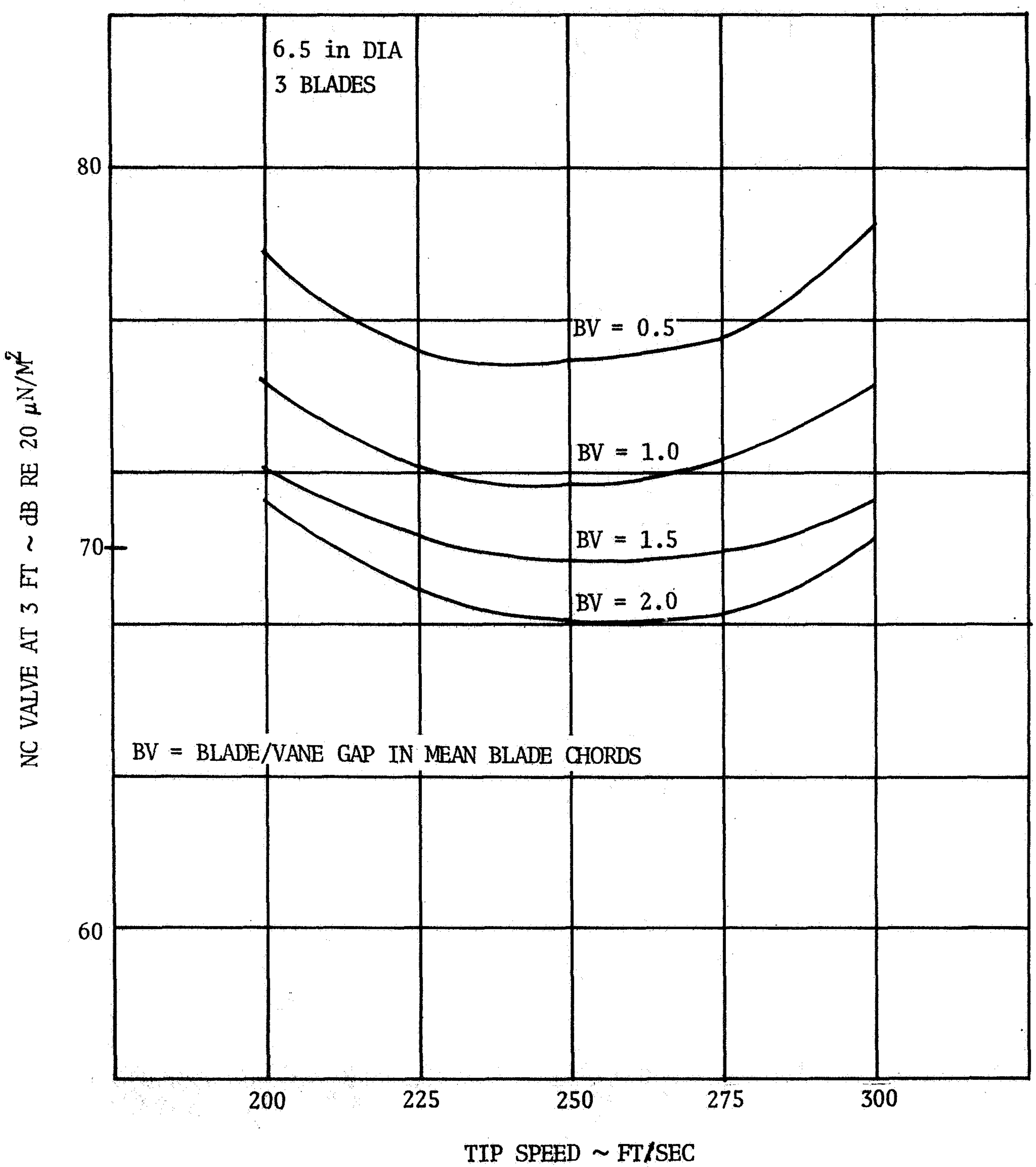
FAN NOISE VARIATION WITH BLADE-VANE GAP
FOR THE 5.0 INCH DIAMETER FAN

FIGURE 113



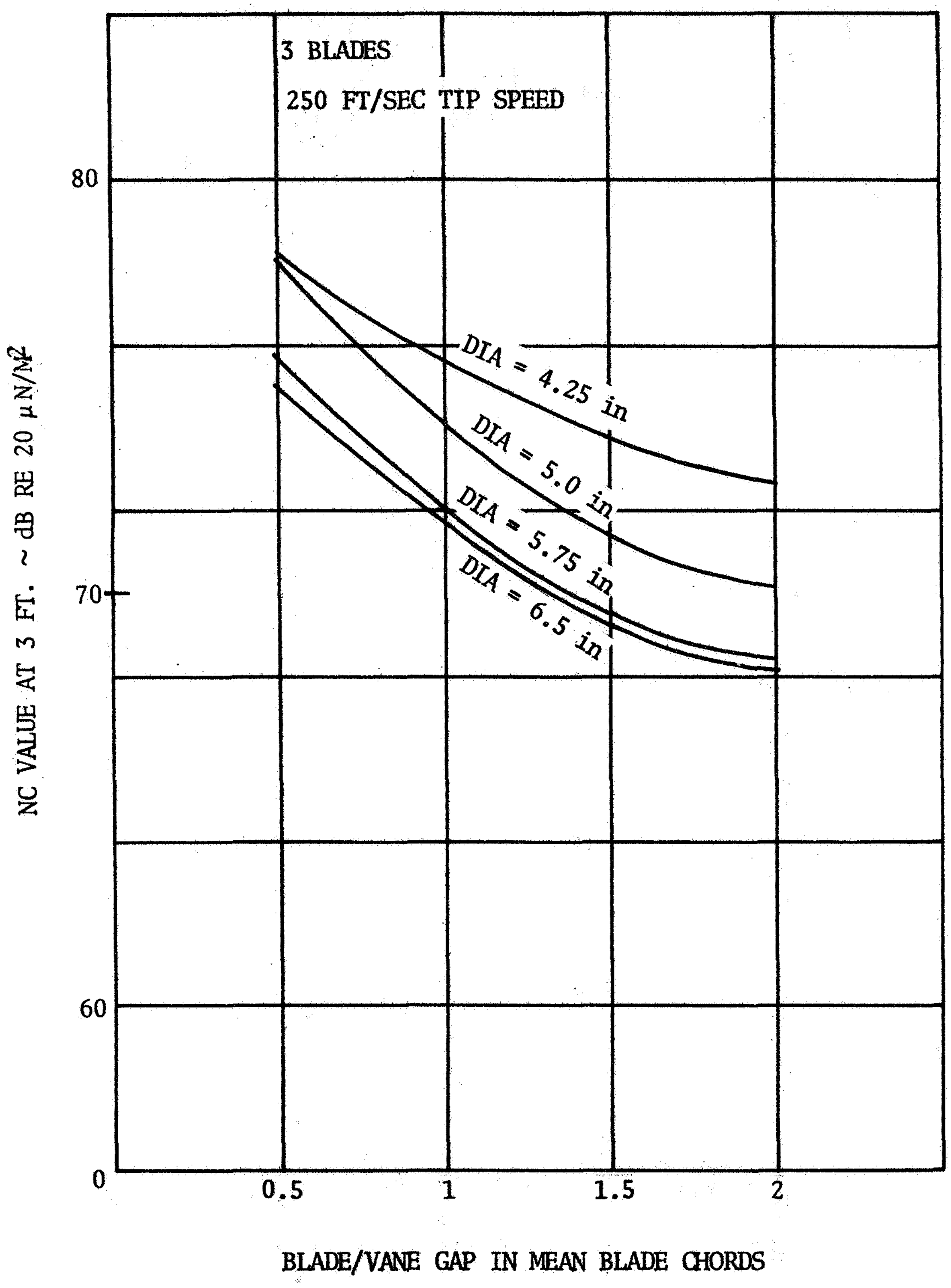
FAN NOISE VARIATION WITH BLADE-VANE GAP
FOR THE 5.75 INCH DIAMETER FAN

FIGURE 114



FAN NOISE VARIATION WITH BLADE-VANE GAP
FOR THE 6.5 INCH DIAMETER FAN

FIGURE 115



SUMMARY OF FAN NOISE DEPENDENCE ON BLADE-VANE GAP

FIGURE 116

Vane Count

For the fan with three blades and a blade-vane spacing of 2 blade chords, it was found that the noise was essentially independent of the number of stator vanes. This is not too surprising, since at this spacing the stator noise is a relatively small contribution to fan noise.

GUIDELINES AND CONSTRAINTS

The noise generated by spacecraft environmental control - life support system components may be divided roughly into those generated by solid to solid contact or vibration of solids (structure generated noise) and those generated by gas turbulence or other periodic gas pressure disturbances due to interaction between gas and solid surfaces (aerodynamic noise). A third source, similar to aerodynamic noise, is produced by flowing liquids.

An example of structure generated noise would be that produced by bearings of a pump or fan. An example of an aerodynamic noise source would be the periodic pressure pulses produced by a fan blade. These pressure pulsations necessarily accompany processes which add energy to or remove energy from a gas. An example of flowing liquid noise is that caused by a liquid flowing at high velocity in a pipe.

Fan Noise Generalization

In order to understand the methods for reducing the noise from fans, a brief review of the aerodynamic noise sources in fans is required. Both axial and centrifugal flow fans produce two types of aerodynamic noise: first, broad band turbulence noise and second, discrete tones related to the frequency at which interactions occur between fan blades and the fluid.

The broad band noise arises from the shedding of vortices at the rotor blade trailing edges when the blade is operating in smooth airflow, which induces local surface pressure fluctuations on the blades. When the blade is operating in turbulent flow, there is an additional noise mechanism due to the randomly fluctuating lift.

The rotational, or tone, noise is caused by the rotating steady blade surface pressure field and by aerodynamic interaction between the rotor and stator blades.

Factors which improve the aerodynamic efficiency of a fan tend to reduce the aerodynamic noise generated by the fan. This occurs because turbulence is associated with aerodynamic losses and aerodynamic noise generation mechanisms are associated with turbulence. Consequently, measures such as designing for smooth inlet flow and using efficient airflow blades with trailing edges designed for minimum flow separation will reduce noise generation.

Depending on which noise mechanisms are postulated, the acoustic power of fans varies with the fourth to sixth power of the relative air velocity, which is approximately equal to the blade tip speed. The following relationship is given by Lowson [23].

$$\text{Acoustic power} \propto D^2 V_t^{\,5}$$

This relationship has general validity in geometrically similar fans. Note that:

$$D^2 V_t^{\,5} = D^2 V_t \, (V_t^{\,2})^2 \propto Q_d \bullet (\Delta P)^2$$

which, when converted to decibels results in

$$10 \log (D^2 V_t^{\,5}) = 10 \log (Q_d \bullet (\Delta P)^2) + K = 10 \log Q_d + 20 \log \Delta P + K$$

where D = rotor tip diameter, V_t = rotor tip speed, Q_d = fan discharge flow, and ΔP = fan pressure rise.

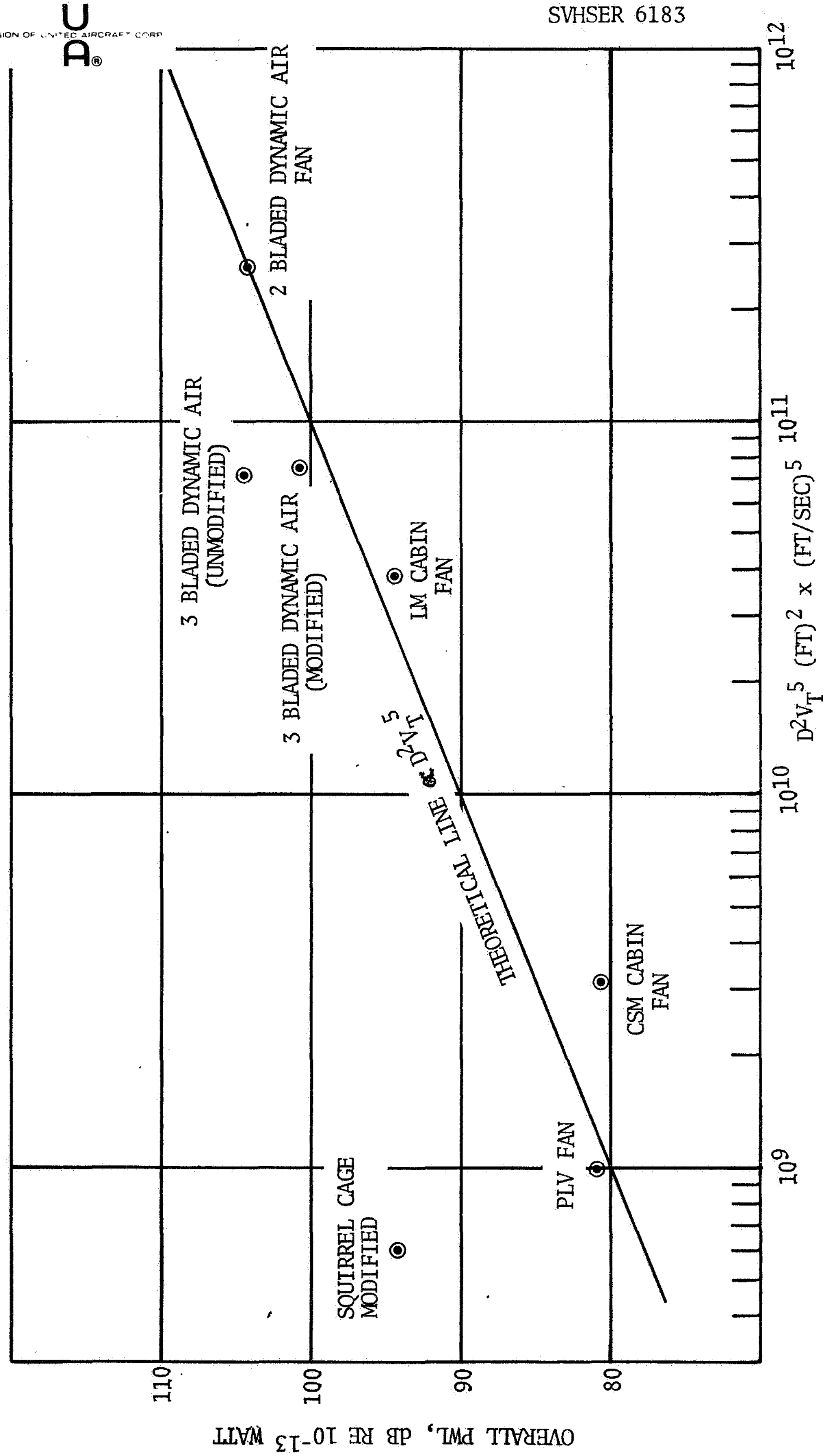
This is the basis for the Allen Method, the Buffalo-Forge Method, and the Hamilton Standard Empirical Fan Noise Estimating Procedure, where the constant K is based on the type of fan utilized.

Minimizing the quantity $D^2V^{\,5}$ is an effective means of reducing noise generation in a fan. However, in selecting a maximum efficiency fan with a given operating point, the range of allowable tip speed variation may be very limited. Figure 114 shows the PWL of the Apollo and verification hardware fans plotted against the parameter $D^2V_t^{\,5}$. Although these fans cover a range of performance and geometries, the correlation is quite good. Note that on this curve the squirrel cage fan's overall noise level is 16 dB above the theoretical line proportional to $D^2V_t^{\,5}$. This is consistent with the earlier observation that the Hamilton Standard Empirical Fan Noise Estimating Procedure had underpredicted the squirrel cage fan noise by approximately 10 dB. Although figure 117 indicates the overall acoustic power of fans, the trends in other noise measuring schemes such as dB(A), dBNC and so forth, would be similar.

In most of the common, high performance axial flow fans the overall noise levels, and in most cases the dB(A) and dBNC noise levels, are generally determined primarily by the levels of the fundamental tone and its harmonics. The broad band, or vortex shedding, noise can be significant in quiet fan designs and can be estimated by[24]:

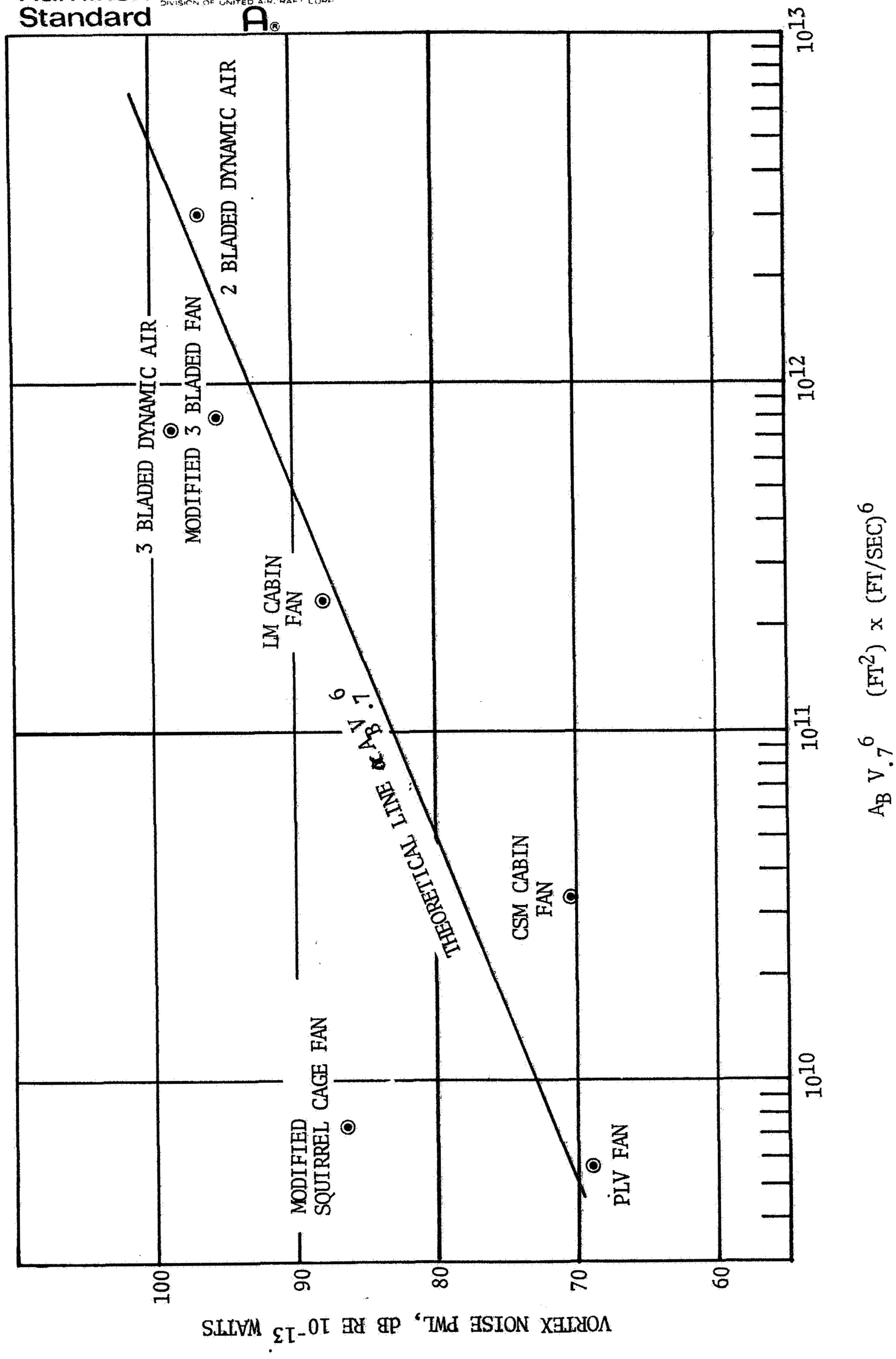
$$\text{PWL} = 10 \log K A_B V_{0.7}^{6}$$

where K is a coefficient of proportionality. Figure 118 presents a correlation



VARIATION OF OVERALL POWER LEVEL WITH $D^2V_T^5$

FIGURE 117



VARIATION OF VORTEX NOISE PWL WITH $A_B V_{.7}$

FIGURE 118

of the measured vortex noise - approximated by summing the levels of the bands defining the broad band peak - of the axial fans and of the squirrel cage fan housing the quiet motor, with the parameter $A_B V_0^6{}_{.7}$. Again, the correlation is seen to be quite good for the axial fans, whereas the squirrel cage fan falls well above the generalized curve.

Smooth Fan Inlet Flow

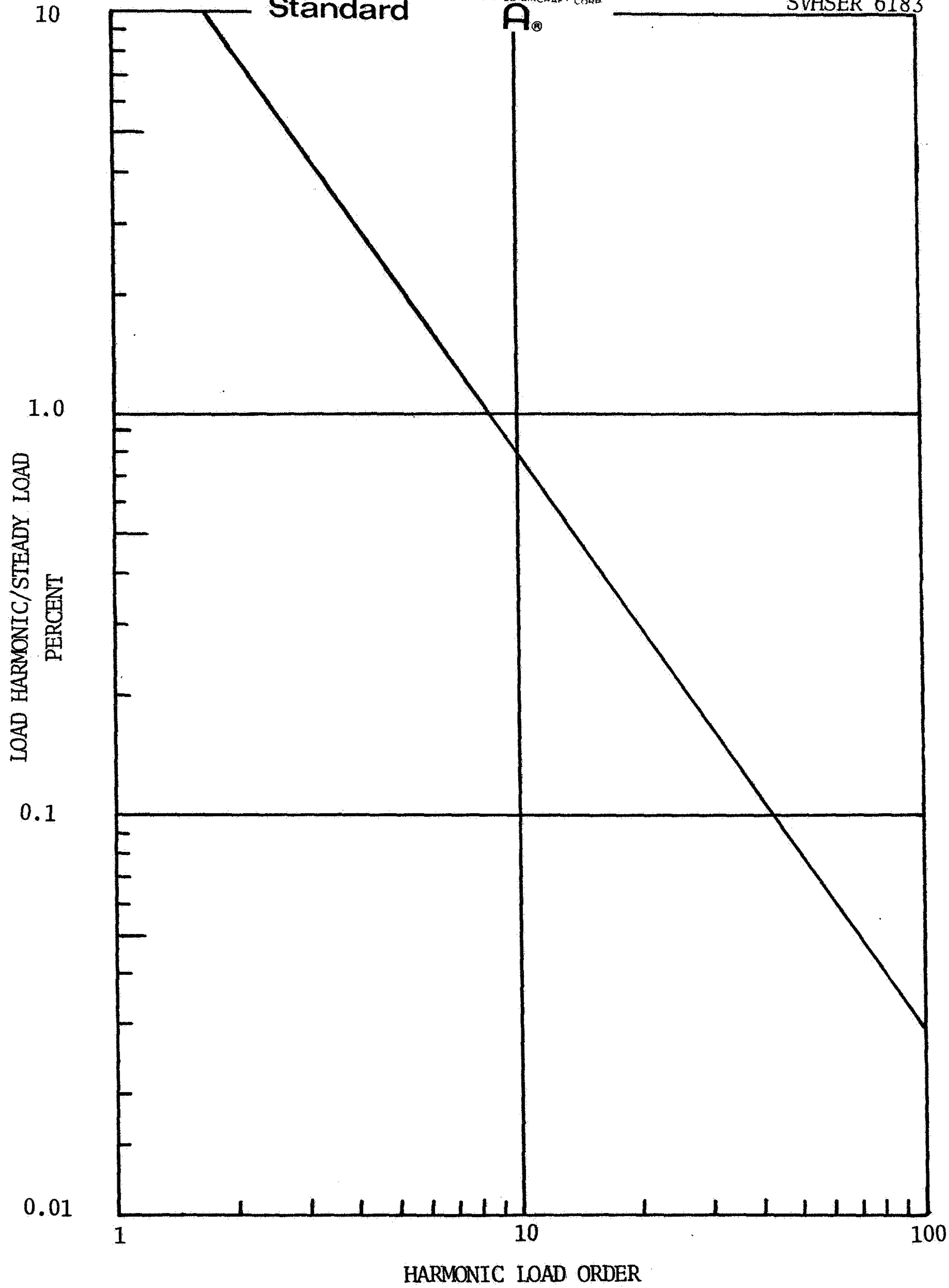
In the generation of aerodynamic noise, a fan is sensitive to distortions in the flow. These distortions cause blade loading fluctuations which result in greatly increased radiation efficiencies and correspondingly increased noise output. This is particularly true of axial flow fans which are extremely sensitive to inlet flow distortion. Thus it is very worthwhile in axial flow fans to minimize noise generations by avoiding any upstream flow obstructions and providing smooth uniform flow by means of large radii bellmouths.

To illustrate the effects of flow distortions on noise, the harmonic sound pressure levels of a free-air rotor (i.e. a rotor with no ducting around it) were calculated using Gutin's theory (25), which assumes steady blade loading. The harmonic sound pressure levels for this same rotor were then calculated with flow distortion. The flow distortion used for this calculation is based on measurements obtained for a propeller on a clean test stand (26). The measured distortion produced a fluctuating blade loading (due to fluctuating velocities and angles of attack of the propeller blades) which had the normalized frequency spectrum shown in figure 119. As this figure shows, the blade loading was about 10 percent of the average blade loading (i.e. the steady portion of the blade loading) at the second harmonic of the rotational speed, decreasing to about 0.03 percent at the 100th harmonic. Table XXIV summarize the calculations. These show that for the steady blade loading case, the levels of the harmonics decrease very rapidly with increasing harmonic order. The case with fluctuating blade loading, however, shows relatively little decrease in the levels with increasing harmonic order. At the third harmonic, for example, the difference is approximately 66 dB; i.e. from a level of 4 dB, which is inaudible, to a level of 70 dB which is very noticeable. This 66 dB increase in level was due to a fluctuating blade load of only approximately 0.5 percent of the steady blade load. (Since this was a 4 bladed rotor, the third blade passing frequency harmonic is equal to the 12th harmonic of the shaft rotational speed).

TABLE XXIV

HARMONIC LEVELS OF A FREE-AIR ROTOR FOR STEADY AND NON-STEADY BLADE LOADING

HARMONIC	STEADY LOADING	NON-STEADY LOADING
1	71.3	73.5
2	38.4	71.3
3	4.2	70.6
4	-30.6	69.1
5	-65.6	68.7



DERIVED HARMONIC LOADS FOR LOW TIP SPEEDS

FIGURE 119

In the case of a shrouded rotor, as for an axial fan, the steady loading tones are further attenuated by the presence of the duct, since the field of a subsonic rotor will always decay, in this case by 12 dB per inch[27] of ducting for the fundamental and even more for the higher harmonics. Thus, one would not expect to see any significant tone content in these fans, provided a short section of duct were provided to attenuate the rotor field. However with distortion in the flow, the fan inflow becomes analogous to the case for rotor-stator interaction, where new modes are generated. In this case, the modes generally will propagate. Thus inlet flow distortion in the axial flow fan is detrimental to low noise output for two reasons. In the first place, the noise generated by the rotor is increased significantly, particularly at the higher harmonics; and secondly, these modes do not decay readily and are radiated from the inlet and outlet.

It is apparent that upstream disturbance to the flow causes high fan noise output. Since a very small disturbance can significantly increase noise, only a small obstruction in the flow is necessary. Thus such items as aerodynamic probes, turning vanes, preswirl vanes and elbows, should not be placed upstream of the fan. Locating a fan, even one with a good bellmouth, right behind an obstruction which causes partial blockage of the inlet should be avoided, since this also will give rise to flow distortion.

One concept which improves the fan inlet flow profile is that of flow straightening devices located upstream of the rotor. Even though this approach appears contrary to the above discussion, it is based on the assumption that if the size of the wakes is small compared to the span and chord of the rotor blades, then the wakes do not act coherently to cause the fluctuating lift which gives rise to the high rotational noise. Thus the effective flow disturbances are reduced and the noise due to non-uniform inflow is correspondingly reduced. This method of noise control can be effected by the use of thin-wall, small cell size honeycomb, several small mesh settling screens, or other similar approaches commonly used in low turbulence wind tunnels.

Porous Blades and Vanes

Porous materials have been applied to small airfoils placed in the stream of a small jet, with some success by Lowson [28], and more recently on small propeller fans by Chanaud [29], and by Tseo [30]. In Chanaud's experiment, a small fan was constructed utilizing both partially and fully porous materials for the blades. The porous material was found to be very effective in reducing the noise of the fan at little or no loss in fan efficiency. In fact, certain materials seemed to give better efficiencies with 10 to 12 dB(A) noise reduction. Although Chanaud shows a potential for 19 dB(A) noise reduction at very low pressure rise, it is probable that this noise reduction will be offset by loss in performance due to back leakage through the material as the static pressure head of the fan is increased.

Tseo achieved some noise reduction by covering the pressure surface of the fan blades with the porous material. Although his data is somewhat limited, reductions in the mid-frequency broad band and tone noise are apparent. Tseo attributes this to the material acting as a high hydrodynamic resistance to attenuate the fluctuation of blade pressure and a relief of the pressure build-up around the blades to reduce the vortex strength. Attenuations of approximately 10 dB in the mid-frequency broad band were achieved using 1/16 inch fiberglass.

Boundary Layer Control

Boundary layer control (BLC) is another means for reducing the aerodynamic noise from fans. With this approach suction is applied in the trailing edge region of the airfoil to reduce the boundary layer thickness and to prevent flow separation. Lockheed Company conducted tests on propellers with BLC and measured reductions in high frequency broad band noise.(37)

Of the four basic sources of fan noise (rotor tones and broad band, and stator tones and broad band), BLC reduces all except the rotor tones. The noise generating mechanisms affected are those which give rise to stator tones and stator broad band. These are caused by the stator interception of the rotor blade wakes and the stator vortex shedding.

A recent study was conducted at Hamilton Standard using the axial fan noise prediction computer program. In this study, the effects of putting BLC on the downstream 1/3 of the chord were evaluated analytically by calculating the behavior of the resulting wakes and their interaction with the stator vanes. Reductions of approximately 18 dB in the rotor broad band noise were estimated based on the reduction of the profile drag. The estimated reduction in fan noise was approximately 5 PNdB, with a slight gain in fan efficiency, including losses in the suction mechanism.

BLC on a stator assembly is relatively easy. However, BLC on the rotor requires the transmission of suction across a rotating interface. In either case, a source of suction is required. Typically this suction removes less than 0.1 percent of the fan flow in providing adequate BLC.

It thus is predicted that BLC could be of significant value in reducing fan noise. A potential of 10 to 15 dB is apparent, but it is relatively difficult to implement due to the complexity of suction across the rotating rotor.

Centrifugal Pumps

The evaluation of small pumps indicates that the centrifugal unit is quieter than other types. Normally the motor noise overshadows the pump noise. However, in cases where the centrifugal pump dominates, even if only in part of the noise spectrum, design for noise is necessary.

It is essential that the pump be operated on or as near as possible its design point. This will help assure low flow noise and non-cavitating operation.

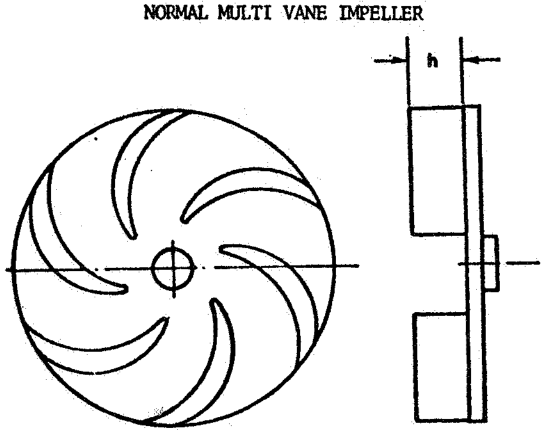
A pump must be hydraulically stable or fluctuating head and flow conditions can develop, leading to noisy operation. A continuously-rising head curve is considered to provide stable operation under "all" operating conditions.

To provide a quiet and efficient, essentially shockless entrance into the pump impeller vane passage the correct blade inlet angle must be chosen. This will be the angle whose tangent is the ratio of the radial fluid velocity to the longitudinal velocity of the inlet tip of the impeller vanes. It is generally an accepted practice to exaggerate the inlet angle as much as 15 to 20 percent, thus shifting the shockless capacity to the right of the design point on the pump head versus capacity curve. For quieting purposes it seems desirable to operate as near the shockless capacity point as possible without seriously affecting efficiency.

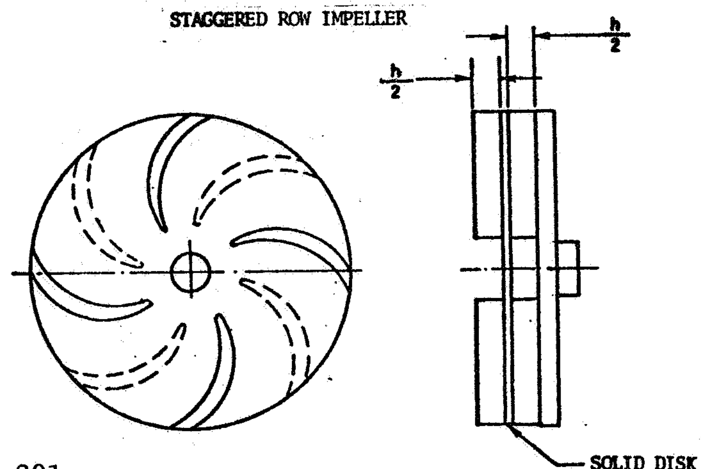
It is generally desirable to have an impeller discharge angle such that the straight line theoretical Euler's head curve - whose shape depends on the discharge angle - approximates the pump curve. This is usually an angle of less than 90°.

From a noise point of view it is necessary to increase the number of vanes over those used in a standard design. Most effective is an impeller of the so-called multi-vane type. This is in essence a many-vaned stacked and staggered row design, manufactured to close hydraulic and mechanical tolerances to assure good hydraulic and mechanical balance and to achieve a low pressure-pulsation level. The very small size of the candidate pumps may well preclude full implementation - particularly multiple rows - due to manufacturing limitations. However, the number of vanes should be kept as high as practical thus increasing the frequency of the vane pulsations but reducing the energy per pulse which will have the effect of smoothing the flow. For example an increase from seven to fourteen vanes could reduce the fluidborne noise level by 27 dB while increasing the frequency by a factor of two. If two rows of seven vanes were used with the rows staggered, an additional 8 dB decrease is estimated. The normal multi vane impeller and a staggered row impeller are illustrated in the sketch below.

NORMAL MULTI VANE IMPELLER



STAGGERED ROW IMPELLER



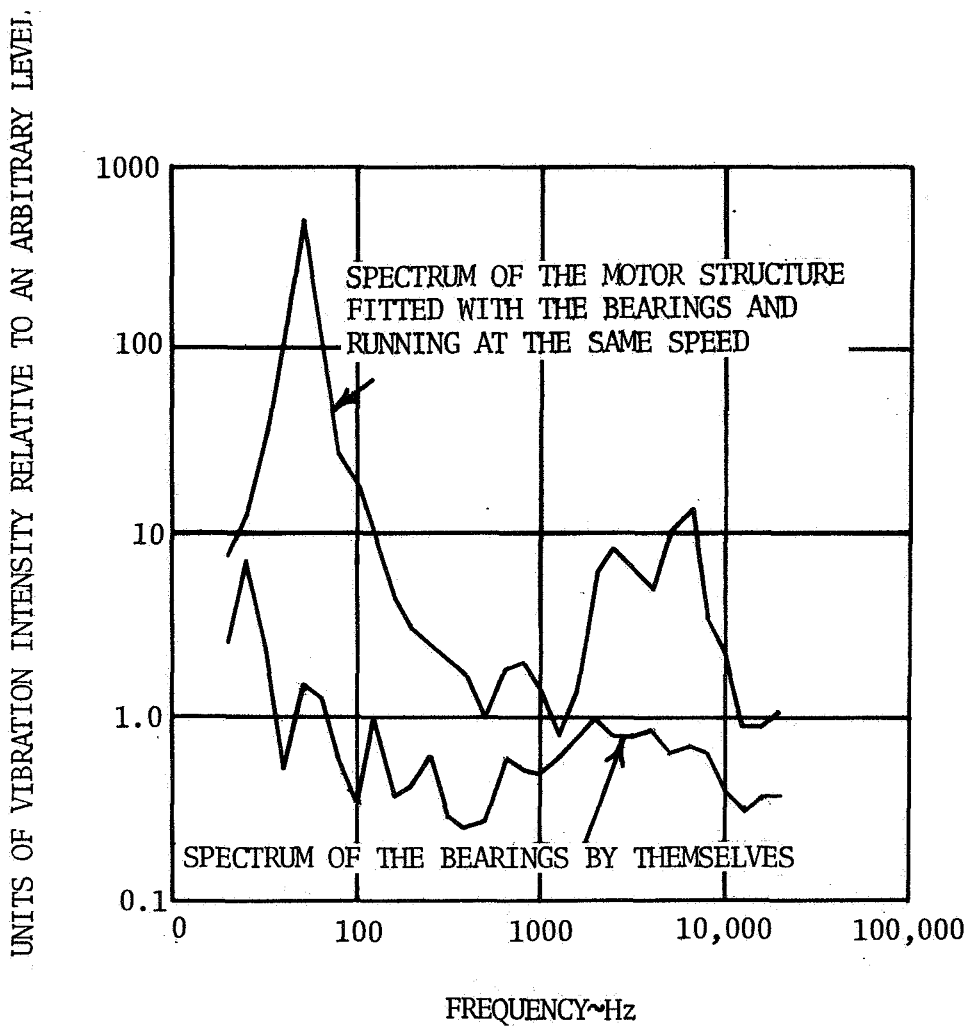
Vane pulsation associated noise is generally decreased as the cutwater clearance - the gap between the impeller outside diameter and the casing inside diameter at the cutwater - is increased. Increasing the cutwater clearance will degrade the efficiency but at a relatively slow rate compared to the noise decrease. For example, a 5 percent efficiency change could yield a 10 to 15 dB noise reduction with a rotor to cutwater diameter ratio change from about 0.9 to 0.7.

Bearing Noise

The noise produced by bearings is caused by vibrations that directly or indirectly originate from the bearings. In normal bearing action, the balls roll over the races and some slipping exerts the elastic portions of the bearing and results in bearing noise. The load on a bearing is transmitted from the outer ring, through the balls as they pass through the zone of contact, to the inner ring. Pesante [31] evaluated the noise from each of the bearing components for bearings of good quality. His findings indicate that the balls are the noisiest component followed by the inner ring and outer ring. The cage produces a negligible noise with respect to the balls and rings.

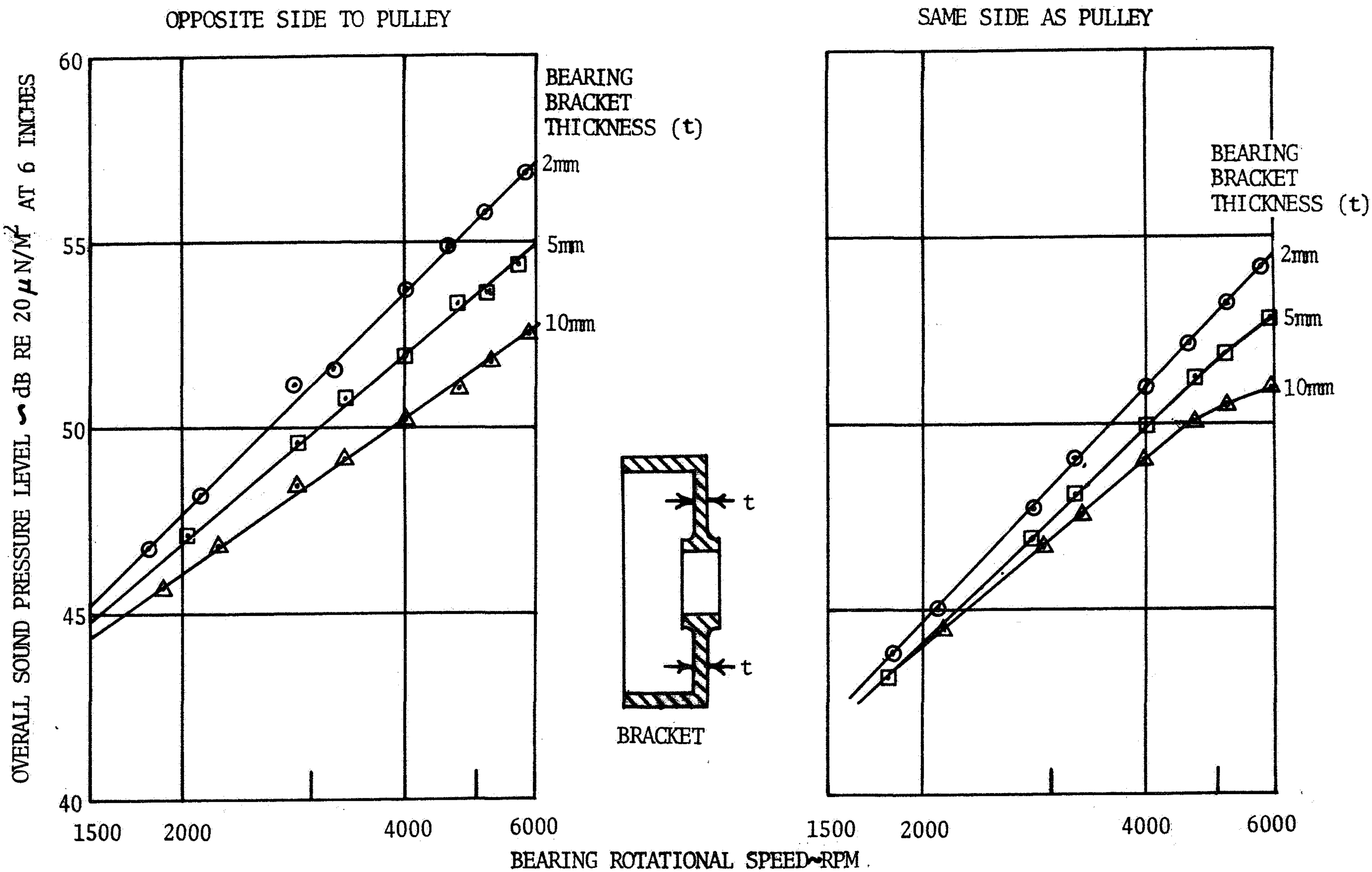
Manufacturing tolerances on the bearing allow uneveness which causes redistribution of the bearing load in the zone of contact. This deviation from a perfectly circular ball causes rapidly repeating sets of impacts and rapidly induced vibrations which show up as noise. The surface roughness of the ball produces noise. Clarke [32] indicates that surface finish of the surfaces in rolling contact is the most important aspect of ball bearings for noise control. Manufacturing processes would require improved materials, honing lapping, running-in and buffing, to achieve quiet bearings. However, Scanlan[33] indicates that even a theoretically perfect geometry and surface finish would still produce some sound. Such surfaces would increase the slippage and fail to pick-up sufficient lubrication. Sound is also produced by the random pumping of the lubricant trapped between the rolling element and the race. This pumping excites metallic waves in the bearing cage and rings. Thus there is a theoretical non-zero level of sound for a bearing.

In bearing installations, the quality of the mating surfaces adjacent to the bearing affects the sound transmitted from the assembly. Clarke shows this in figure 120 for the testing of a small motor. Igarashi [34] also shows this effect for a bearing bracket on a half-horsepower, three phase, four pole AC motor. Figure 121 also indicates the variation of noise with speed. His curve for a simple ball bearing, figure 122, is similar to the work of Nishimura and Takahashi [35] who in their work on ball bearing noise found that the acoustic pressure is proportional to the 6/5 power of the rotational speed as shown in figure 123.



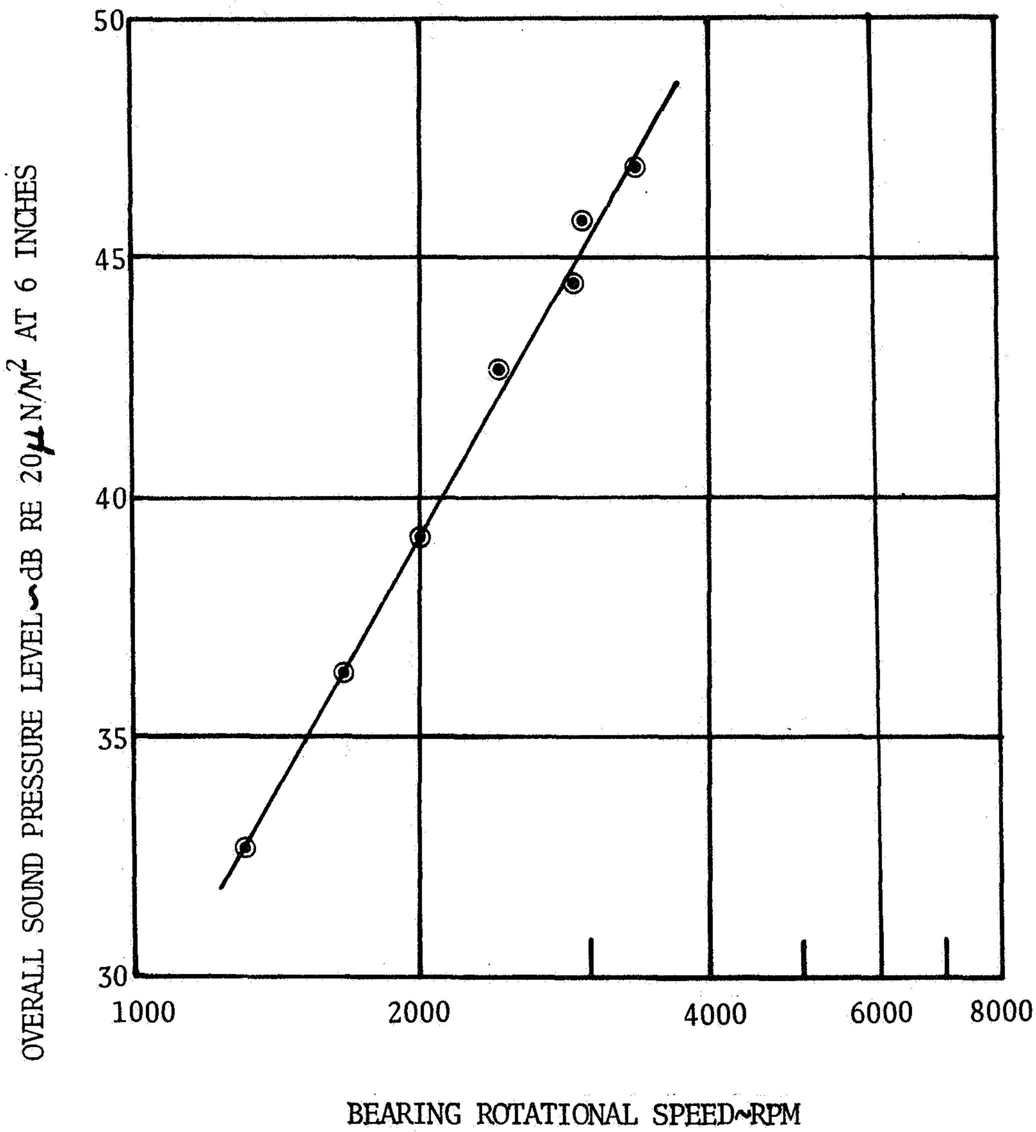
EFFECT OF STRUCTURE ON BEARING NOISE

FIGURE 120



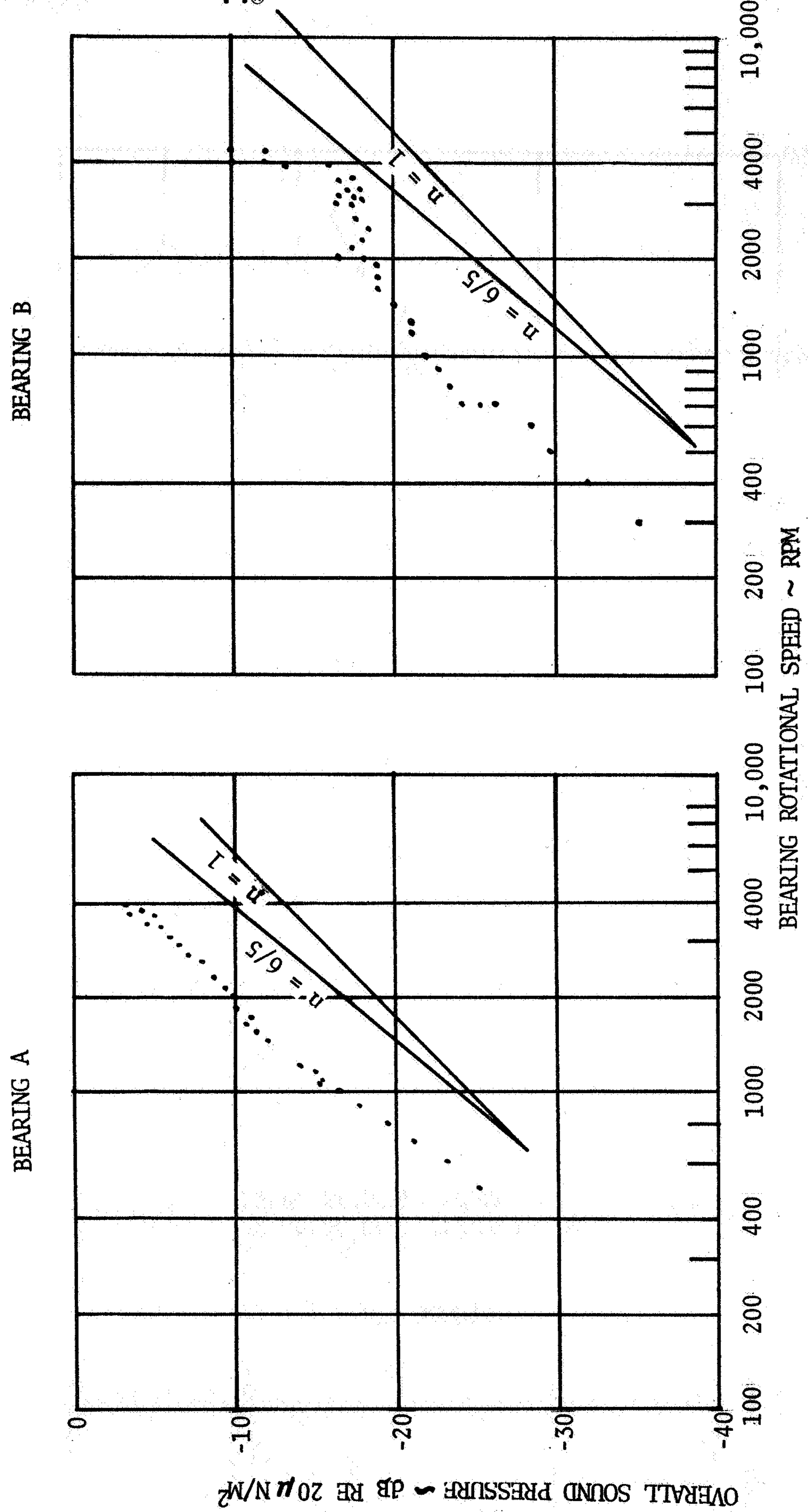
EFFECT OF BRACKET THICKNESS ON BEARING NOISE

FIGURE 121



NOISE VERSUS BEARING SPEED
FOR A SIMPLE BALL BEARING

FIGURE 122



NOISE TREND WITH SPEED FOR 2 BALL BEARINGS

FIGURE 123

The levels of the noise from ball bearings shown in figure 122 indicate that for a rotational speed of 11,200 rpm, as might be considered for Space Shuttle use, the expected bearing noise level is in the 60 to 65 dB range. Since these measurements were made at 6 inches from the bearing, these levels represent 45 to 50 dB at three feet from the source. Based on the Apollo and verification hardware testing, it is apparent that a bearing noise level 45 to 50 dB is not a significant noise source in the ventilation fans, but may be the dominant noise source in the water pump.

Therefore, high quality ball bearings may be used in the fan motors under the present aerodynamic noise levels. However, quieter types of bearings must be used in the pump motors and also in fans required to achieve a 30 dBNC nois level.

Sliding bearings are inherently quieter than rolling (ball)bearings. Sliding bearings are primarily transmitters of sound. They can generate noise but basically the transmission characteristics predominate. The selection of the quietest sliding bearing is centered around the bearing transmission characteristics. The bearing which has the lowest parameters of stiffness, damping, and transmissibility is the best to attenuate noise.

The sliding bearing characteristics that affect its noise generation, transmission, and attenuation are [36]:

- Type of bearing
- Method of lubrication
- Viscosity of lubricant
- Cavitation
- Turbulence
- Bearing geometry
- Diametral clearance

Elliptical, pivoted toe, and three-lobed bearings are less prone to oil whip than cylindrical bearings. Externally pressurized lubrication systems are usually noisier than non-pressurized systems because of the external hardware. The viscosity of the lubricant influences the critical rotor speed. Cavitation occurs when the local pressure drops below the vapor pressure. This is dependent upon the supply pressure and the geometry of the bearing. Turbulence can exist in the bearing and is dependent upon bearing type, geometry, clearance, grooving and so forth. Ruffini [36] presents a complete analysis of the various sliding bearing parameters and their interaction in achieving the quietest sliding bearing for a given application.

FINAL CONCEPT DEFINITION

The concept definitions of a fan and pump for Space Shuttle require both quiet and efficient units. First, the power source for these units was optimized on the basis of Space Shuttle application. Then the concepts were selected, based on the results of the test data evaluation and on data from the analytical estimating procedures. The squirrel cage and axial fans were evaluated against each other using the same criteria used for the preliminary concept candidates. From this comparison an axial fan was selected. A centrifugal pump also was selected on the basis of the preliminary candidate selection criteria. The geometries of both concepts then were optimized for noise and efficiency. Design drawings are presented herein for both of these concepts.

AC VERSUS DC MOTOR TRADE-OFF STUDY

The optimum choice of motor type is closely tied to the generation and distribution characteristics of the spacecraft power system. Although the basic Space Shuttle power source is DC from the fuel cell, the distribution system could be DC, AC with central inverters, or DC with local inversion to AC. The final choice is determined by the lowest equivalent weight penalty. With a DC distribution system the choice of motors would be between pseudo DC motors - AC motors with build-in inverters - or true brushless DC motors of which the Hamilton Standard Modular Motor is a recent development. Conventional brush-type DC motors would not be acceptable because of reliability, safety and performance characteristics. Normally, AC motors would be used with an AC distribution system. Thus the viable choices are:

- Central inverter; AC transmission; AC motors.
- DC transmission; local inverters; AC motors.
- DC transmission; true brushless DC motors.

The significant factors affecting the choice of transmission type will be considered based on available Shuttle study results.

Cabling for all electrical and electronic components aboard the spacecraft represents a significant factor in the weight allocation. The type of power transmission, AC or DC, directly affects the type of cabling used and its weight. Consider for example a large spacecraft which consumes 17 KW with a typical distribution loss of 0.7 KW, which is approximately 4 percent. The cabling weight for a DC power system could be kept acceptably low only by using a 300 VDC system. However, various converters would then be needed for scaling the voltage down to 28 VDC for the different subsystems. This results in a high total weight for power distribution. Considering an AC power system using 115 VAC rms, initially the main feeders of the system would be large but their runs could be severely reduced by immediate branching. Conversion circuitry would be minimized in the various subsystems since the front-ends incorporate power supplies already for transient and voltage ripple protection. Thus, the transmission of a particular type of power is the predominant element in spacecraft power system weight allocations, as opposed to the user items such as fans and pumps. Consequently AC is selected as the primary Shuttle transmission system. The differences in efficiency between various types of motors is not significant enough to influence the choice of transmission system. Thus a system consisting of a central inverter, AC transmission and AC motors is most applicable to Space Shuttle, and AC motors should power fans and pumps.

FAN SELECTION - AXIAL FAN VERSUS SQUIRREL CAGE FAN

Based upon the results of the testing of the verification hardware a comparison of the axial and squirrel cage fans was made. Coordination with the NASA had resulted in the definition of four factors for evaluation. These factors were weight, noise, power, and volume, with weight being weighted approximately twice as important as noise.

For comparison purposes weight, volume, power, and noise are estimated for flight optimized designs. This comparison is shown in Table XXV.

TABLE XXV

FLIGHT DESIGN FAN COMPARISON

	Axial	Squirrel Cage
Flow - cfm	400	400
Pressure Rise - inches H_2O	2.5	2.5
Speed - rpm	11200	3430
Overall Dimensions - inches (OD x length)	7x10.5	11.5x8
Fan Efficiency - %	.70	.50
Motor Efficiency - %	.78	.72
Input Power - watts	221	329
Fan Weight - lbs	1.8	3.3
Motor Weight - lbs	3.6	6.6
Total Weight - lbs	5.4	9.9
Noise Level at 3 feet - dBNC	76	70

Although the squirrel cage unit is quieter than the axial unit, the axial appears to be the best selection for Shuttle. While the 6 dB noise difference between units is at the lower level of detection, the weight and power advantages for the axial unit are substantial. To improve the weight, and perhaps efficiency, of the squirrel cage unit it would have to be run at a higher speed. The diameter must remain the same to accommodate the high airflow. To obtain the same head at higher tip speeds the blades must be changed from forward curved to backward curved to accommodate higher relative air velocities. Both the higher tip speed and higher relative air velocities would tend to increase the noise level and negate any weight advantage to be gained. Although this comparison was made for the cabin fan design conditions, the conclusions should be similar for other aerospace fan designs. The squirrel cage fan must run at lower speeds than either an axial or radial blade centrifugal and will therefore be heavier. Present state-of-the-art efficiencies for squirrel cage units are substantially below those obtainable from present axial and radial blade centrifugal units. Therefore the squirrel cage design will consume more power.

Flight Design Optimization Groundrules

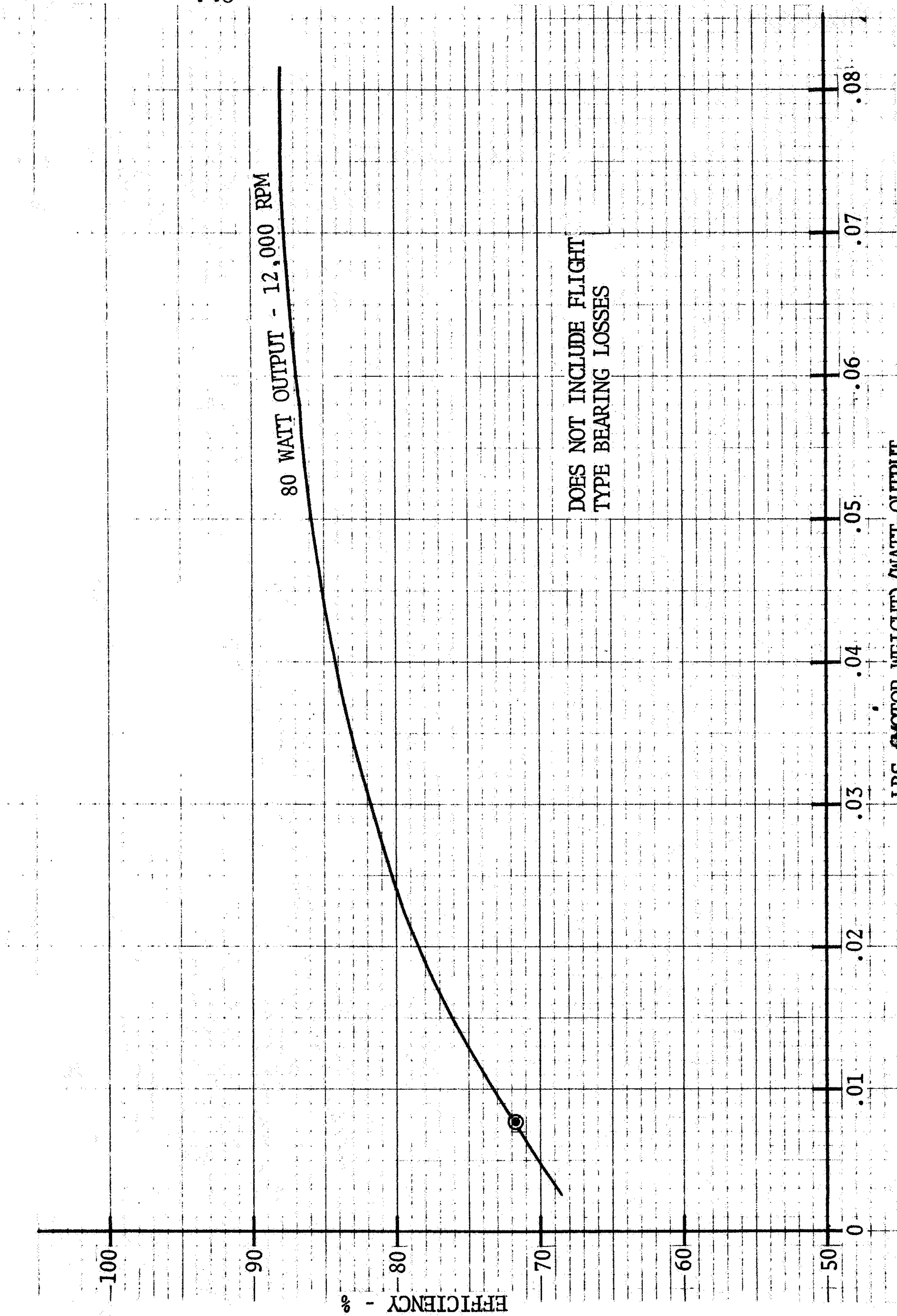
The following groundrules were used for the flight design estimates described in the following pages.

Power equivalent weight = 0.6 lbs/watt.

Fail-op, fail-safe requires dual redundancy, that is: 3 units installed, one operating.

Flight Motor Weight Estimates

The weight of a motor and its efficiency are directly related. The major losses which are the copper and iron losses can be decreased by increasing the amount of copper and iron. Since housing weight is a relatively small percentage, about 20%, overall motor weight varies directly with the amount of copper and iron used. Figure 124 shows a graph of weight versus efficiency for a 12,000 rpm motor. This data was used for estimating flight motor weights. Although the graph is for an 80 watt output motor it should be relatively accurate in the range of consideration.



MOTOR WEIGHT VERSUS EFFICIENCY

FIGURE 124

Motor Weight Versus RPM

For a given power output, motor torque is inversely proportional to rpm. Since torque is directly proportional to I (current), current must go up as rpm goes down. To maintain electrical efficiency iron and copper weight must increase. Available motor data shows weight to be nearly inversely proportional to rpm.

Bearing Losses

Figure 124 does not include flight type bearing losses. As the unit becomes heavier bearings must become larger to withstand launch vibrational loads and will have more friction at a given rpm.

Table XXVI shows test data for Krytox lubricated ball bearings of different rpm's. Both units weigh approximately 2 pounds.

TABLE XXVI

BEARING LOSS

Unit	RPM	Bearing Loss-Watts
PLSS Fan	18,000	4
LM	13,000	2.1

From these data points bearing loss for a 2-pound fan is

$$\text{Bearing Loss} = 1.23 \left(\frac{\text{RPM}}{10{,}000}\right)^2 .$$

It also is assumed that bearing loss will vary roughly as unit weight. The estimated bearing loss used for comparison is therefore

$$\text{Bearing Loss} = \frac{\text{Unit Weight}}{2} \times 1.23 \left(\frac{\text{RPM}}{10{,}000}\right)^2 = \text{Watts} .$$

Squirrel Cage Fan Optimization

Fan Sizing

The squirrel cage fan as received ran at 3870 rpm and delivered 300 cfm at a head of 2.4 inches of water. To meet the required flow of 400 cfm, and to keep the same geometry a 15% increase ($\sqrt{400/300}=1.15$) in diameter and length would be required. The increased size unit would run at

$$3870 \times \frac{1}{1.15} \times \sqrt{\frac{2.5}{2.4}} = 3430 \text{ rpm}$$

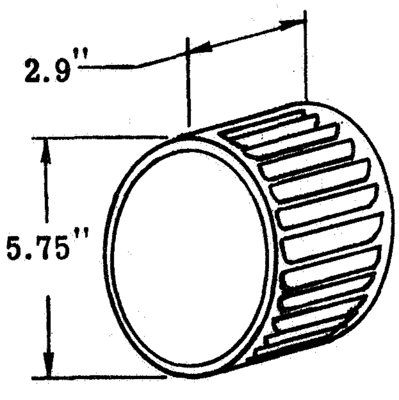
to deliver the required head of 2.5 inches of water.

The specific speed, Ns, of the enlarged fan would be

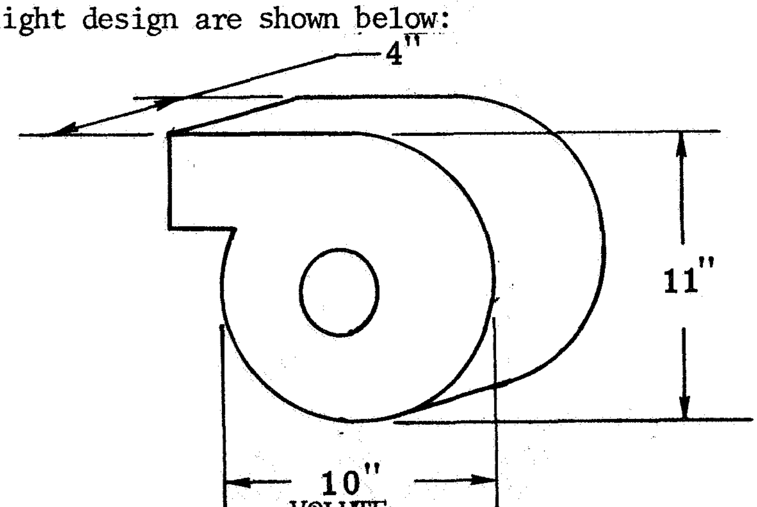
$$Ns = \frac{N\sqrt{Qd}}{(\text{Head})^{.75}} = \frac{3430\sqrt{400}}{\left(\frac{2.5}{12} \times 0.0765\right)^{.75}} = 32{,}400 \text{ rpm}.$$

This is in the range of Ns=20,000 to 35,000 rpm which literature search indicates is required for peak efficiency. For the flight optimization the peak efficiency found in the literature of 50% was used. This results in a fan input power of 236 watts.

The dimensions of the flight design are shown below:



ROTOR



VOLUTE

Weight estimates are:

Rotor	=	0.4 lbs
Volute	=	2.4 lbs
Flanges	=	0.5 lbs
Total	=	3.3 pounds

Squirrel Cage Fan Motor Optimization

The optimization of the motor for the squirrel cage fan is shown in Table XXVII.

TABLE XXVII

SQUIRREL CAGE FAN MOTOR OPTIMIZATION

N = 3430 rpm Output Power = 236 Watts

1	2	3
Motor Weight Lbs/100 Watts @ 12,000 rpm	Motor Weight ~ Lbs $1 \times 2.36 \times \frac{12}{3.43}$	Bearing Loss~Watts $\frac{2 \times 1.23}{2} \times \left[\frac{3430}{10{,}000}\right]^2$
.5	4.13	.6
.8	6.60	.9
1	8.25	1.2
2	16.50	2.4
3	24.75	3.6

4	5	6	7
Motor Effic-iency~%	Motor Input Power~Watts $\frac{236+3}{4}$	Power Penalty ~ Lbs .6x5	Total Penalty ~ Lbs 2x 3+6
.70	347	203	220.3
.72	329	197	217
.73	325	195	220
.78	305	183	232.5
.815	294	176	250.0

The motor for the squirrel cage optimizes at 6.6 lbs and requires an input of 329 watts.

Noise Estimate

The as-received squirrel cage fan noise level at 3870 rpm was 69 dBNC after subtracting out the motor noise.

Since tip speed of the increased design is essentially unchanged the only predicted noise increase should be due to the 33% increase in flow. The fan noise variation with discharge flow, from the Hamilton Standard Empirical Fan Noise Estimating Procedure, is given as

$$\Delta dB = 10 \log Q_d/Q_d \text{ ref.}$$

In this case, a 33% increase in flow represents an increase in noise of

$$\Delta dB = 10 \log 1.33 = 1.2 \text{ dB}$$

This represents an estimated noise level for this fan at its adjusted flow condition of 70 dBNC at 3 feet.

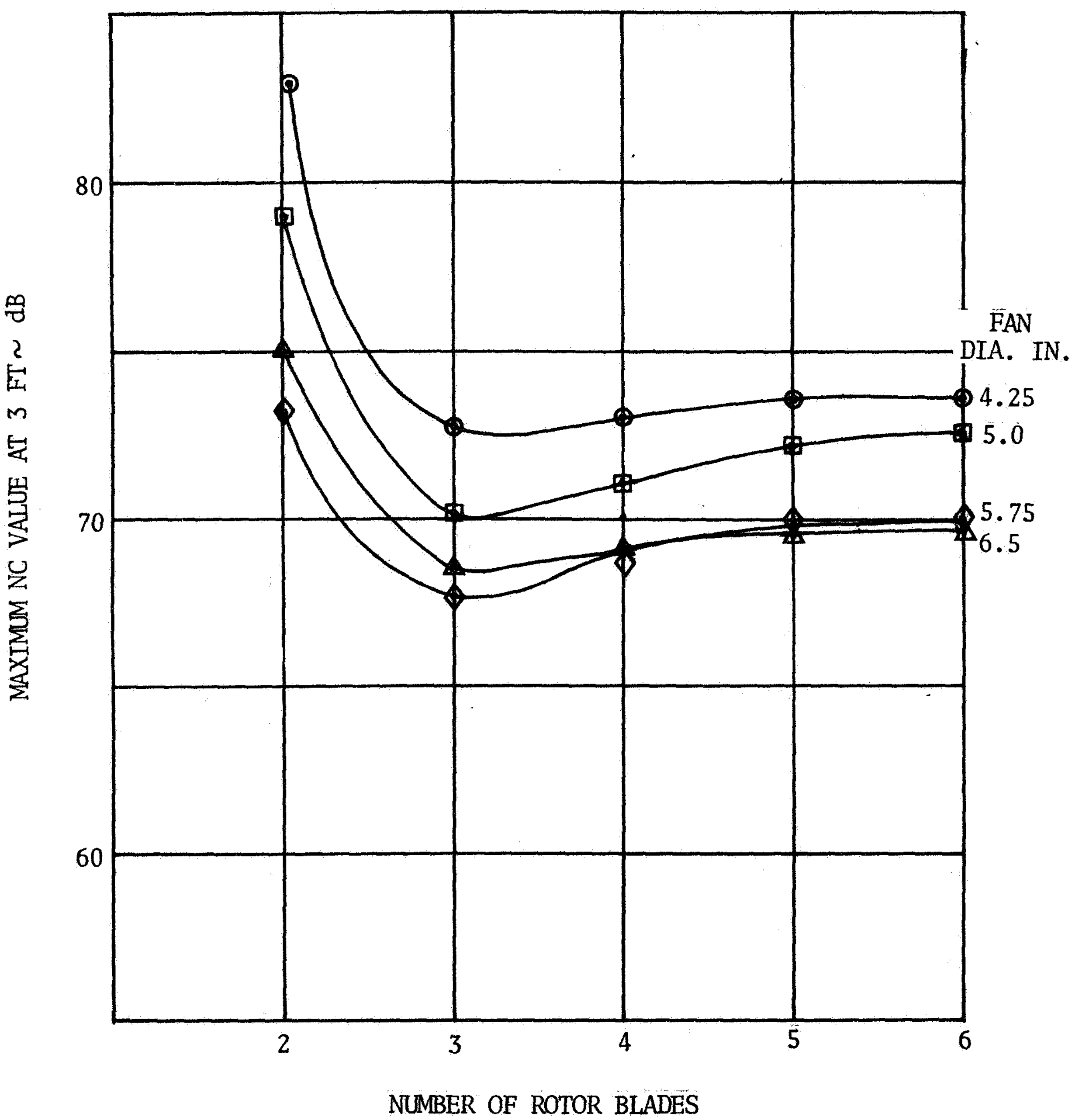
Since the fan noise is aerodynamic rather than mechanical no great effort is made to minimize motor noise. However, a well-balanced motor using top grade ball bearings is required.

Axial Fan Optimization

Fan Sizing

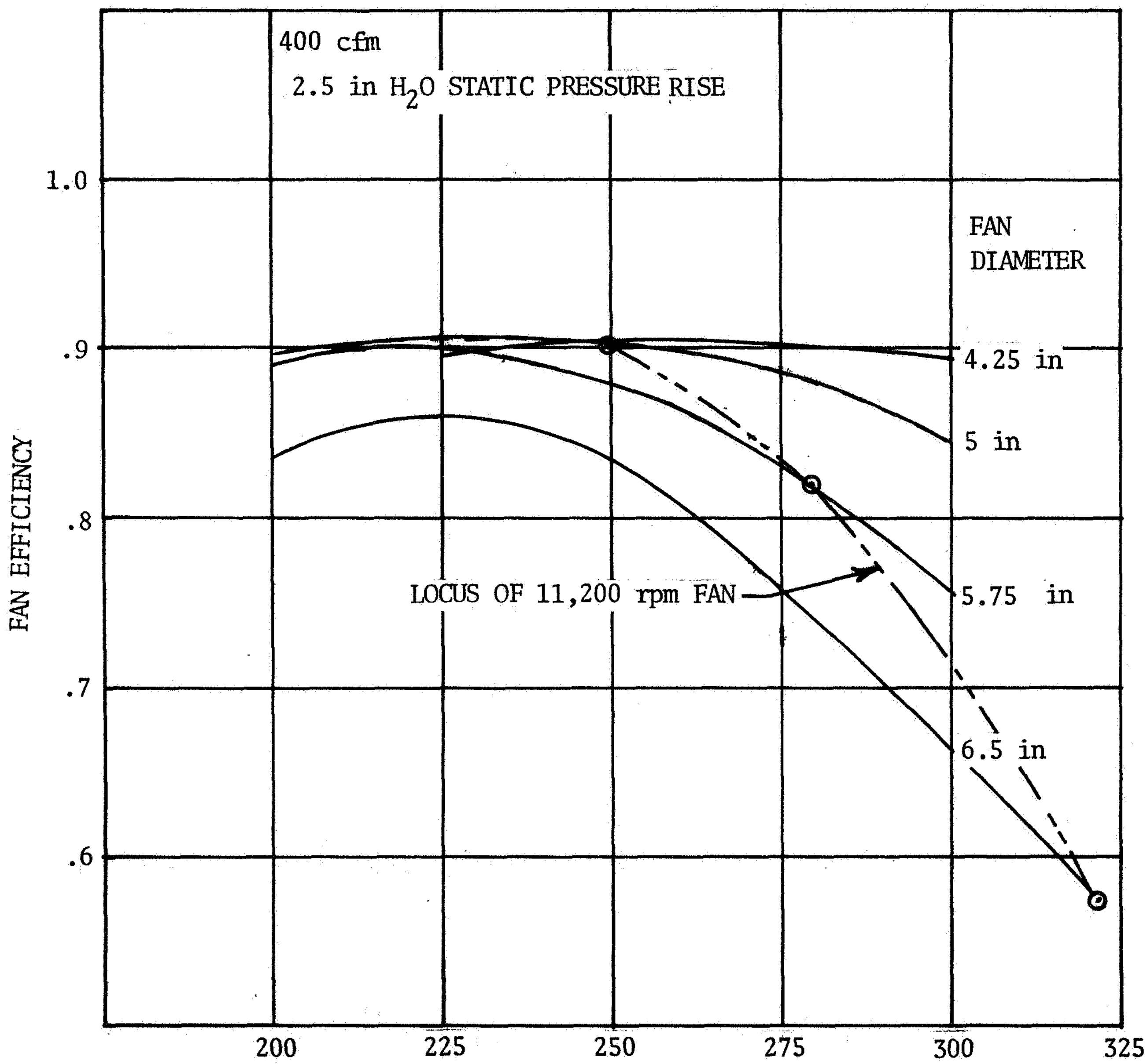
The optimization of an axial fan on the basis of geometry is presented in the section on Axial Fan Parametric Noise Mapping.

From figure 110 repeated here as figure 125 it can be seen that a three-bladed rotor yields the lowest noise. All of the rotors presented in figure 125 have efficiencies over 80 percent and are considered acceptable for the Space Shuttle fan concept. Again, referring back to the axial fan parametric mapping section, figures 109 and 111 were taken and modified to include a line representing an 11,200 rpm fan. These curves are shown in figures 126 and 127. The dotted line on figure 126 presents the locus of an 11,200 rpm fan from which fan rotor efficiency can be determined. Figure 127 presents a similar locus on a dBNC noise curve. From these curves of an 11,200 rpm unit the fan noise and rotor efficiency can be plotted as a function of diameter as shown in figure 128. Here it can be seen that a 5.5 inch diameter fan is optimum from a noise standpoint and a 4.75 inch diameter fan is optimum from an efficiency standpoint.



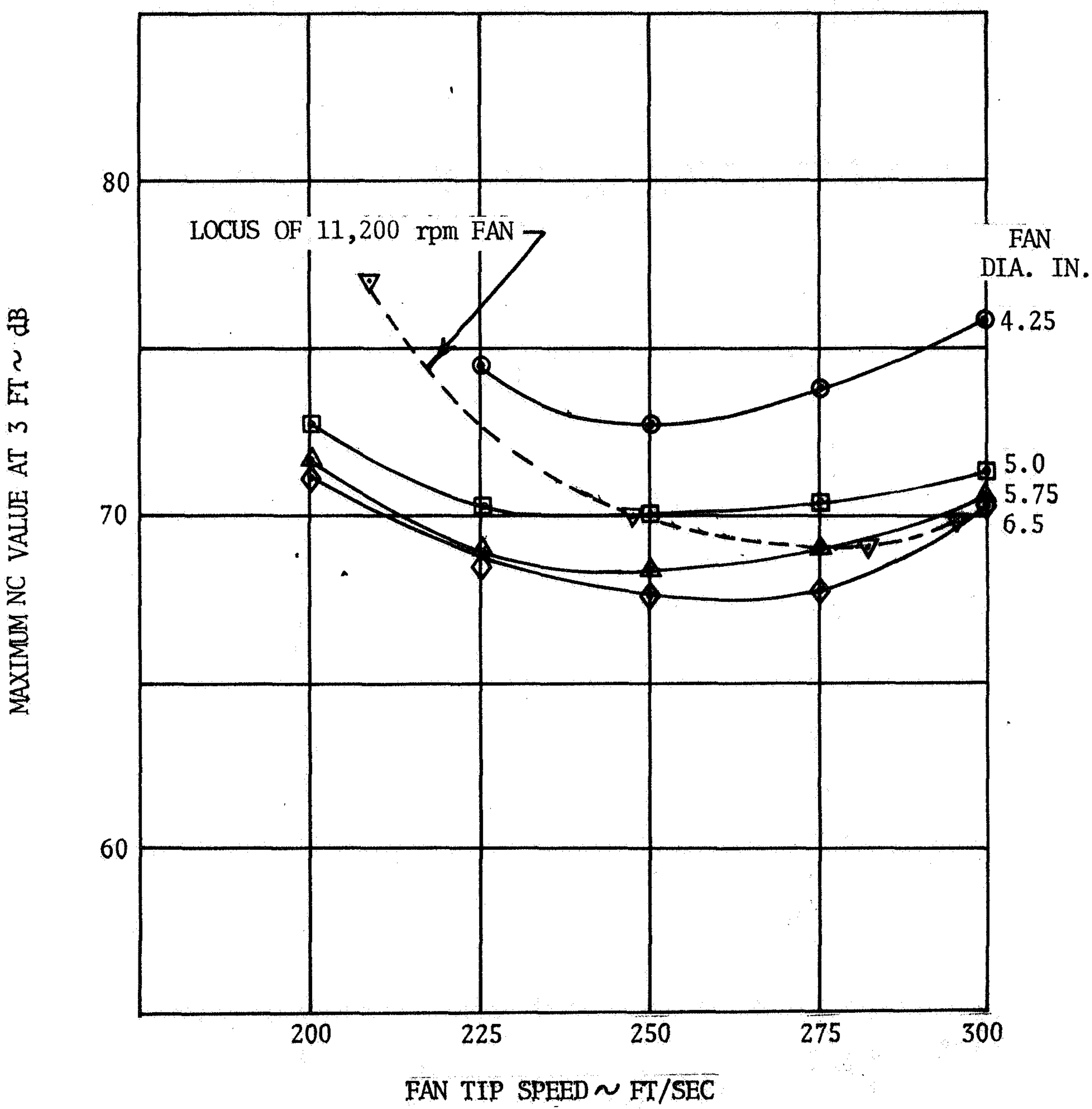
FAN NOISE VS NUMBER OF ROTOR BLADES

FIGURE 125



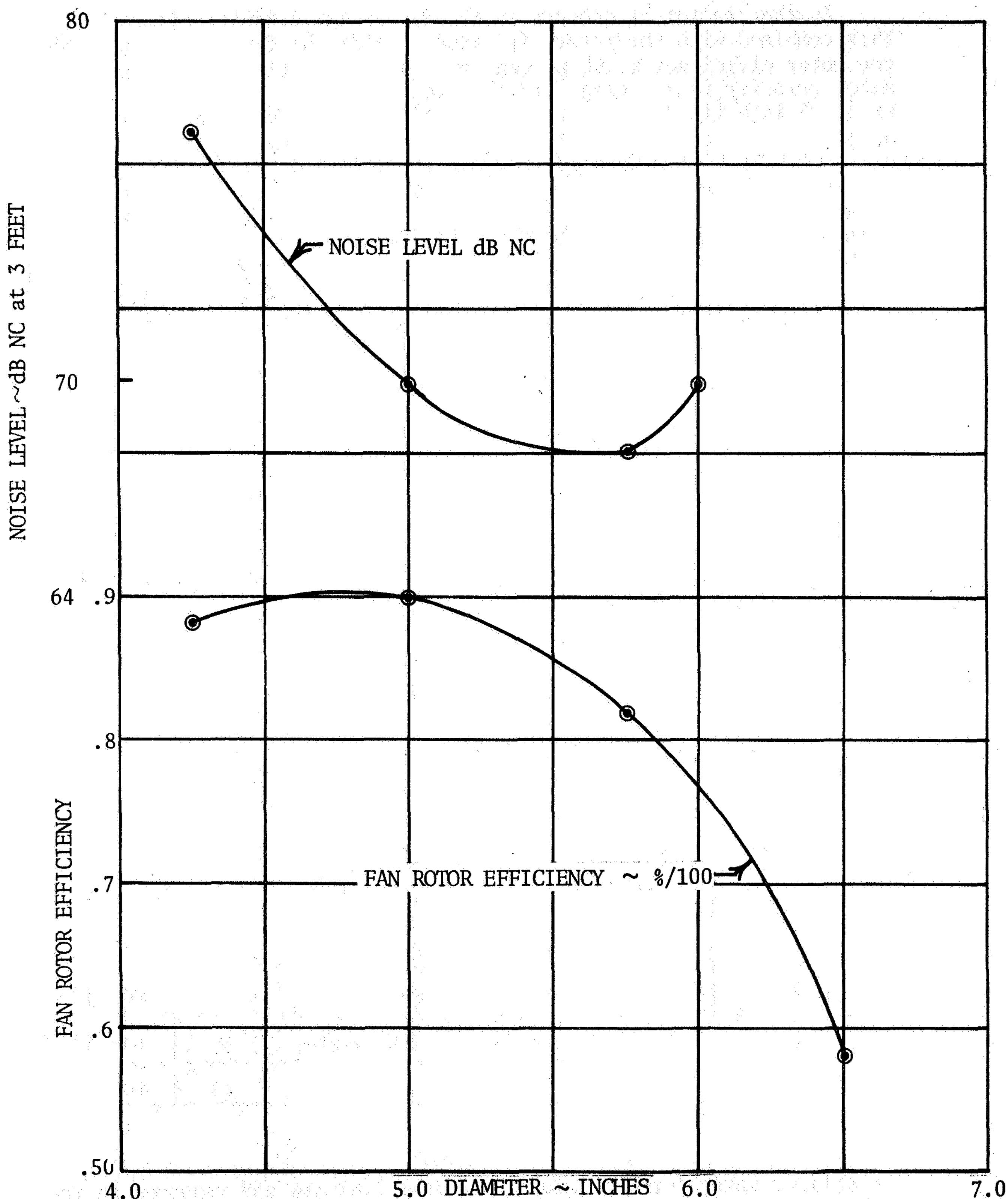
FAN EFFICIENCY VS TIP SPEED AND DIAMETER

FIGURE 126



FAN NOISE VS TIP SPEED

FIGURE 127



11,200 RPM AXIAL FAN NOISE AND ROTOR EFFICIENCY
AS A FUNCTION OF ROTOR TIP DIAMETER
(GAP TO CHORD RATIO = 2)
FIGURE 128

Another factor of concern in the fan is the diffuser efficiency. This combined with the rotor efficiency yields the fan efficiency. While the rotor efficiency is 90 percent at a 4.75 inch tip diameter the fluid axial velocity is 72 ft/sec and the dynamic head is 1.2 inches of water. At a 5.5 inch tip diameter the rotor efficiency is 86 percent but the axial flow velocity is 55 ft/sec and the dynamic head is only 0.55 inches of water. Thus, the friction turning losses and dumping losses in the stator will be less and fan efficiencies equal to those of the 4.75 inch diameter unit will be achieved. On this basis, the 5.5 inch rotor tip diameter, which yields the lowest noise fan, was selected for the Space Shuttle fan concept.

From figures 113 and 114 a composite curve was obtained for a 5.0 inch and 5.75 inch tip diameter unit running at 11,200 rpm. These curves are presented in figure 129 along with an interpolation of the 5.5 inch tip diameter selected. From figure 129 a gap to chord ratio of 1.5 was selected for the concept. Little is gained by a larger gap to chord ratio and the added overhang on the support stators could require an increase in blade tip clearance of the unit.

Axial Fan Motor Optimization

Based on previously stated groundrules, a motor for the axial fan was selected from a total penalty as shown in Table XXVIII.

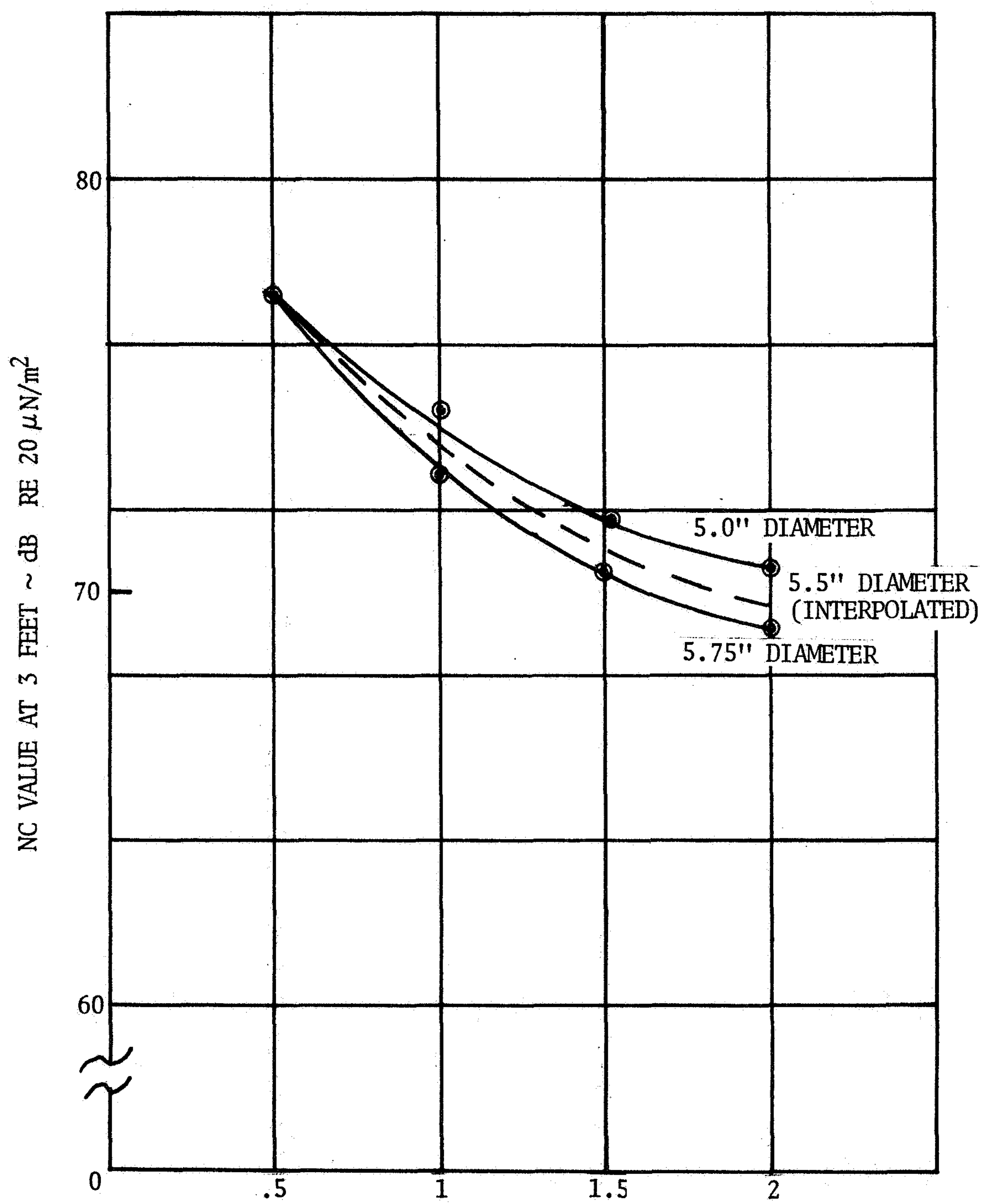
TABLE XXVIII

AXIAL FAN MOTOR OPTIMIZATION

N = 11,200 rpm   Motor Output Power = 169 Watts

Motor Weight Lbs/100 Watts	Motor Weight ~ Lbs ① $\times 1.69 \times \frac{12}{11.2}$	Bearing Loss Watts $\frac{②}{2} \times 1.23 \left(\frac{11,200}{10,000}\right)^2$	Motor Efficiency %	Motor Input ~Watts $\frac{169+③}{④}$	Power Penalty ~Lbs .6x⑤	Total Penalty ~Lbs ②x3+⑥
1	1.81	1.4	.73	234	140	145
2	3.62	2.8	.78	221	132	143
3	5.43	4.2	.815	213	127	143
4	7.24	5.6	.84	208	125	147

The optimum motor for the axial fan weighs 3.62 lbs and requires an input power of 221 watts.



11,200 RPM FAN NOISE VARIATION WITH BLADE/VANE GAP

FIGURE 129

SPACE SHUTTLE FAN CONCEPT

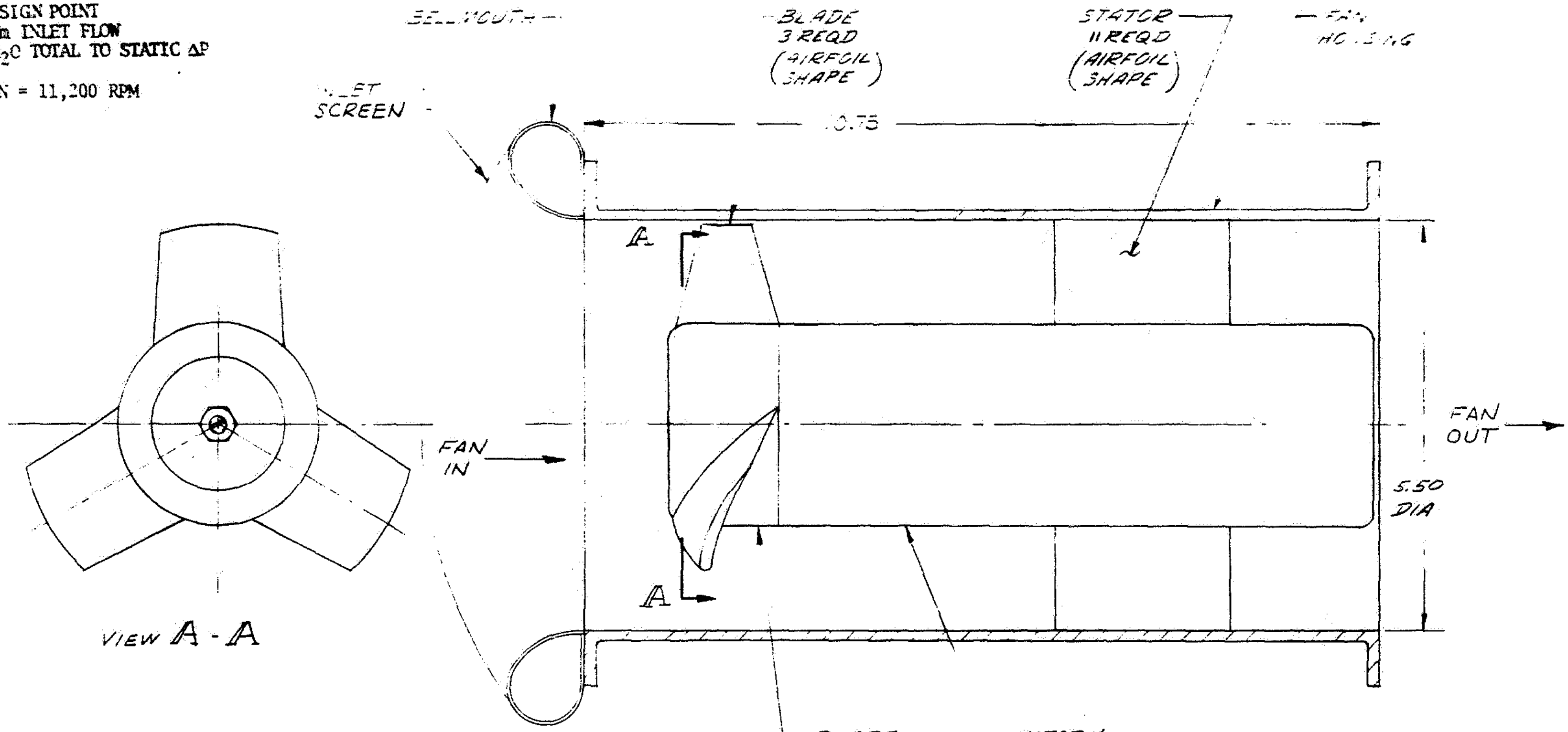
Figure 130 shows the Space Shuttle fan concept. The unit uses a large bellmouth and screen to provide smooth inlet flow. The screen is located somewhat upstream of the rotor and also at a larger diameter, to minimize pressure drop. The screen also serves as a safety device for both the Space Shuttle occupants and for the fan.

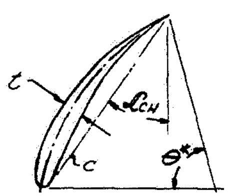
A short 1.5 inch length of duct is provided upstream of the rotor to allow the decay of the rotor tones to levels below those of the broad band noise. The airfoil shaped rotor and stator blades were selected using the considerable previous airfoil experience at Hamilton Standard. The rotor uses three, series 16 airfoils as blade sections. These blade types were found to have both high efficiency and low noise. Rotor tip clearance is kept small - 0.008 inch - to minimize the generation of rotor tip vortices. Rotor to stator gap is four inches, which is approximately 1.5 mean rotor chord lengths. The reduction of noise for increases in this gap length is small and a further increase in this length will only increase the overhang of the motor. The verification fan operated with a four inch gap between the rotor and stators and as such, the experience gained on that overhung unit aided in selecting the gap in this fan concept. The 11 stator vanes of series 400 airfoils were designed on the basis of optimum solidity for high efficiency and low noise. To reduce the overall length of the unit many short vanes were used rather than several long ones. This also reduced the secondary flow losses and improved the noise levels. With five vanes, the interaction modes would be such that they would have a low decay rate for the second harmonic, which thus would propagate unless very long ducts were used on the inlet and exhaust of the fan. With 11 vanes, the interaction modes have good decay rates up through the third harmonic and it therefore is expected that they will have decayed to levels below those of the broad band noise by the time they reach the fan inlet and exhaust. The vanes serve as the structural supports for the motor. Following the stator vanes is another short two inch length of duct and hub to allow decay of the rotor and stator interaction modes. This also prevents the unit from being installed too near a heat exchanger or other system components, which would couple to the stator wakes and cause significant noise.

The overall dimensions including the bellmouth are eight inches in diameter by thirteen inches long. The unit has an estimated weight of 5.4 pounds. The estimated power consumption and noise level are 221 watts and 76 dBNC at three feet.

FAN DESIGN POINT
400 cfm INLET FLOW
2.5" H_2O TOTAL TO STATIC ΔP

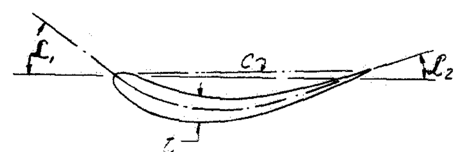
N = 11,200 RPM





ROTOR
SERIES 16 BLADES

$\mathcal{D}$	$\mathcal{L}_{CH}$	θ *	t/c
5.50	9.7	37.8	.060
4.33	16.7	41.8	.098
2.75	41.2	26.9	.144



STATOR
SERIES 400 BLADES
t/c = .10

$\mathcal{D}$	$\mathcal{L}_1$	$\mathcal{L}_2$
5.50	34.8	10°
4.33	45.5	10°
2.75	54.9	10°

SPACE SHUTTLE CABIN FAN CONCEPT
FIGURE 130

SPACE SHUTTLE PUMP CONCEPT

Selection Parameters

As noted from the LM pump and motor noise data, figure 10, the use of sliding vanes produces significant noise. Significant sources of noise also are expected from pump types utilizing intermeshing gears, vibrating diaphragms, or oscillating pistons. Therefore, the centrifugal pump is expected to be quieter than these other types. This conclusion was reached as a result of the Preliminary Concept Definition Study, as summarized in Table XIV and supported by the verification and Apollo hardware tests. Thus low noise and relatively good efficiency make the centrifugal pump the best concept for Space Shuttle application.

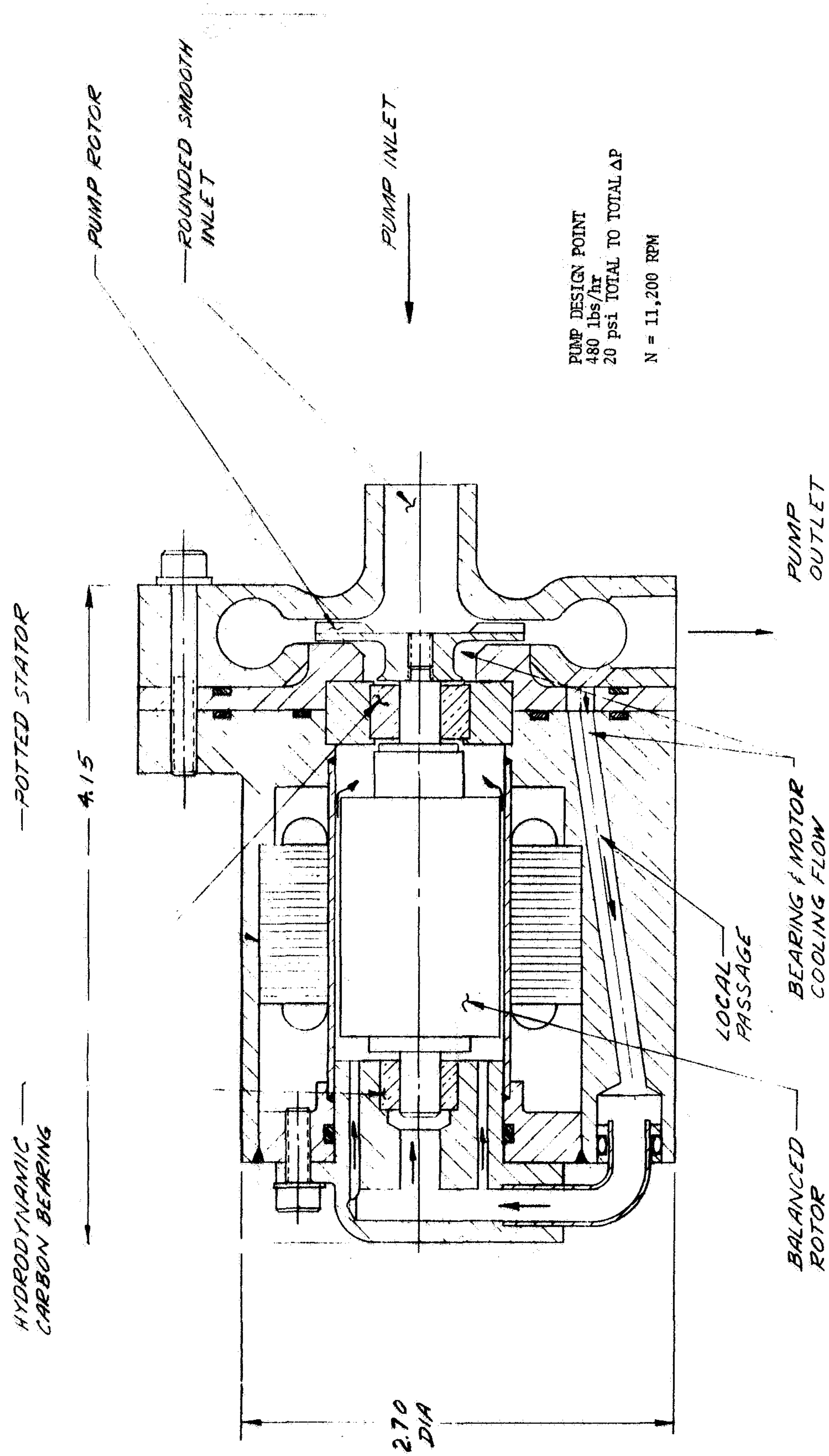
The selection of a motor to drive this centrifugal rotor presents an important aspect of the concept. With a quiet, non-cavitating pump, the source of noise in all of the testing conducted on centrifugal units is the motor. The basis for this noise is both bearings and dynamic unbalance of the rotating assembly. Balancing can be achieved upon assembly. However, the bearing noise may be difficult to minimize. Figure 88 shows the difference in noise spectrum using ball bearings and sintered bronze bushings. The 8 dBNC improvement is significant and must be incorporated into the design. To achieve long life, hydrodynamic bearings will be used instead of the bronze bushings. These should have similar noise characteristics to the bronze bushings tested. The speed of the unit for a 208 VAC, 400 Hz, three phase, power source with a reasonable slip can be 5500 rpm, or 7400 rpm, or 11,200 rpm. A comparison of the performance efficiencies for these motors shows them to be approximately the same. However, as the speed increases the unit becomes smaller and lighter. As such, an 11,200 rpm motor speed was selected to power the pump concept.

Pump Concept Design

Figures 131 and 132 show the Space Shuttle pump concept and its rotor. Flow enters the unit through a smooth, well rounded inlet and enters the rotor. The rotor design is similar to that of the verification test rotor. It has six backward swept blades with a rounded, sloping inlet and rounded outlet. The 0.050 inch blade height is optimized for the flow and speed conditions. From the rotor the flow passes through a smooth gradually increasing outlet passage. The unit is driven by a motor whose electronics and stator windings are isolated from the pump fluid by a hermetic seal. A well potted stator is utilized to minimize winding noise. The motor uses carbon, hydrodynamic bearings.

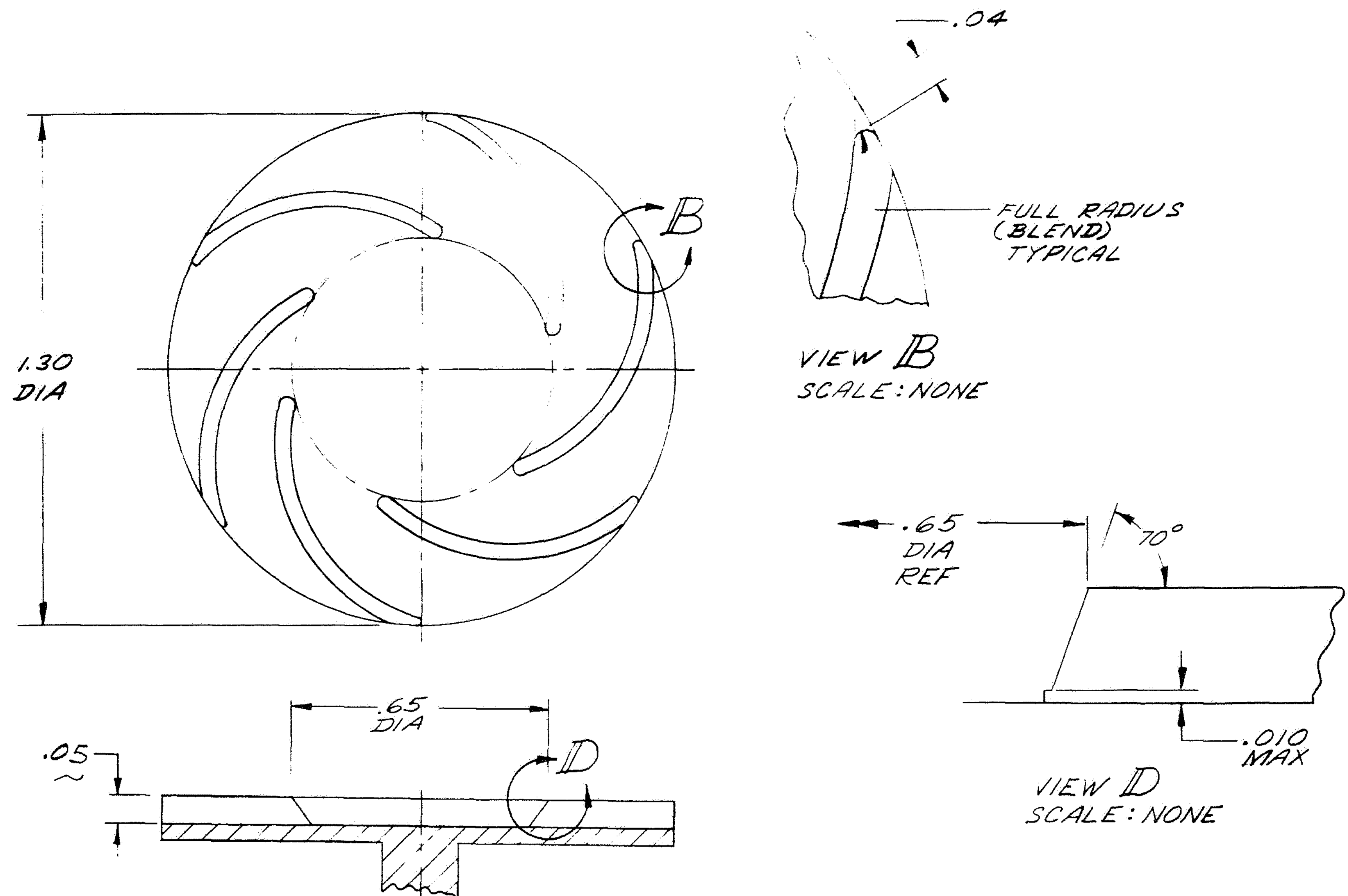
A small portion of the high pressure fluid from the outlet scroll is routed to the rear of the motor. Here it divides. Some passes through the rear bearing providing a lubricating film for hydrodynamic operation. The larger portion of the fluid bypasses the rear bearing and provides cooling flow for the motor and lubrication for the front bearing. The fluid enters the low pressure region behind the rotor and then is pumped into the main fluid stream and out of the pump. Both the pump rotor and the motor rotor are balanced to minimize these noise sources.

The pump overall dimensions are 3.5 inches in diameter by 4.75 inches long. The estimated weight is 2.5 pounds. The estimated power and noise level are 110 watts and 40 dBNC at three feet.



SPACE SHUTTLE CABIN HEAT TRANSPORT LOOP PUMP

FIGURE 131



SPACE SHUTTLE CABIN HEAT TRANSPORT LOOP PUMP ROTOR
FIGURE 132

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APPENDIX A

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APPENDIX B

SUMMARY OF MEASURED NOISE LEVELS

PART I - APOLLO HARDWARE TEST DATA

FAN NOISE DATA

TEST UNIT :CSM ECS PLV FAN
CONDITION :INLET NOISE @ 14.7 PSIA
MIKE RAD (IN):24

```
MICROPHONE=   7.5 DEG
:=  60.2:=  59.0:=  47.0:=  42.2:=  45.5:=  52.2:=  38.2:=  35.5
:=  41.0:=  39.0:=  39.7:=  45.2:=  42.0:=  42.5:=  39.2:=  39.2
:=  37.2:=  37.0:=  40.2:=  42.5:=  37.5:=  40.0:=  40.0:=  35.7
:=  37.5:=  38.7:=  30.2:=  34.7:=  28.0:=  21.0

MICROPHONE=  22.5 DEG
:=  63.5:=  64.2:=  48.5:=  42.0:=  39.7:=  46.5:=  34.5:=  34.0
:=  39.0:=  37.2:=  35.5:=  41.7:=  41.0:=  39.7:=  37.0:=  38.7
:=  47.0:=  41.0:=  45.5:=  44.0:=  38.7:=  43.7:=  46.2:=  40.0
:=  45.0:=  45.2:=  37.5:=  42.5:=  36.2:=  28.7

MICROPHONE=  37.5 DEG
:=  60.7:=  59.7:=  48.0:=  41.2:=  40.7:=  45.2:=  35.0:=  34.0
:=  37.5:=  35.7:=  35.5:=  40.5:=  41.5:=  38.5:=  36.7:=  36.2
:=  47.5:=  41.5:=  45.7:=  46.2:=  42.2:=  45.0:=  45.0:=  43.5
:=  45.7:=  44.5:=  39.2:=  43.7:=  36.2:=  29.0

MICROPHONE=  52.5 DEG
:=  61.0:=  60.7:=  49.0:=  43.7:=  47.5:=  46.7:=  38.2:=  37.5
:=  37.7:=  35.5:=  38.2:=  39.5:=  41.0:=  39.7:=  38.5:=  40.5
:=  50.0:=  43.7:=  47.2:=  48.5:=  44.0:=  48.5:=  48.5:=  45.2
:=  47.2:=  44.5:=  40.2:=  42.0:=  39.7:=  30.0

MICROPHONE=  67.5 DEG
:=  62.0:=  62.5:=  51.5:=  46.2:=  45.7:=  47.7:=  40.0:=  39.2
:=  37.7:=  36.0:=  39.5:=  37.5:=  41.5:=  42.0:=  39.7:=  42.7
:=  49.2:=  43.7:=  47.5:=  48.2:=  43.7:=  49.5:=  51.5:=  45.0
:=  47.2:=  45.0:=  40.7:=  42.7:=  40.5:=  30.7

MICROPHONE=  82.5 DEG
:=  62.5:=  62.2:=  50.7:=  49.2:=  45.2:=  52.2:=  42.0:=  40.0
:=  38.7:=  36.7:=  38.7:=  37.0:=  43.0:=  43.0:=  41.5:=  43.2
:=  51.7:=  45.0:=  46.5:=  46.5:=  43.5:=  52.2:=  47.7:=  45.7
:=  48.5:=  44.5:=  41.0:=  44.2:=  38.5:=  31.5

1/3 OCTAVE BAND PWL  DB RE 10↑-13 WATT
=  75.2=  75.1=  62.2=  56.9=  57.9=  62.5=  51.0=  49.7
=  52.6=  50.7=  51.4=  55.7=  55.0=  54.3=  51.9=  53.1
=  60.9=  55.1=  58.9=  59.4=  54.9=  59.6=  60.2=  56.0
=  58.7=  57.4=  51.7=  55.3=  50.4=  42.0
FULL OCTAVE BAND PWL  DB RE 10↑-13 WATT
=  78.3=  64.6=  56.0=  58.0=  58.7=  62.4
=  62.9=  63.7=  61.6=  56.7*
```

FAN NOISE DATA

SVHSER 6183

TEST UNIT :CSM ECS FLV FAN
CONDITION :OUTLET NOISE @ 14.7 PSIA
MIKE RAD (IN):25

```
MICROPHONE=   7.5 DEG
:=  55.7:=  53.7:=  44.5:=  46.5:=  49.7:=  58.2:=  44.7:=  38.0
:=  40.5:=  40.0:=  39.7:=  38.7:=  43.7:=  44.7:=  36.2:=  39.0
:=  36.2:=  39.0:=  42.7:=  46.7:=  39.2:=  42.2:=  41.5:=  38.2
:=  43.2:=  43.7:=  34.7:=  42.5:=  35.2:=  26.7

MICROPHONE=  22.5 DEG
:=  55.2:=  53.5:=  44.0:=  45.2:=  42.2:=  55.5:=  42.5:=  34.7
:=  38.7:=  38.0:=  37.5:=  39.7:=  43.0:=  44.5:=  35.2:=  36.5
:=  43.2:=  47.0:=  47.5:=  50.5:=  40.0:=  42.7:=  47.2:=  42.7
:=  46.2:=  47.2:=  37.2:=  43.2:=  37.5:=  30.0

MICROPHONE=  37.5 DEG
:=  55.2:=  53.0:=  43.0:=  45.5:=  42.2:=  48.0:=  36.7:=  34.0
:=  36.7:=  36.2:=  37.7:=  41.0:=  43.0:=  41.2:=  34.7:=  34.7
:=  43.2:=  49.0:=  48.0:=  50.0:=  41.5:=  40.5:=  43.7:=  45.5
:=  42.7:=  43.0:=  37.7:=  43.7:=  37.0:=  30.2

MICROPHONE=  52.5 DEG
:=  56.7:=  54.5:=  46.0:=  53.0:=  48.2:=  49.5:=  40.5:=  38.2
:=  37.2:=  37.2:=  42.0:=  43.5:=  43.0:=  41.0:=  36.7:=  39.7
:=  47.7:=  52.7:=  49.7:=  52.0:=  43.0:=  45.7:=  46.5:=  47.2
:=  46.0:=  45.0:=  41.0:=  48.0:=  41.7:=  34.0

MICROPHONE=  67.5 DEG
:=  55.0:=  53.0:=  44.0:=  49.7:=  48.5:=  57.0:=  44.2:=  38.0
:=  36.2:=  35.7:=  42.0:=  40.0:=  41.0:=  39.7:=  35.0:=  39.0
:=  49.0:=  49.0:=  46.7:=  48.2:=  41.5:=  47.0:=  45.7:=  44.0
:=  43.5:=  44.0:=  40.5:=  41.7:=  38.2:=  31.5

MICROPHONE=  82.5 DEG
:=  55.0:=  53.0:=  44.0:=  50.0:=  49.0:=  57.5:=  44.0:=  38.0
:=  36.0:=  36.0:=  42.0:=  40.0:=  41.0:=  40.0:=  40.2:=  41.5
:=  48.7:=  47.0:=  45.2:=  46.0:=  39.2:=  45.5:=  46.0:=  41.5
:=  45.7:=  44.7:=  35.7:=  38.7:=  32.0:=  28.5

1/3 OCTAVE BAND PWL  DB RE 10↑-13 WATT
=  69.4=  67.4=  58.2=  62.4=  61.0=  69.3=  56.5=  50.6
=  52.3=  51.9=  53.7=  54.5=  56.8=  57.0=  49.8=  52.0
=  58.7=  62.3=  61.0=  63.6=  54.8=  57.5=  59.1=  57.8
=  58.5=  58.8=  52.0=  58.1=  51.9=  44.4
FULL OCTAVE BAND PWL  DB RE 10↑-13 WATT
=  71.8=  70.6=  58.6=  58.3=  60.3=  64.1
=  65.8=  63.0=  62.1=  59.1*
```

SVHSER 6183

```
FAN NOISE DATA

TEST UNIT    :LM ECS SUIT FAN
CONDITION    :INLET NOISE @ 5 PSIA
MIKE RAD (IN):24


MICROPHONE=   7.5 DEG
:=  74.2:=  88.5:=  65.0:=  55.0:=  68.5:=  48.2:=  50.0:=  57.2
:=  53.0:=  54.0:=  52.5:=  57.2:=  66.7:=  62.5:=  51.7:=  48.7
:=  52.7:=  58.2:=  61.5:=  58.7:=  58.5:=  69.5:=  66.0:=  61.0
:=  53.2:=  55.5:=  53.0:=  51.0:=  50.0:=  46.0:=  73.7:=  88.0

MICROPHONE=  22.5 DEG
:=  74.5:=  88.0:=  64.7:=  54.5:=  68.2:=  47.2:=  46.5:=  54.2
:=  55.5:=  52.0:=  52.0:=  56.7:=  64.7:=  60.7:=  49.5:=  49.7
:=  56.2:=  61.5:=  63.7:=  60.2:=  60.5:=  72.5:=  68.7:=  60.5
:=  56.7:=  62.5:=  58.0:=  57.5:=  56.5:=  52.5:=  76.0:=  88.0

MICROPHONE=  37.5 DEG
:=  74.0:=  87.7:=  64.5:=  53.7:=  67.0:=  47.0:=  46.5:=  48.7
:=  52.5:=  48.7:=  52.5:=  56.7:=  62.7:=  58.0:=  48.2:=  54.0
:=  58.5:=  62.5:=  66.0:=  62.5:=  63.2:=  72.0:=  68.0:=  66.0
:=  60.0:=  65.0:=  62.2:=  62.2:=  59.0:=  56.2:=  76.7:=  87.7

MICROPHONE=  52.5 DEG
:=  74.0:=  88.0:=  65.0:=  53.5:=  67.0:=  49.2:=  52.7:=  44.5
:=  49.7:=  47.0:=  53.2:=  56.7:=  61.0:=  57.7:=  49.7:=  58.5
:=  59.7:=  65.5:=  68.2:=  65.0:=  66.7:=  75.2:=  70.5:=  69.0
:=  64.5:=  67.2:=  66.2:=  65.7:=  61.5:=  58.0:=  80.0:=  88.0

MICROPHONE=  67.5 DEG
:=  73.0:=  87.2:=  64.2:=  53.2:=  66.7:=  51.5:=  56.5:=  50.5
:=  44.7:=  46.7:=  53.0:=  55.0:=  62.0:=  60.0:=  50.7:=  57.5
:=  62.5:=  65.5:=  69.7:=  66.2:=  68.2:=  76.0:=  72.0:=  66.5
:=  65.7:=  67.5:=  67.0:=  68.0:=  64.7:=  60.7:=  80.7:=  87.5

MICROPHONE=  82.5 DEG
:=  72.5:=  87.2:=  64.0:=  54.2:=  68.5:=  54.2:=  59.2:=  55.2
:=  44.5:=  46.0:=  51.2:=  54.5:=  63.7:=  59.7:=  52.5:=  58.2
:=  63.0:=  66.2:=  71.2:=  67.0:=  69.0:=  76.5:=  72.0:=  63.0
:=  64.7:=  66.7:=  65.2:=  68.2:=  66.5:=  62.0:=  80.5:=  87.7

1/3 OCTAVE BAND PWL  DB RE 10↑-13 WATT
=   92.4= 106.3=  83.0=  72.5=  86.1=  67.1=  70.0=  72.1
=   73.1=  69.5=  70.8=  74.9=  82.7=  78.7=  68.6=  72.9
=   76.7=  81.2=  84.5=  81.1=  82.4=  91.5=  87.4=  83.4
=   79.4=  82.7=  80.9=  81.2=  78.2=  74.5=  95.9= 106.2

FULL OCTAVE BAND PWL  DB RE 10↑-13 WAIT
= 106.5=  86.3=  76.7=  77.2=  84.3=  83.0
=  87.7=  93.3=  86.0=  83.5=  95.9= 106.2
*
```

FAN NOISE DATA

TEST UNIT :LM ECS SUIT FAN
CONDITION :OUTLET NOISE @ 5 PSIA
MIKE RAD (IN):24

MICROPHONE= 7.5 DEG

:=	50.2:=	50.7:=	45.0:=	60.2:=	73.2:=	49.5:=	39.0:=	48.0
:=	48.5:=	49.2:=	48.2:=	52.0:=	55.5:=	46.0:=	48.7:=	51.5
:=	43.5:=	49.7:=	58.0:=	64.7:=	62.2:=	61.0:=	64.0:=	72.0
:=	52.7:=	48.5:=	55.0:=	49.0:=	52.5:=	41.5:=	74.7:=	76.5

MICROPHONE= 22.5 DEG

:=	51.0:=	50.2:=	41.0:=	41.7:=	47.0:=	39.0:=	33.5:=	39.5
:=	44.7:=	43.5:=	48.2:=	48.7:=	54.7:=	43.0:=	46.5:=	51.0
:=	46.5:=	55.0:=	61.5:=	66.2:=	64.0:=	63.5:=	66.5:=	74.0
:=	54.7:=	51.7:=	53.7:=	54.0:=	58.5:=	45.0:=	76.5:=	76.0

MICROPHONE= 37.5 DEG

:=	52.0:=	51.2:=	41.2:=	41.0:=	46.0:=	39.0:=	34.2:=	35.7
:=	42.0:=	41.2:=	50.2:=	50.2:=	54.0:=	40.2:=	45.0:=	50.2
:=	48.7:=	55.0:=	62.5:=	68.5:=	65.2:=	63.7:=	67.2:=	77.2
:=	58.5:=	55.5:=	59.0:=	55.0:=	59.2:=	47.7:=	78.7:=	78.2

MICROPHONE= 52.5 DEG

:=	51.0:=	50.0:=	44.7:=	61.5:=	74.2:=	50.2:=	41.2:=	47.7
:=	46.2:=	48.0:=	51.0:=	53.2:=	51.7:=	44.0:=	44.7:=	52.5
:=	49.0:=	56.7:=	63.0:=	68.2:=	67.0:=	66.0:=	68.5:=	78.5
:=	62.0:=	59.7:=	67.2:=	55.7:=	56.7:=	51.5:=	80.2:=	80.7

MICROPHONE= 67.5 DEG

:=	52.0:=	51.7:=	47.5:=	61.5:=	74.2:=	51.2:=	43.7:=	49.2
:=	46.7:=	48.7:=	51.2:=	53.2:=	49.5:=	44.7:=	45.7:=	51.7
:=	50.5:=	55.7:=	62.2:=	69.0:=	68.2:=	67.0:=	70.5:=	79.7
:=	63.7:=	65.5:=	75.5:=	65.7:=	68.0:=	55.5:=	81.7:=	82.5

MICROPHONE= 82.5 DEG

:=	57.7:=	56.0:=	52.0:=	61.2:=	73.7:=	51.2:=	45.7:=	48.5
:=	45.7:=	47.7:=	49.7:=	52.5:=	52.5:=	44.2:=	45.7:=	52.0
:=	51.0:=	55.7:=	63.2:=	68.7:=	67.2:=	66.0:=	69.0:=	78.2
:=	61.0:=	62.7:=	73.2:=	61.0:=	61.7:=	44.5:=	80.5:=	81.2

1/3 OCTAVE BAND PWL DB RE 10↑-13 WATT

=	69.6=	69.0=	62.6=	76.3=	89.1=	65.8=	57.4=	63.9
=	64.1=	64.8=	67.5=	69.4=	72.0=	61.9=	64.6=	69.3
=	65.7=	72.5=	79.5=	85.2=	83.2=	82.1=	85.2=	94.3
=	76.9=	76.3=	85.2=	75.8=	78.5=	67.1=	96.3=	96.7

FULL OCTAVE BAND PWL DB RE 10↑-13 WATT

=	72.7=	89.3=	67.4=	72.4=	73.0=	74.8
=	88.0=	95.1=	86.3=	80.6=	96.3=	96.7

*

FAN NOISE DATA

TEST UNIT :CSM ECS CABIN FAN
CONDITION :INLET NOISE @ 5 PSIA
MIKE RAD (IN):24

MICROPHONE= 7.5 DEG

:=	51.0:=	47.2:=	40.2:=	41.2:=	48.7:=	37.2:=	35.5:=	35.7
:=	42.0:=	48.7:=	33.2:=	34.0:=	33.7:=	34.0:=	37.2:=	39.2
:=	33.5:=	38.5:=	42.5:=	40.5:=	44.5:=	40.7:=	40.0:=	40.2
:=	38.7:=	41.7:=	39.7:=	39.0:=	38.0:=	34.5:=	51.7:=	59.0

MICROPHONE= 22.5 DEG

:=	52.5:=	50.0:=	41.0:=	39.2:=	39.0:=	37.0:=	36.0:=	35.0
:=	38.7:=	43.7:=	32.5:=	35.0:=	34.0:=	32.5:=	36.0:=	40.5
:=	40.2:=	43.2:=	46.5:=	41.0:=	47.5:=	44.7:=	44.5:=	44.0
:=	41.2:=	46.2:=	43.2:=	43.0:=	42.5:=	41.0:=	55.2:=	60.5

MICROPHONE= 37.5 DEG

:=	50.5:=	46.7:=	38.5:=	36.2:=	38.0:=	35.0:=	34.7:=	32.0
:=	35.7:=	39.0:=	29.7:=	33.7:=	32.5:=	30.2:=	35.2:=	43.0
:=	40.5:=	43.0:=	48.5:=	41.0:=	46.5:=	43.0:=	42.2:=	43.5
:=	40.5:=	45.7:=	42.5:=	41.5:=	41.5:=	39.0:=	55.0:=	58.7

MICROPHONE= 52.5 DEG

:=	50.2:=	47.0:=	40.2:=	40.5:=	48.7:=	38.0:=	37.0:=	35.2
:=	38.0:=	44.2:=	32.0:=	33.5:=	32.0:=	33.0:=	36.0:=	45.5
:=	41.7:=	43.5:=	47.5:=	40.7:=	47.0:=	44.2:=	43.2:=	44.5
:=	42.0:=	46.7:=	43.0:=	41.2:=	41.5:=	38.5:=	55.5:=	59.5

MICROPHONE= 67.5 DEG

:=	49.2:=	45.5:=	40.2:=	41.2:=	48.7:=	38.5:=	37.2:=	35.7
:=	37.7:=	43.7:=	32.0:=	31.7:=	32.0:=	34.5:=	36.0:=	44.2
:=	42.7:=	44.0:=	50.5:=	41.5:=	46.2:=	44.2:=	45.0:=	44.5
:=	41.2:=	47.7:=	42.2:=	38.5:=	43.0:=	36.7:=	56.0:=	59.2

MICROPHONE= 82.5 DEG

:=	49.7:=	47.0:=	40.2:=	42.0:=	49.0:=	39.0:=	39.5:=	37.2
:=	35.7:=	35.5:=	31.7:=	31.2:=	32.7:=	34.2:=	37.0:=	43.7
:=	42.2:=	44.2:=	50.5:=	41.5:=	43.0:=	43.5:=	44.2:=	42.7
:=	39.5:=	45.2:=	40.7:=	36.7:=	38.2:=	28.0:=	55.5:=	59.5

1/3 OCTAVE BAND PWL DB RE 10↑-13 WATT

=	69.3=	66.1=	58.4=	58.3=	64.8=	55.5=	54.5=	53.3
=	57.5=	63.5=	50.4=	52.2=	51.4=	51.3=	54.6=	60.9
=	58.4=	60.9=	65.6=	59.2=	64.6=	61.7=	61.4=	61.6
=	58.9=	63.9=	60.5=	59.4=	59.6=	56.8=	73.0=	77.8

FULL OCTAVE BAND PWL DB RE 10↑-13 WATT

=	71.3=	66.1=	60.2=	64.0=	57.5=	65.0
=	68.7=	66.3=	66.4=	63.5=	73.0=	77.8

FAN NOISE DATA

```
TEST UNIT     :CSM ECS CABIN FAN
CONDITION     :OUTLET NOISE @ 5 PSIA
MIKE RAD (IN):24


MICROPHONE=   7.5 DEG
:=  50.2:=  47.0:=  39.0:=  43.0:=  50.0:=  36.7:=  35.5:=  36.7
:=  42.7:=  46.5:=  33.7:=  37.0:=  37.7:=  35.5:=  36.0:=  40.2
:=  33.0:=  36.5:=  40.2:=  43.7:=  44.2:=  38.7:=  38.0:=  38.2
:=  37.7:=  43.2:=  40.0:=  37.2:=  35.5:=  31.2:=  51.5:=  58.5


MICROPHONE=  22.5 DEG
:=  50.5:=  46.7:=  38.7:=  40.5:=  36.7:=  35.5:=  35.0:=  34.5
:=  40.0:=  42.5:=  32.0:=  36.2:=  37.0:=  33.2:=  34.2:=  38.0
:=  37.2:=  40.5:=  42.7:=  44.0:=  44.7:=  40.2:=  40.5:=  40.5
:=  38.0:=  48.2:=  42.0:=  40.0:=  37.7:=  34.5:=  53.5:=  58.5


MICROPHONE=  37.5 DEG
:=  51.2:=  48.7:=  40.5:=  38.5:=  37.5:=  35.7:=  36.0:=  33.5
:=  37.2:=  38.0:=  32.0:=  36.5:=  36.0:=  31.7:=  34.2:=  39.5
:=  39.2:=  40.2:=  42.0:=  44.7:=  45.5:=  40.7:=  39.2:=  41.2
:=  39.0:=  48.7:=  42.5:=  39.2:=  36.5:=  32.5:=  53.7:=  59.0


MICROPHONE=  52.5 DEG
:=  50.0:=  47.0:=  41.0:=  40.2:=  48.7:=  37.2:=  37.7:=  35.2
:=  36.0:=  35.5:=  32.0:=  35.2:=  34.7:=  33.2:=  33.7:=  41.5
:=  40.0:=  39.0:=  40.7:=  42.5:=  46.5:=  40.5:=  39.5:=  40.7
:=  38.7:=  49.2:=  41.5:=  38.5:=  36.7:=  32.0:=  54.0:=  58.5


MICROPHONE=  67.5 DEG
:=  49.2:=  46.2:=  41.0:=  41.0:=  48.7:=  38.5:=  39.0:=  36.7
:=  36.0:=  33.7:=  32.5:=  33.5:=  33.5:=  34.2:=  34.2:=  39.7
:=  40.5:=  38.5:=  40.5:=  40.7:=  45.0:=  41.0:=  41.2:=  40.5
:=  39.5:=  48.7:=  41.0:=  39.5:=  37.7:=  32.5:=  53.2:=  58.2


MICROPHONE=  82.5 DEG
:=  49.2:=  45.7:=  41.0:=  40.5:=  49.0:=  37.5:=  38.5:=  35.7
:=  34.7:=  33.5:=  30.7:=  31.5:=  33.5:=  34.2:=  34.2:=  38.5
:=  39.0:=  37.7:=  40.0:=  38.7:=  44.0:=  40.0:=  39.2:=  37.5
:=  35.5:=  39.7:=  35.2:=  28.7:=  22.7:=  13.7:=  51.0:=  53.0


1/3 OCTAVE BAND PWL   DB RE 10↑-13 WATT
=  68.7=  65.6=  58.2=  59.3=  65.3=  54.9=  54.8=  53.7
=  58.1=  60.9=  50.8=  54.4=  54.7=  52.1=  53.0=  58.1
=  56.4=  57.5=  59.7=  61.8=  63.4=  58.4=  57.9=  58.5
=  56.7=  65.9=  59.7=  57.1=  54.9=  50.9=  71.4=  76.8

FULL OCTAVE BAND PWL   DB RE 10↑-13 WATT
=  70.7=  66.6=  60.7=  62.1=  58.2=  62.1
=  66.7=  63.0=  67.2=  59.8=  71.4=  76.8
*
```

FAN NOISE DATA


```
TEST UNIT      :CSM ECS CABIN FAN
CONDITION      :INLET NOISE @ 14.7 PSIA
MIKE RAD (IN):24


MICROPHONE=   7.5 DEG
:=   62.2:=   55.2:=   45.5:=   46.7:=   49.7:=   38.5:=   34.2:=   39.0
:=   60.0:=   49.5:=   36.7:=   36.5:=   36.0:=   39.0:=   43.0:=   42.5
:=   40.5:=   48.0:=   41.7:=   39.7:=   48.0:=   43.7:=   46.0:=   45.0
:=   37.2:=   45.2:=   40.7:=   35.7:=   33.5:=   29.5:=   55.5:=   68.5


MICROPHONE=  22.5 DEG
:=   63.2:=   56.2:=   46.2:=   45.7:=   40.7:=   36.5:=   32.0:=   36.2
:=   56.2:=   46.0:=   34.5:=   35.7:=   35.7:=   38.2:=   40.5:=   39.0
:=   39.7:=   49.0:=   47.0:=   42.0:=   51.0:=   47.0:=   50.0:=   47.5
:=   42.0:=   50.5:=   45.7:=   42.5:=   38.0:=   36.7:=   58.5:=   69.0


MICROPHONE=  37.5 DEG
:=   63.2:=   54.2:=   45.5:=   45.0:=   40.5:=   36.0:=   33.5:=   36.2
:=   52.5:=   42.2:=   32.5:=   36.5:=   35.5:=   36.2:=   42.2:=   43.2
:=   43.7:=   49.7:=   48.7:=   45.2:=   52.0:=   47.5:=   48.5:=   49.7
:=   44.2:=   52.2:=   49.2:=   47.0:=   40.5:=   40.0:=   60.0:=   69.0


MICROPHONE=  52.5 DEG
:=   60.5:=   54.5:=   44.5:=   44.7:=   48.5:=   36.7:=   36.5:=   38.0
:=   46.5:=   37.2:=   32.2:=   36.0:=   34.5:=   35.2:=   39.2:=   45.0
:=   43.5:=   50.2:=   48.0:=   45.0:=   50.7:=   47.5:=   48.7:=   50.2
:=   46.5:=   53.2:=   49.0:=   45.2:=   41.5:=   37.5:=   59.7:=   67.0


MICROPHONE=  67.5 DEG
:=   60.7:=   55.5:=   45.0:=   47.0:=   50.2:=   39.7:=   39.5:=   39.0
:=   46.5:=   37.0:=   33.5:=   35.7:=   34.7:=   36.0:=   42.2:=   47.0
:=   45.7:=   51.2:=   51.2:=   46.0:=   51.0:=   49.0:=   51.7:=   49.7
:=   47.0:=   55.0:=   48.5:=   44.0:=   44.0:=   37.7:=   61.0:=   67.5


MICROPHONE=  82.5 DEG
:=   62.0:=   56.2:=   44.2:=   48.2:=   52.0:=   44.0:=   42.0:=   41.0
:=   49.2:=   39.5:=   34.0:=   35.0:=   35.5:=   36.5:=   43.5:=   48.0
:=   46.2:=   53.0:=   51.2:=   45.7:=   46.5:=   49.0:=   48.7:=   48.5
:=   46.7:=   54.2:=   49.7:=   46.2:=   43.0:=   36.7:=   60.7:=   68.5


1/3 OCTAVE BAND PWL  DB RE 10↑-13 WATT
=   75.9=   68.8=   59.0=   59.5=   61.0=   51.5=   49.2=   51.4
=   69.6=   59.3=   48.0=   49.6=   49.0=   51.0=   55.3=   57.1
=   56.8=   62.5=   61.2=   57.2=   64.0=   60.4=   62.4=   61.9
=   57.4=   65.1=   60.7=   57.5=   53.5=   50.6=   72.5=   82.0

FULL OCTAVE BAND PWL  DB RE 10↑-13 WATT
=   76.7=   63.6=   69.7=   60.0=   57.3=   64.3
=   66.4=   66.5=   66.9=   59.5=   72.5=   82.0
*
```

FAN NOISE DATA

TEST UNIT :CSM ECS CABIN FAN
CONDITION :OUTLET NOISE @ 14.7 PSIA
MIKE RAD (IN):24

MICROPHONE= 7.5 DEG

:=	60.0:=	54.2:=	42.7:=	46.7:=	50.7:=	39.5:=	34.5:=	37.5
:=	46.2:=	40.5:=	35.5:=	36.7:=	37.7:=	36.5:=	49.5:=	41.0
:=	36.7:=	36.7:=	36.7:=	46.0:=	49.0:=	41.0:=	44.2:=	42.5
:=	38.0:=	47.7:=	43.5:=	41.7:=	35.0:=	32.5:=	55.5:=	65.7

MICROPHONE= 22.5 DEG

:=	60.2:=	55.0:=	44.0:=	45.5:=	43.5:=	39.5:=	37.0:=	39.0
:=	44.5:=	40.2:=	38.0:=	39.0:=	37.7:=	36.5:=	48.5:=	42.5
:=	38.0:=	48.5:=	43.7:=	48.7:=	49.7:=	45.2:=	48.7:=	44.2
:=	41.5:=	52.0:=	47.2:=	45.5:=	38.0:=	35.7:=	57.5:=	66.2

MICROPHONE= 37.5 DEG

:=	61.0:=	55.2:=	47.5:=	45.0:=	42.0:=	38.2:=	34.7:=	35.7
:=	41.7:=	37.0:=	32.2:=	37.0:=	36.0:=	34.5:=	49.2:=	40.0
:=	36.7:=	43.5:=	41.5:=	50.2:=	50.7:=	43.7:=	46.5:=	47.0
:=	44.5:=	53.0:=	48.7:=	45.7:=	39.0:=	38.2:=	58.0:=	66.5

MICROPHONE= 52.5 DEG

:=	60.7:=	53.0:=	45.0:=	45.0:=	49.2:=	38.5:=	37.7:=	38.0
:=	41.5:=	35.7:=	33.7:=	37.2:=	35.7:=	34.5:=	45.2:=	42.0
:=	38.0:=	42.7:=	41.5:=	46.5:=	51.2:=	44.5:=	45.5:=	46.5
:=	45.5:=	54.0:=	48.7:=	46.2:=	41.5:=	38.2:=	58.2:=	66.5

MICROPHONE= 67.5 DEG

:=	59.7:=	56.0:=	46.2:=	49.7:=	49.2:=	41.0:=	39.0:=	39.0
:=	41.0:=	35.0:=	34.5:=	36.2:=	35.0:=	36.0:=	44.2:=	40.7
:=	39.7:=	41.7:=	42.5:=	46.7:=	49.2:=	45.7:=	46.2:=	45.5
:=	46.2:=	53.7:=	49.2:=	46.2:=	44.7:=	39.0:=	58.0:=	66.2

MICROPHONE= 82.5 DEG

:=	55.2:=	55.2:=	45.2:=	49.0:=	48.5:=	40.5:=	39.2:=	40.5
:=	40.0:=	36.0:=	37.0:=	36.5:=	36.2:=	35.5:=	43.2:=	42.0
:=	39.5:=	42.0:=	42.2:=	42.7:=	47.7:=	45.0:=	43.5:=	43.0
:=	43.2:=	48.7:=	45.2:=	39.0:=	28.7:=	19.2:=	55.0:=	60.2

1/3 OCTAVE BAND PWL DB RE 10↑-13 WATT

=	73.8=	68.2=	58.7=	60.0=	61.5=	52.9=	50.1=	51.5
=	57.4=	52.3=	49.1=	51.0=	50.3=	49.3=	61.7=	54.9
=	51.2=	58.0=	55.1=	61.5=	63.5=	57.6=	60.0=	58.7
=	56.8=	65.6=	60.9=	58.4=	53.2=	50.1=	70.8=	79.6

FULL OCTAVE BAND PWL DB RE 10↑-13 WATT

=	74.9=	64.2=	59.0=	55.7=	62.2=	60.3
=	66.0=	63.6=	67.3=	60.0=	70.8=	79.6

*

FAN NOISE DATA

TEST UNIT :LM ECS CABIN FAN
CONDITION :INLET NOISE @ 5 PSIA
MIKE RAD (IN):24

MICROPHONE= 7.5 DEG

:=	52.2:=	51.2:=	46.5:=	46.2:=	55.7:=	41.2:=	43.2:=	54.0
:=	44.0:=	45.2:=	47.7:=	42.7:=	44.2:=	43.7:=	43.2:=	39.0
:=	38.7:=	40.5:=	43.0:=	58.5:=	64.2:=	45.0:=	48.0:=	51.0
:=	52.5:=	52.5:=	47.7:=	41.7:=	41.5:=	37.0:=	66.5:=	67.0

MICROPHONE= 22.5 DEG

:=	53.7:=	50.7:=	45.7:=	43.7:=	41.2:=	40.0:=	39.0:=	38.2
:=	41.7:=	41.5:=	38.0:=	41.0:=	42.0:=	40.2:=	42.5:=	38.5
:=	41.0:=	43.7:=	45.0:=	61.2:=	67.0:=	47.5:=	51.2:=	54.0
:=	57.5:=	57.0:=	51.0:=	46.7:=	47.0:=	43.2:=	69.5:=	69.0

MICROPHONE= 37.5 DEG

:=	51.7:=	49.5:=	45.0:=	42.2:=	40.5:=	38.0:=	38.7:=	36.0
:=	39.0:=	38.0:=	35.5:=	39.7:=	40.0:=	38.0:=	41.2:=	40.7
:=	42.0:=	44.0:=	46.0:=	61.5:=	68.0:=	48.5:=	52.2:=	57.5
:=	59.7:=	60.0:=	55.0:=	49.2:=	49.5:=	45.5:=	70.5:=	70.2

MICROPHONE= 52.5 DEG

:=	52.5:=	49.0:=	45.2:=	42.7:=	49.7:=	41.0:=	40.2:=	38.2
:=	38.7:=	37.2:=	36.5:=	39.0:=	39.0:=	40.7:=	41.5:=	41.7
:=	42.5:=	45.0:=	47.2:=	62.5:=	69.2:=	51.5:=	54.2:=	60.0
:=	62.5:=	62.5:=	56.5:=	49.5:=	50.2:=	46.0:=	72.0:=	71.7

MICROPHONE= 67.5 DEG

:=	52.5:=	51.2:=	45.0:=	42.2:=	49.5:=	43.2:=	42.7:=	40.0
:=	40.0:=	37.5:=	37.7:=	37.2:=	39.7:=	42.7:=	44.7:=	41.7
:=	44.5:=	46.0:=	48.7:=	60.0:=	66.5:=	52.0:=	56.0:=	60.5
:=	63.2:=	63.0:=	57.0:=	53.0:=	53.7:=	48.5:=	70.7:=	70.7

MICROPHONE= 82.5 DEG

:=	52.2:=	49.0:=	44.2:=	41.5:=	49.5:=	45.0:=	44.2:=	42.5
:=	41.5:=	38.7:=	38.2:=	37.5:=	40.2:=	42.5:=	47.0:=	42.7
:=	44.7:=	47.2:=	49.2:=	57.0:=	61.5:=	51.5:=	56.0:=	59.0
:=	62.7:=	64.0:=	57.0:=	56.2:=	51.7:=	47.2:=	68.7:=	69.5

1/3 OCTAVE BAND PWL DB RE 10↑-13 WATT

=	70.9=	68.7=	63.9=	62.3=	69.4=	59.2=	59.5=	66.8
=	59.9=	60.1=	61.1=	59.0=	60.1=	59.8=	61.2=	58.6
=	60.0=	62.2=	64.3=	79.1=	85.3=	67.3=	70.8=	75.4
=	78.0=	78.1=	72.3=	67.4=	67.3=	62.9=	88.1=	88.0

FULL OCTAVE BAND PWL DB RE 10↑-13 WATT

=	73.5=	70.5=	68.2=	64.9=	65.2=	65.3
=	86.3=	77.1=	81.6=	71.1=	88.1=	88.0

*

FAN NOISE DATA

TEST UNIT :LM ECS CABIN FAN
CONDITION :OUTLET NOISE @ 5 PSIA
MIKE RAD (IN):24

MICROPHONE= 7.5 DEG

:=	54.5:=	53.0:=	47.5:=	45.7:=	50.7:=	41.5:=	41.7:=	43.5
:=	48.5:=	44.7:=	42.2:=	46.2:=	46.7:=	43.7:=	44.2:=	40.7
:=	41.0:=	49.2:=	56.0:=	68.2:=	70.2:=	52.0:=	59.0:=	61.5
:=	55.5:=	58.5:=	49.7:=	44.7:=	43.7:=	39.5:=	74.2:=	73.7

MICROPHONE= 22.5 DEG

:=	55.5:=	53.5:=	48.2:=	45.0:=	43.2:=	41.7:=	41.2:=	42.0
:=	46.5:=	43.2:=	40.5:=	45.0:=	45.5:=	41.2:=	42.7:=	40.2
:=	45.2:=	54.2:=	59.5:=	68.0:=	70.5:=	56.2:=	63.2:=	65.2
:=	59.5:=	62.7:=	56.7:=	50.7:=	49.0:=	46.0:=	75.2:=	74.5

MICROPHONE= 37.5 DEG

:=	55.5:=	53.0:=	47.2:=	43.0:=	42.5:=	41.2:=	41.2:=	40.0
:=	44.0:=	40.7:=	39.7:=	45.0:=	44.5:=	39.5:=	41.7:=	42.7
:=	48.0:=	54.2:=	58.0:=	69.5:=	72.2:=	55.0:=	63.0:=	66.2
:=	62.0:=	62.2:=	57.5:=	52.5:=	49.5:=	46.2:=	76.5:=	76.0

MICROPHONE= 52.5 DEG

:=	54.5:=	52.5:=	47.7:=	43.0:=	49.5:=	41.7:=	42.0:=	40.2
:=	43.2:=	39.7:=	38.5:=	43.5:=	42.2:=	40.7:=	40.7:=	45.0
:=	47.5:=	54.5:=	57.5:=	69.2:=	72.2:=	56.0:=	63.5:=	66.0
:=	63.2:=	62.0:=	57.2:=	53.2:=	53.0:=	50.2:=	76.5:=	75.7

MICROPHONE= 67.5 DEG

:=	54.0:=	51.7:=	46.7:=	43.2:=	49.5:=	43.7:=	43.2:=	41.0
:=	42.7:=	39.7:=	38.2:=	40.2:=	40.7:=	42.2:=	42.7:=	44.0
:=	49.0:=	53.2:=	57.2:=	69.0:=	72.5:=	56.2:=	64.2:=	65.0
:=	62.5:=	61.2:=	56.7:=	56.2:=	55.2:=	49.0:=	76.5:=	76.0

MICROPHONE= 82.5 DEG

:=	50.5:=	51.5:=	46.7:=	42.7:=	49.0:=	44.5:=	44.7:=	41.0
:=	42.7:=	39.5:=	38.5:=	40.0:=	43.0:=	44.0:=	42.7:=	43.7
:=	48.7:=	52.2:=	55.0:=	63.2:=	66.0:=	56.2:=	63.0:=	63.0
:=	60.7:=	56.2:=	51.0:=	50.5:=	49.5:=	43.5:=	71.7:=	71.7

1/3 OCTAVE BAND PWL DB RE 10↑-13 WATT

=	73.2=	71.2=	65.9=	62.7=	66.4=	60.2=	60.2=	60.1
=	64.3=	60.8=	58.7=	63.1=	63.2=	60.2=	61.0=	60.8
=	64.7=	71.5=	76.1=	86.9=	89.6=	73.4=	80.9=	83.1
=	79.0=	79.7=	74.2=	70.1=	68.8=	64.9=	93.9=	93.3

FULL OCTAVE BAND PWL DB RE 10↑-13 WATT

=	75.8=	68.6=	66.8=	66.0=	66.5=	72.7
=	91.6=	85.5=	83.0=	73.2=	93.9=	93.3

*

FAN NOISE DATA

```
TEST UNIT     :CSM SUIT COMPRESSOR
CONDITION     :INLET NOISE @ 5 PSIA
MIKE RAD (IN):25


MICROPHONE=   7.5 DEG
:=  46.7:=  46.5:=  42.0:=  60.2:=  73.2:=  49.2:=  39.0:=  48.2
:=  48.7:=  48.5:=  43.0:=  51.7:=  56.5:=  45.7:=  47.7:=  44.2
:=  47.5:=  49.5:=  49.0:=  55.2:=  61.0:=  54.2:=  50.7:=  51.7
:=  49.5:=  49.2:=  46.5:=  45.0:=  42.7:=  37.5

MICROPHONE=  22.5 DEG
:=  45.2:=  43.7:=  36.5:=  37.0:=  43.7:=  34.0:=  33.5:=  37.2
:=  43.7:=  40.2:=  38.2:=  45.7:=  54.5:=  41.2:=  45.7:=  44.0
:=  51.5:=  53.5:=  52.2:=  57.0:=  63.0:=  57.2:=  52.7:=  53.5
:=  52.5:=  52.7:=  49.5:=  48.0:=  43.7:=  39.7

MICROPHONE=  37.5 DEG
:=  44.2:=  45.0:=  36.0:=  36.0:=  41.7:=  34.2:=  34.0:=  34.5
:=  41.0:=  39.0:=  38.5:=  45.2:=  52.2:=  39.7:=  44.0:=  47.0
:=  53.5:=  54.2:=  54.0:=  58.7:=  65.2:=  58.5:=  53.5:=  56.5
:=  54.5:=  54.5:=  52.5:=  49.2:=  44.7:=  41.2

MICROPHONE=  52.5 DEG
:=  43.7:=  45.2:=  41.2:=  60.0:=  73.2:=  49.2:=  39.5:=  47.7
:=  46.7:=  48.5:=  42.7:=  51.0:=  50.7:=  43.5:=  44.0:=  51.7
:=  55.2:=  56.2:=  56.5:=  61.2:=  67.2:=  61.5:=  55.2:=  57.7
:=  58.0:=  56.5:=  55.5:=  52.0:=  47.2:=  43.2

MICROPHONE=  67.5 DEG
:=  44.7:=  46.2:=  42.5:=  60.5:=  73.5:=  49.5:=  41.0:=  48.7
:=  47.2:=  49.0:=  43.2:=  51.2:=  46.2:=  45.0:=  45.0:=  51.5
:=  56.7:=  56.7:=  56.7:=  62.0:=  69.0:=  63.2:=  58.5:=  59.2
:=  57.7:=  58.0:=  56.0:=  53.0:=  48.0:=  44.2

MICROPHONE=  82.5 DEG
:=  42.7:=  47.0:=  42.5:=  60.5:=  73.7:=  50.0:=  42.5:=  48.2
:=  46.5:=  48.5:=  43.0:=  51.0:=  45.5:=  43.2:=  46.5:=  51.7
:=  57.0:=  57.5:=  56.0:=  62.0:=  70.0:=  65.2:=  59.7:=  59.0
:=  57.7:=  56.2:=  55.7:=  53.0:=  47.7:=  43.5

1/3 OCTAVE BAND PWL  DB RE 10↑-13 WATT
=  63.8=  64.1=  58.9=  76.3=  89.4=  65.5=  56.7=  64.5
=  64.9=  65.1=  60.1=  68.3=  72.5=  62.1=  64.5=  66.9
=  71.9=  72.9=  72.5=  77.6=  84.1=  78.1=  73.1=  74.6
=  73.5=  73.0=  71.2=  68.3=  63.9=  59.9
FULL OCTAVE BAND PWL  DB RE 10↑-13 WATT
=  67.6=  89.6=  68.0=  70.4=  73.5=  76.0
=  85.2=  80.6=  77.4=  70.1*
```

FAN NOISE DATA

TEST UNIT :CSM SUIT COMPRESSOR
CONDITION :OUTLET NOISE @ 5 PSIA
MIKE RAD (IN):25

MICROPHONE= 7.5 DEG

:=	46.5:=	47.5:=	40.0:=	54.7:=	67.5:=	44.2:=	38.0:=	46.5
:=	50.0:=	49.5:=	45.7:=	52.5:=	52.7:=	53.2:=	56.7:=	51.2
:=	49.7:=	56.7:=	55.0:=	56.7:=	60.0:=	58.2:=	56.7:=	56.0
:=	51.7:=	52.5:=	53.2:=	54.5:=	47.5:=	43.0		

MICROPHONE= 22.5 DEG

:=	46.2:=	46.5:=	36.0:=	38.2:=	47.7:=	34.7:=	34.7:=	38.7
:=	46.7:=	46.7:=	44.5:=	51.0:=	51.2:=	49.2:=	54.7:=	50.7
:=	51.2:=	59.7:=	58.0:=	57.5:=	60.7:=	60.2:=	59.0:=	57.7
:=	55.7:=	58.0:=	57.5:=	58.0:=	52.7:=	48.7		

MICROPHONE= 37.5 DEG

:=	44.7:=	47.2:=	35.7:=	38.5:=	49.2:=	34.2:=	34.0:=	37.2
:=	44.2:=	44.0:=	44.2:=	51.2:=	50.2:=	47.5:=	53.5:=	50.7
:=	54.5:=	60.2:=	59.0:=	58.5:=	61.5:=	59.7:=	58.2:=	60.0
:=	57.5:=	58.5:=	58.5:=	58.5:=	53.5:=	50.0		

MICROPHONE= 52.5 DEG

:=	44.2:=	49.2:=	39.5:=	56.2:=	69.0:=	45.0:=	38.2:=	45.0
:=	46.0:=	47.2:=	45.5:=	52.5:=	49.7:=	50.0:=	51.5:=	52.7
:=	54.0:=	62.7:=	59.2:=	60.5:=	63.2:=	61.0:=	59.2:=	61.0
:=	59.5:=	59.7:=	58.5:=	58.0:=	54.2:=	48.0		

MICROPHONE= 67.5 DEG

:=	44.5:=	47.5:=	41.0:=	59.0:=	71.7:=	47.7:=	39.0:=	46.0
:=	45.0:=	47.0:=	45.5:=	52.7:=	50.2:=	51.0:=	52.0:=	53.7
:=	56.0:=	62.0:=	60.5:=	61.5:=	63.7:=	61.5:=	61.0:=	61.5
:=	58.0:=	60.0:=	59.7:=	62.2:=	57.5:=	51.5		

MICROPHONE= 82.5 DEG

:=	43.5:=	47.7:=	41.2:=	59.2:=	71.5:=	47.5:=	39.7:=	45.7
:=	44.5:=	45.7:=	45.2:=	53.0:=	50.2:=	49.2:=	54.2:=	53.7
:=	56.5:=	61.5:=	61.5:=	62.2:=	63.5:=	60.0:=	59.7:=	59.2
:=	53.7:=	54.7:=	55.0:=	53.0:=	46.0:=	41.2		

1/3 OCTAVE BAND PWL DB RE 10↑-13 WATT

=	63.9=	65.9=	57.1=	72.4=	85.1=	61.6=	55.4=	62.3
=	65.6=	65.7=	63.4=	70.3=	69.5=	69.1=	72.9=	70.1
=	71.6=	78.6=	76.8=	77.3=	80.1=	78.3=	77.1=	77.5
=	75.0=	76.2=	75.8=	76.5=	71.5=	66.7		

FULL OCTAVE BAND PWL DB RE 10↑-13 WATT

=	68.4=	85.3=	67.5=	72.2=	75.6=	79.9
=	83.1=	82.4=	80.4=	78.0*		

FAN NOISE DATA

TEST UNIT :CSM SUIT COMPRESSOR
CONDITION :INLET NOISE @ 14.7 PSIA
MIKE RAD (IN):25

MICROPHONE= 7.5 DEG
:= 51.0:= 54.0:= 44.2:= 61.5:= 74.2:= 50.5:= 42.0:= 50.7
:= 55.0:= 55.2:= 48.2:= 57.0:= 49.7:= 48.7:= 49.5:= 55.2
:= 58.7:= 55.2:= 56.7:= 59.5:= 68.2:= 56.5:= 58.5:= 58.7
:= 55.2:= 53.0:= 49.5:= 46.7:= 43.7:= 38.2

MICROPHONE= 22.5 DEG
:= 50.2:= 53.2:= 41.2:= 39.7:= 48.0:= 38.0:= 34.0:= 42.7
:= 51.7:= 51.2:= 45.2:= 52.7:= 45.0:= 44.5:= 45.0:= 51.5
:= 55.5:= 60.5:= 62.0:= 61.0:= 67.2:= 56.0:= 60.0:= 60.5
:= 57.5:= 57.2:= 54.5:= 52.0:= 47.7:= 44.0

MICROPHONE= 37.5 DEG
:= 49.5:= 52.0:= 41.5:= 40.2:= 48.5:= 37.2:= 32.5:= 38.5
:= 49.2:= 48.7:= 45.5:= 51.7:= 43.7:= 42.2:= 44.7:= 54.0
:= 59.7:= 63.5:= 63.2:= 62.7:= 69.7:= 57.5:= 60.5:= 63.2
:= 60.2:= 58.2:= 57.5:= 52.7:= 49.7:= 47.5

MICROPHONE= 52.5 DEG
:= 48.0:= 51.5:= 44.0:= 61.2:= 74.0:= 50.2:= 40.5:= 48.0
:= 49.7:= 50.0:= 47.7:= 54.0:= 46.2:= 44.5:= 44.5:= 56.5
:= 62.5:= 64.0:= 64.7:= 64.2:= 72.0:= 60.2:= 60.2:= 63.5
:= 62.7:= 60.2:= 60.2:= 56.2:= 53.5:= 50.2

MICROPHONE= 67.5 DEG
:= 49.2:= 54.2:= 44.7:= 62.7:= 75.2:= 51.7:= 44.5:= 49.0
:= 48.5:= 50.0:= 48.5:= 53.7:= 46.7:= 44.2:= 46.0:= 58.5
:= 64.5:= 66.5:= 66.7:= 65.5:= 73.7:= 62.7:= 65.5:= 65.5
:= 62.2:= 61.7:= 60.7:= 58.0:= 53.2:= 50.5

MICROPHONE= 82.5 DEG
:= 49.0:= 51.5:= 44.2:= 61.5:= 74.5:= 51.7:= 46.5:= 49.7
:= 47.5:= 49.7:= 48.0:= 53.7:= 46.5:= 43.5:= 47.2:= 59.0
:= 64.7:= 66.0:= 64.5:= 66.0:= 75.2:= 64.0:= 66.0:= 64.5
:= 61.5:= 60.7:= 59.7:= 57.5:= 53.0:= 49.0

1/3 OCTAVE BAND PWL DB RE 10↑-13 WATT
= 63.7= 66.9= 57.0= 73.0= 85.7= 62.2= 54.4= 61.5
= 65.9= 66.0= 60.9= 68.3= 60.8= 59.6= 60.6= 69.2
= 74.4= 76.4= 76.8= 76.5= 84.2= 72.7= 75.1= 76.2
= 73.6= 72.1= 71.1= 67.6= 64.0= 60.9
FULL OCTAVE BAND PWL DB RE 10↑-13 WATT
= 68.9= 85.9= 67.4= 70.8= 65.1= 79.0
= 85.5= 79.6= 77.2= 69.8*

FAN NOISE DATA

TEST UNIT :CSM SUIT COMPRESSOR
CONDITION :OUTLET NOISE @ 14.7 PSIA
MIKE RAD (IN):25

MICROPHONE= 7.5 DEG
:= 53.0:= 54.2:= 43.7:= 58.5:= 71.0:= 47.5:= 40.7:= 48.7
:= 55.0:= 57.2:= 52.2:= 59.0:= 57.0:= 57.2:= 58.2:= 57.7
:= 55.7:= 58.0:= 62.0:= 66.2:= 76.5:= 66.7:= 64.0:= 67.7
:= 58.0:= 59.0:= 58.7:= 58.0:= 50.2:= 42.5

MICROPHONE= 22.5 DEG
:= 52.7:= 53.0:= 41.2:= 45.0:= 56.5:= 40.5:= 37.7:= 44.2
:= 53.0:= 55.0:= 50.5:= 58.2:= 54.2:= 54.2:= 54.7:= 55.0
:= 55.7:= 64.5:= 66.5:= 67.0:= 73.0:= 66.0:= 66.7:= 66.5
:= 62.5:= 64.5:= 63.7:= 63.0:= 55.5:= 49.7

MICROPHONE= 37.5 DEG
:= 52.0:= 54.0:= 41.5:= 43.5:= 54.5:= 38.5:= 37.5:= 43.0
:= 50.7:= 52.0:= 50.0:= 59.7:= 54.7:= 52.5:= 55.2:= 53.0
:= 60.0:= 67.5:= 67.5:= 68.2:= 74.5:= 66.7:= 65.5:= 69.5
:= 65.2:= 64.5:= 64.2:= 63.2:= 55.7:= 49.2

MICROPHONE= 52.5 DEG
:= 51.2:= 52.2:= 45.7:= 60.7:= 72.2:= 48.0:= 41.7:= 48.0
:= 50.2:= 50.7:= 51.2:= 59.7:= 54.0:= 51.7:= 52.0:= 55.2
:= 61.2:= 67.7:= 68.2:= 69.7:= 74.7:= 67.5:= 67.0:= 70.0
:= 67.0:= 66.0:= 65.2:= 62.7:= 58.2:= 50.5

MICROPHONE= 67.5 DEG
:= 50.7:= 51.0:= 45.2:= 66.0:= 77.2:= 52.2:= 43.2:= 47.5
:= 49.0:= 50.0:= 52.2:= 60.2:= 54.2:= 51.7:= 53.0:= 57.5
:= 62.2:= 68.0:= 68.7:= 70.2:= 74.5:= 68.5:= 68.7:= 69.2
:= 65.2:= 66.5:= 65.5:= 64.2:= 57.0:= 48.0

MICROPHONE= 82.5 DEG
:= 58.0:= 57.0:= 53.2:= 65.2:= 75.5:= 51.5:= 46.2:= 47.5
:= 47.7:= 48.7:= 52.0:= 59.2:= 54.7:= 51.0:= 55.2:= 58.0
:= 63.5:= 67.2:= 69.7:= 71.0:= 72.5:= 68.0:= 67.5:= 66.0
:= 62.7:= 65.2:= 65.2:= 63.0:= 47.2:= 34.5

1/3 OCTAVE BAND PWL DB RE 10↑-13 WATT
= 66.5= 67.4= 58.4= 73.4= 84.8= 60.9= 54.5= 60.6
= 66.4= 68.3= 65.1= 73.1= 69.1= 68.3= 69.5= 69.9
= 73.1= 79.6= 80.6= 82.1= 88.7= 80.8= 80.1= 82.3
= 77.8= 78.1= 77.5= 76.2= 69.3= 62.2
FULL OCTAVE BAND PWL DB RE 10↑-13 WATT
= 70.3= 85.2= 67.7= 74.8= 73.8= 80.9
= 90.1= 86.0= 82.6= 77.1*

```
PUMP NOISE DATA

TEST UNIT:LM-PUMP   MIKE RADIUS (IN):24                SVHSER 6183

MICROPHONE=   0.0 DEG
:=  59.5:=  68.7:=  55.5:=  50.5:=  41.5:=  39.2:=  33.7:=  34.2
:=  30.5:=  30.7:=  33.2:=  38.0:=  46.7:=  30.5:=  36.2:=  43.0
:=  34.2:=  38.0:=  40.0:=  44.0:=  45.5:=  47.5:=  49.7:=  50.2
:=  53.0:=  49.5:=  44.0:=  44.2:=  41.0:=  30.7
MICROPHONE=  20.0 DEG
:=  60.2:=  69.0:=  55.5:=  50.0:=  44.5:=  38.7:=  34.0:=  33.2
:=  31.2:=  30.5:=  32.7:=  34.0:=  37.0:=  30.7:=  36.0:=  34.2
:=  33.0:=  39.0:=  38.5:=  41.2:=  44.0:=  49.0:=  46.5:=  47.0
:=  49.0:=  47.5:=  43.0:=  43.5:=  42.5:=  34.2
MICROPHONE=  40.0 DEG
:=  59.0:=  68.5:=  54.2:=  48.7:=  42.7:=  35.2:=  33.5:=  35.2
:=  32.5:=  32.0:=  32.7:=  36.7:=  44.7:=  29.2:=  36.7:=  43.0
:=  36.7:=  39.2:=  39.7:=  40.5:=  46.7:=  46.0:=  45.0:=  48.0
:=  46.0:=  39.7:=  40.2:=  40.5:=  40.0:=  33.7
MICROPHONE=  60.0 DEG
:=  58.7:=  68.5:=  52.7:=  47.5:=  42.0:=  34.7:=  33.2:=  32.0
:=  30.0:=  29.7:=  29.0:=  32.7:=  41.5:=  26.0:=  31.5:=  37.0
:=  37.7:=  36.7:=  39.2:=  39.7:=  46.2:=  49.2:=  47.0:=  43.2
:=  44.0:=  42.7:=  39.5:=  44.0:=  38.5:=  32.7
MICROPHONE=  80.0 DEG
:=  57.5:=  58.0:=  50.0:=  47.0:=  42.7:=  37.5:=  34.7:=  32.5
:=  30.5:=  30.2:=  28.5:=  31.7:=  40.5:=  27.2:=  34.7:=  40.7
:=  34.7:=  37.5:=  39.0:=  40.2:=  45.5:=  50.5:=  51.0:=  49.2
:=  45.7:=  42.0:=  40.0:=  42.7:=  42.0:=  34.2
MICROPHONE= 100.0 DEG
:=  56.5:=  56.2:=  49.5:=  45.0:=  43.7:=  41.2:=  35.7:=  32.7
:=  29.5:=  29.2:=  26.7:=  31.0:=  40.5:=  26.2:=  34.0:=  38.5
:=  35.5:=  38.5:=  40.0:=  41.7:=  46.0:=  49.2:=  51.0:=  48.5
:=  46.2:=  43.7:=  44.5:=  46.7:=  45.5:=  39.5
MICROPHONE= 120.0 DEG
:=  55.0:=  55.0:=  47.5:=  42.7:=  43.5:=  43.0:=  37.0:=  33.0
:=  33.0:=  33.0:=  29.7:=  33.0:=  40.2:=  27.7:=  33.7:=  37.5
:=  32.7:=  38.5:=  38.2:=  41.0:=  44.5:=  43.7:=  44.2:=  43.5
:=  45.0:=  42.7:=  41.5:=  47.2:=  44.0:=  39.0
MICROPHONE= 140.0 DEG
:=  53.5:=  53.0:=  45.7:=  43.5:=  42.2:=  42.7:=  34.0:=  31.0
:=  31.0:=  31.5:=  28.5:=  31.2:=  38.2:=  27.0:=  30.2:=  27.5
:=  30.5:=  32.5:=  36.5:=  43.0:=  45.0:=  45.5:=  46.5:=  42.7
:=  40.7:=  39.7:=  36.7:=  38.5:=  38.5:=  32.0
MICROPHONE= 160.0 DEG
:=  53.0:=  52.5:=  43.7:=  43.5:=  43.2:=  39.0:=  33.5:=  31.7
:=  30.5:=  31.5:=  28.2:=  30.7:=  39.7:=  28.5:=  30.0:=  27.2
:=  27.7:=  30.7:=  35.2:=  42.5:=  41.5:=  39.5:=  42.0:=  42.0
:=  37.5:=  37.2:=  35.2:=  38.5:=  37.2:=  30.7
MICROPHONE= 180.0 DEG
:=  52.5:=  52.2:=  43.2:=  42.7:=  41.0:=  31.5:=  28.0:=  26.7
:=  28.0:=  30.7:=  24.7:=  30.2:=  40.0:=  27.5:=  29.2:=  27.5
:=  25.7:=  31.2:=  36.7:=  41.0:=  42.7:=  42.7:=  46.5:=  42.0
:=  37.5:=  36.5:=  35.0:=  35.5:=  36.2:=  32.0

1/3 OCTAVE BAND PWL   DB RE 10↑-13 WATT
=  73.7=  80.7=  67.6=  63.0=  59.5=  56.6=  51.4=  49.3
=  47.6=  47.5=  46.1=  49.5=  57.6=  44.2=  50.5=  55.2
=  51.4=  54.1=  55.3=  57.7=  61.9=  64.6=  64.8=  63.2
=  61.9=  59.3=  57.8=  60.8=  58.8=  52.7
FULL OCTAVE BAND PWL   DB RE 10↑-13 WATT
=  81.7=  65.2=  54.5=  52.7=  58.5=  58.6=  64.0=  69.0=  64.7=  63.3
*
```

PUMP NOISE DATA

SVHSER 6183

TEST UNIT:CSM-PUMP   MIKE RADIUS (IN):24

```
MICROPHONE=   0.0 DEG
:=  59.5:=  60.5:=  56.5:=  55.7:=  42.0:=  47.0:=  34.5:=  35.2
:=  29.5:=  29.0:=  27.0:=  28.2:=  35.0:=  26.2:=  29.7:=  36.2
:=  26.2:=  31.2:=  30.0:=  42.0:=  37.2:=  30.0:=  32.0:=  37.0
:=  43.0:=  43.7:=  46.5:=  37.2:=  46.0:=  36.2
MICROPHONE=  20.0 DEG
:=  59.5:=  60.0:=  56.7:=  54.5:=  42.2:=  44.5:=  34.5:=  35.0
:=  30.7:=  30.2:=  29.2:=  31.5:=  38.7:=  28.2:=  29.2:=  40.2
:=  31.0:=  31.0:=  32.5:=  43.2:=  36.2:=  32.2:=  35.7:=  40.5
:=  43.7:=  48.5:=  53.0:=  39.2:=  46.0:=  37.0
MICROPHONE=  40.0 DEG
:=  60.0:=  62.0:=  55.2:=  53.0:=  41.5:=  39.0:=  32.5:=  32.7
:=  32.0:=  32.0:=  28.0:=  31.2:=  40.7:=  27.2:=  30.0:=  42.2
:=  33.5:=  33.0:=  29.5:=  40.7:=  36.5:=  32.5:=  37.7:=  43.2
:=  40.2:=  46.2:=  54.7:=  38.0:=  44.0:=  35.0
MICROPHONE=  60.0 DEG
:=  58.7:=  60.5:=  54.0:=  51.5:=  40.2:=  35.7:=  33.5:=  33.7
:=  30.0:=  29.5:=  27.2:=  29.0:=  37.2:=  26.2:=  32.0:=  42.0
:=  33.2:=  35.0:=  33.2:=  43.2:=  36.2:=  34.7:=  33.2:=  40.2
:=  42.7:=  45.0:=  51.0:=  39.7:=  44.5:=  34.5
MICROPHONE=  80.0 DEG
:=  59.2:=  59.7:=  53.0:=  49.0:=  41.0:=  43.5:=  34.5:=  32.5
:=  29.2:=  28.0:=  27.2:=  28.0:=  36.2:=  26.7:=  31.2:=  37.5
:=  32.0:=  31.5:=  34.5:=  43.0:=  34.5:=  35.5:=  37.7:=  41.5
:=  41.0:=  47.2:=  45.5:=  37.5:=  41.5:=  35.2
MICROPHONE= 100.0 DEG
:=  59.2:=  60.2:=  52.7:=  44.7:=  42.0:=  48.0:=  35.7:=  32.2
:=  28.0:=  26.7:=  25.7:=  28.7:=  39.5:=  27.2:=  28.5:=  41.5
:=  34.0:=  32.5:=  35.2:=  43.2:=  36.0:=  35.7:=  38.0:=  46.5
:=  42.7:=  49.0:=  53.0:=  38.7:=  48.2:=  38.5
MICROPHONE= 120.0 DEG
:=  57.2:=  57.7:=  49.2:=  43.0:=  43.0:=  49.0:=  36.7:=  33.0
:=  33.5:=  33.5:=  29.7:=  31.5:=  40.5:=  27.7:=  29.7:=  43.0
:=  34.2:=  34.0:=  32.7:=  37.7:=  34.0:=  33.2:=  40.5:=  45.7
:=  44.0:=  46.7:=  39.7:=  38.0:=  41.0:=  33.0
MICROPHONE= 140.0 DEG
:=  56.0:=  56.7:=  48.0:=  46.0:=  42.7:=  48.7:=  35.7:=  31.5
:=  31.5:=  31.7:=  28.5:=  31.0:=  42.0:=  28.5:=  31.7:=  42.5
:=  33.0:=  34.2:=  33.2:=  40.7:=  34.7:=  32.5:=  38.0:=  41.0
:=  40.2:=  42.5:=  47.2:=  41.0:=  48.5:=  36.2
MICROPHONE= 160.0 DEG
:=  53.5:=  53.2:=  45.5:=  46.2:=  40.2:=  43.7:=  32.5:=  30.5
:=  30.0:=  29.5:=  28.5:=  32.0:=  43.7:=  28.0:=  30.2:=  39.7
:=  30.7:=  32.5:=  30.5:=  40.5:=  32.2:=  28.2:=  31.5:=  39.7
:=  39.0:=  42.5:=  47.2:=  35.0:=  42.0:=  35.2
MICROPHONE= 180.0 DEG
:=  53.7:=  52.7:=  45.7:=  47.5:=  39.7:=  37.0:=  27.7:=  28.7
:=  28.7:=  28.2:=  26.0:=  32.7:=  45.5:=  27.0:=  30.0:=  36.2
:=  29.7:=  30.5:=  29.2:=  39.2:=  32.2:=  27.0:=  33.0:=  41.5
:=  36.0:=  39.7:=  47.5:=  35.5:=  44.0:=  31.0

1/3 OCTAVE BAND PWL   DB RE 10↑-13  WATT
=  75.0=  76.1=  69.4=  66.2=  58.2=  62.5=  51.4=  49.3
=  47.4=  47.0=  44.4=  46.7=  56.5=  43.9=  47.0=  57.9
=  49.6=  49.8=  49.9=  58.5=  51.8=  50.6=  54.1=  60.0
=  58.6=  63.2=  67.1=  55.2=  61.9=  52.4
FULL OCTAVE BAND PWL   DB RE 10↑-13  WATT
=  79.1=  68.2=  54.4=  51.0=  57.2=  59.1=  59.8=  61.4=  69.0=  63.1
*
```

PART II - UNMODIFIED VERIFICATION HARDWARE TEST DATA

```
     FAN NOISE DATA

TEST UNIT       :2 BLADED AXIAL FAN
CONDITION       :INLET
MIKE RAD (IN):36

MICROPHONE=    0.0 DEG
:=   58.2:=   59.0:=   53.5:=   61.0:=   58.5:=   50.0:=   48.0:=   53.0
:=   48.7:=   49.0:=   50.7:=   53.0:=   68.7:=   62.0:=   56.2:=   84.0
:=   69.2:=   72.7:=   71.5:=   74.5:=   68.[illegible]:=   67.0:=   66.5:=   65.0
:=   64.2:=   62.2:=   61.7:=   57.5:=   53.0:=   41.7:=   85.0:=   85.5
MICROPHONE=   20.0 DEG
:=   58.0:=   60.2:=   54.0:=   61.2:=   58.7:=   50.7:=   47.7:=   53.5
:=   49.7:=   49.5:=   50.7:=   52.2:=   67.5:=   61.7:=   55.7:=   83.2
:=   69.0:=   73.7:=   70.2:=   73.2:=   68.7:=   68.0:=   57.2:=   66.5
:=   63.7:=   63.0:=   62.0:=   58.2:=   54.5:=   43.5:=   84.5:=   85.0
MICROPHONE=   40.0 DEG
:=   58.5:=   60.5:=   53.5:=   59.2:=   58.2:=   52.2:=   49.0:=   53.5
:=   50.0:=   50.2:=   51.2:=   52.7:=   68.2:=   62.0:=   65.5:=   83.2
:=   68.5:=   72.7:=   68.5:=   72.2:=   68.7:=   68.2:=   67.7:=   65.5
:=   64.2:=   63.5:=   63.2:=   60.7:=   58.0:=   50.0:=   84.5:=   85.2
MICROPHONE=   60.0 DEG
:=   57.0:=   59.0:=   50.2:=   57.7:=   53.5:=   53.0:=   48.7:=   52.7
:=   50.2:=   50.5:=   50.7:=   51.7:=   64.2:=   61.2:=   64.0:=   81.7
:=   67.0:=   69.7:=   64.5:=   66.7:=   66.5:=   66.7:=   63.5:=   62.2
:=   63.0:=   62.0:=   59.7:=   55.7:=   50.0:=   39.2:=   82.2:=   83.2
MICROPHONE=   80.0 DEG
:=   58.0:=   58.0:=   47.7:=   56.7:=   53.0:=   54.5:=   48.2:=   53.2
:=   49.5:=   52.0:=   51.0:=   52.0:=   65.0:=   60.0:=   61.5:=   79.0
:=   64.0:=   66.2:=   62.2:=   62.5:=   63.7:=   62.5:=   58.5:=   57.5
:=   57.0:=   56.0:=   53.7:=   50.5:=   44.7:=   33.7:=   78.7:=   79.7
MICROPHONE=  100.0 DEG
:=   57.5:=   57.5:=   46.5:=   57.5:=   54.5:=   55.2:=   49.0:=   52.7
:=   49.5:=   54.0:=   50.5:=   52.2:=   69.2:=   59.2:=   60.0:=   77.0
:=   61.7:=   63.0:=   61.0:=   60.2:=   61.0:=   58.0:=   55.0:=   53.0
:=   53.0:=   52.5:=   48.5:=   45.0:=   40.7:=   31.5:=   77.7:=   79.0
MICROPHONE=  120.0 DEG
:=   57.0:=   55.7:=   46.2:=   59.2:=   55.2:=   55.5:=   47.7:=   50.7
:=   49.0:=   55.0:=   50.7:=   51.7:=   67.0:=   57.7:=   59.2:=   76.0
:=   61.0:=   58.7:=   56.5:=   58.7:=   57.7:=   56.7:=   53.7:=   51.7
:=   50.7:=   52.0:=   46.5:=   42.2:=   40.2:=   30.7:=   76.2:=   77.5
MICROPHONE=  140.0 DEG
:=   56.7:=   54.0:=   49.0:=   62.5:=   57.2:=   55.7:=   48.0:=   46.7
:=   50.2:=   55.7:=   51.2:=   54.2:=   71.2:=   58.7:=   60.2:=   74.5
:=   60.5:=   62.2:=   56.2:=   55.5:=   54.2:=   53.7:=   50.0:=   49.0
:=   48.2:=   48.0:=   44.5:=   40.5:=   37.0:=   30.0:=   75.2:=   77.0
MICROPHONE=  160.0 DEG
:=   54.0:=   50.7:=   50.5:=   63.2:=   58.2:=   56.5:=   47.7:=   46.2
:=   51.0:=   58.5:=   52.0:=   54.5:=   71.5:=   58.0:=   59.7:=   74.5
:=   60.7:=   63.5:=   61.5:=   57.7:=   55.0:=   53.5:=   48.7:=   48.0
:=   48.7:=   50.0:=   41.7:=   36.5:=   31.5:=   30.0:=   75.5:=   77.2

1/3 OCTAVE BAND PWL  DB RE 10↑-13 WATT
=   77.4=   77.9=   69.9=   79.6=   76.0=   74.6=   68.4=   72.1
=   69.8=   73.9=   71.0=   72.6=   88.3=   80.1=   82.5=   99.7
=   85.0=   88.2=   84.3=   86.8=   84.4=   83.8=   82.0=   80.5
=   79.6=   78.8=   77.4=   74.2=   70.6=   61.8=  100.5=  101.4

FULL OCTAVE BAND PWL  DB RE 10↑-13 WATT
=   81.0=   82.0=   75.2=   77.4=   89.8=  100.2
=   90.1=   87.1=   83.5=   75.9=  100.5=  101.4
*
```

2 BLADED AXIAL FAN NOISE DATA

```
    FAN NOISE DATA

TEST UNIT      :2 BLADED AXIAL FAN
CONDITION      :OUTLET
MIKE RAD (IN):36

MICROPHONE=  20.0 DEG
:=   76.0:=  71.5:=  66.2:=  59.0:=  58.5:=  53.5:=  49.5:=  50.0
:=   53.5:=  54.0:=  56.2:=  59.0:=  69.7:=  67.0:=  65.2:=  78.2
:=   70.0:=  74.5:=  72.5:=  74.5:=  70.2:=  71.0:=  71.2:=  68.2
:=   64.2:=  63.0:=  59.5:=  56.0:=  51.0:=  42.0:=  83.0:=  85.2
MICROPHONE=  40.0 DEG
:=   56.7:=  53.7:=  47.7:=  49.7:=  57.5:=  52.5:=  48.0:=  49.2
:=   52.0:=  54.0:=  56.5:=  59.2:=  68.0:=  67.5:=  64.7:=  79.2
:=   68.7:=  72.0:=  73.2:=  73.0:=  70.5:=  70.7:=  71.2:=  67.2
:=   65.0:=  62.7:=  61.0:=  57.7:=  51.7:=  42.5:=  83.0:=  83.0
MICROPHONE=  60.0 DEG
:=   54.7:=  53.7:=  44.2:=  47.7:=  51.0:=  52.2:=  47.5:=  46.7
:=   51.5:=  54.2:=  56.5:=  59.5:=  68.0:=  67.0:=  63.7:=  77.5
:=   67.5:=  71.5:=  71.2:=  71.2:=  69.5:=  68.0:=  68.2:=  65.0
:=   63.7:=  62.0:=  59.5:=  56.0:=  49.2:=  38.2:=  81.2:=  81.5
MICROPHONE=  80.0 DEG
:=   53.2:=  51.2:=  42.5:=  47.7:=  50.5:=  52.7:=  47.5:=  46.7
:=   51.7:=  55.7:=  57.0:=  59.2:=  67.5:=  66.2:=  63.2:=  76.0
:=   66.5:=  69.5:=  69.2:=  68.5:=  66.7:=  64.0:=  63.7:=  59.5
:=   58.0:=  56.2:=  53.7:=  48.5:=  43.0:=  39.2:=  79.5:=  80.0
MICROPHONE= 100.0 DEG
:=   53.2:=  51.5:=  42.7:=  47.7:=  50.5:=  52.5:=  47.2:=  46.2
:=   52.7:=  56.7:=  56.2:=  58.2:=  65.5:=  65.5:=  62.0:=  74.0
:=   65.0:=  67.0:=  69.0:=  65.0:=  63.2:=  60.2:=  58.2:=  53.0
:=   51.2:=  49.5:=  43.5:=  35.7:=  36.5:=  34.5:=  77.2:=  77.7
MICROPHONE= 120.0 DEG
:=   51.2:=  49.2:=  43.2:=  49.7:=  51.2:=  53.5:=  47.0:=  45.5
:=   53.7:=  57.7:=  55.7:=  57.0:=  66.7:=  65.5:=  62.2:=  75.2
:=   64.5:=  67.7:=  69.2:=  64.5:=  62.5:=  60.5:=  57.7:=  52.2
:=   49.7:=  48.7:=  43.5:=  38.2:=  32.7:=  30.0:=  77.7:=  78.5
MICROPHONE= 140.0 DEG
:=   50.7:=  48.0:=  44.0:=  52.5:=  51.5:=  53.0:=  47.0:=  44.7
:=   54.0:=  58.7:=  56.5:=  58.2:=  66.0:=  64.5:=  62.5:=  76.5
:=   65.5:=  66.7:=  66.5:=  63.5:=  61.5:=  60.2:=  58.5:=  53.7
:=   50.5:=  47.7:=  42.7:=  36.5:=  31.5:=  30.0:=  78.0:=  78.7
MICROPHONE= 160.0 DEG
:=   50.0:=  45.7:=  45.0:=  52.7:=  51.0:=  52.5:=  46.0:=  44.5
:=   53.7:=  61.2:=  56.5:=  59.0:=  65.2:=  64.7:=  62.0:=  77.0
:=   65.5:=  68.5:=  65.5:=  64.0:=  61.2:=  59.5:=  57.2:=  51.2
:=   48.2:=  47.5:=  40.2:=  35.0:=  31.0:=  30.0:=  78.2:=  79.0


1/3 OCTAVE BAND PWL  DB RE 10:-13 WATT
=   84.6=  80.4=  74.9=  71.5=  73.3=  72.8=  67.5=  66.9
=   72.8=  76.9=  76.5=  78.7=  87.2=  86.2=  83.2=  96.7
=   86.8=  90.1=  90.2=  89.4=  87.0=  86.1=  86.1=  82.5
=   80.2=  78.4=  75.9=  72.3=  66.3=  58.0= 100.0= 100.7

FULL OCTAVE BAND PWL  DB RE 10:-13 WATT
=   86.3=  77.4=  74.7=  82.3=  90.6=  97.9
=   93.8=  90.0=  83.3=  73.4= 100.0= 100.7
+
```

2 BLADED AXIAL FAN NOISE DATA (CONCLUDED)

```
FAN NOISE DATA

TEST UNIT      :3 BLADED AXIAL FAN
CONDITION      :INLET
MIKE RAD (IN):36

MICROPHONE=   0.0 DEG
:=   58.0:=   59.5:=   54.7:=   61.7:=   59.7:=   50.5:=   48.2:=   52.2
:=   51.5:=   49.5:=   53.0:=   57.0:=   71.5:=   82.7:=   66.0:=   72.5
:=   82.2:=   67.0:=   68.2:=   72.2:=   70.5:=   66.7:=   64.7:=   56.5
:=   61.5:=   60.5:=   57.5:=   52.5:=   45.2:=   41.5:=   84.8:=   85.5
MICROPHONE=  20.0 DEG
:=   56.7:=   59.2:=   54.2:=   60.5:=   59.5:=   51.7:=   48.2:=   51.5
:=   50.5:=   49.5:=   53.2:=   55.0:=   70.5:=   81.5:=   65.2:=   72.0
:=   81.5:=   66.7:=   67.5:=   71.5:=   71.0:=   67.5:=   67.0:=   53.7
:=   61.2:=   59.7:=   57.2:=   53.5:=   46.2:=   41.0:=   84.2:=   85.2
MICROPHONE=  40.0 DEG
:=   55.0:=   58.2:=   51.7:=   58.5:=   53.7:=   51.7:=   48.0:=   49.7
:=   50.0:=   48.0:=   53.0:=   55.0:=   69.5:=   80.2:=   65.0:=   71.2
:=   81.2:=   65.5:=   67.0:=   70.5:=   71.2:=   67.2:=   65.7:=   63.0
:=   59.2:=   58.5:=   56.5:=   52.0:=   43.5:=   38.5:=   83.5:=   84.7
MICROPHONE=  60.0 DEG
:=   55.7:=   58.5:=   50.0:=   57.2:=   52.7:=   53.2:=   48.5:=   51.0
:=   51.0:=   47.7:=   52.7:=   54.5:=   69.7:=   80.2:=   63.5:=   68.7
:=   77.7:=   63.7:=   66.0:=   68.0:=   68.5:=   65.5:=   63.0:=   60.0
:=   57.5:=   56.7:=   54.0:=   49.7:=   42.0:=   36.7:=   81.0:=   82.7
MICROPHONE=  80.0 DEG
:=   56.2:=   57.7:=   48.2:=   57.2:=   53.7:=   54.5:=   48.7:=   52.0
:=   52.7:=   48.0:=   52.7:=   54.2:=   70.0:=   81.2:=   61.7:=   67.7
:=   77.5:=   62.7:=   64.7:=   65.2:=   63.7:=   61.2:=   58.0:=   57.0
:=   53.5:=   51.7:=   49.0:=   46.5:=   37.5:=   31.7:=   80.7:=   83.0
MICROPHONE= 100.0 DEG
:=   57.2:=   57.0:=   46.0:=   57.5:=   53.7:=   54.7:=   48.0:=   51.5
:=   53.2:=   46.5:=   52.0:=   52.5:=   65.7:=   76.7:=   60.2:=   62.7
:=   71.0:=   59.5:=   61.5:=   62.5:=   61.2:=   57.2:=   57.0:=   52.0
:=   53.2:=   47.0:=   44.2:=   42.7:=   33.0:=   30.0:=   76.0:=   78.5
MICROPHONE= 120.0 DEG
:=   56.7:=   55.5:=   46.0:=   60.0:=   55.5:=   55.5:=   47.7:=   49.5
:=   53.7:=   46.5:=   52.5:=   54.7:=   68.0:=   79.2:=   60.2:=   63.0
:=   72.0:=   57.0:=   58.7:=   60.0:=   59.0:=   56.0:=   54.0:=   52.7
:=   53.7:=   46.0:=   45.2:=   48.0:=   34.5:=   30.0:=   77.5:=   80.2
MICROPHONE= 140.0 DEG
:=   54.0:=   52.7:=   48.7:=   62.0:=   57.0:=   55.7:=   47.7:=   49.0
:=   53.7:=   47.7:=   52.5:=   54.5:=   65.5:=   76.2:=   61.0:=   62.5
:=   69.5:=   57.0:=   58.0:=   58.0:=   57.5:=   52.2:=   50.0:=   50.7
:=   51.0:=   42.7:=   40.0:=   35.7:=   31.7:=   30.0:=   75.0:=   77.5
MICROPHONE= 160.0 DEG
:=   51.7:=   49.2:=   50.2:=   63.5:=   57.7:=   56.0:=   47.5:=   48.2
:=   53.5:=   48.2:=   52.7:=   54.0:=   66.0:=   77.2:=   62.0:=   64.5
:=   73.5:=   58.0:=   60.5:=   60.5:=   57.2:=   53.7:=   50.0:=   48.0
:=   46.0:=   42.5:=   40.5:=   40.7:=   31.5:=   30.0:=   76.5:=   79.2


1/3 OCTAVE BAND PWL  DB RE 10:-13 WATT
=   76.0=  77.1=  69.5=  79.6=  75.4=  74.5=  68.2=  70.7
=   72.6=  67.7=  72.7=  74.3=  88.6=  99.5=  82.5=  87.6
=   97.0=  82.4=  84.1=  86.4=  86.3=  82.8=  81.1=  78.5
=   76.0=  74.1=  71.7=  68.4=  59.9=  55.0= 100.2= 102.0

FULL OCTAVE BAND PWL  DB RE 10:-13 WATT
=   80.0=  81.9=  75.7=  77.1=  99.9=  97.6
=   90.5=  85.9=  79.1=  69.1= 100.2= 102.0
+
```

3 BLADED AXIAL FAN NOISE DATA

```
    FAN NOISE DATA

TEST UNIT      :3 BLADED AXIAL FAN
CONLITION      :OUTLET
MIKE RAD (IN):36

MICROPHONE=  20.0 DEG
:=   70.7:=  67.2:=  60.7:=  55.2:=  52.2:=  52.5:=  48.5:=  48.7
:=   56.2:=  52.7:=  57.7:=  56.0:=  64.2:=  78.2:=  65.5:=  66.2
:=   74.0:=  74.2:=  72.2:=  74.0:=  71.0:=  70.0:=  66.0:=  63.2
:=   61.2:=  59.2:=  54.7:=  51.7:=  47.5:=  40.5:=  82.2:=  84.0
MICROPHONE=  40.0 DEG
:=   56.7:=  55.2:=  50.0:=  50.2:=  51.2:=  52.5:=  48.0:=  48.2
:=   55.5:=  53.0:=  57.5:=  56.0:=  63.7:=  77.0:=  65.5:=  66.0
:=   74.0:=  74.2:=  72.5:=  75.0:=  72.2:=  69.7:=  67.5:=  65.5
:=   62.0:=  59.7:=  57.2:=  54.7:=  50.0:=  41.7:=  82.5:=  83.7
MICROPHONE=  60.0 DEG
:=   53.5:=  53.2:=  44.7:=  48.5:=  49.7:=  53.2:=  47.7:=  48.0
:=   55.0:=  53.2:=  58.5:=  57.5:=  64.2:=  78.0:=  64.2:=  65.0
:=   72.7:=  73.0:=  71.5:=  73.5:=  71.2:=  67.0:=  66.0:=  63.2
:=   59.7:=  57.5:=  56.2:=  53.2:=  48.7:=  38.2:=  81.7:=  82.0
MICROPHONE=  80.0 DEG
:=   52.5:=  51.2:=  43.0:=  47.5:=  48.5:=  53.2:=  48.0:=  48.0
:=   54.7:=  53.7:=  59.0:=  57.5:=  63.2:=  76.2:=  64.0:=  64.5
:=   72.2:=  71.7:=  70.2:=  71.5:=  67.7:=  63.5:=  62.5:=  59.2
:=   54.7:=  54.2:=  52.2:=  49.5:=  44.5:=  35.7:=  79.7:=  80.5
MICROPHONE= 100.0 DEG
:=   54.2:=  51.5:=  43.2:=  48.7:=  48.7:=  54.0:=  48.0:=  47.7
:=   56.5:=  53.2:=  59.0:=  56.5:=  62.0:=  75.0:=  63.7:=  63.0
:=   69.0:=  70.7:=  71.7:=  68.5:=  65.0:=  60.7:=  59.0:=  53.7
:=   60.2:=  50.5:=  47.0:=  47.5:=  39.2:=  33.5:=  78.7:=  79.0
MICROPHONE= 120.0 DEG
:=   52.2:=  50.5:=  44.2:=  51.0:=  49.0:=  53.7:=  47.7:=  47.5
:=   57.7:=  53.5:=  59.0:=  56.2:=  59.7:=  71.7:=  62.7:=  62.7
:=   68.0:=  70.7:=  72.5:=  69.0:=  65.5:=  60.5:=  57.2:=  51.7
:=   50.2:=  46.0:=  43.2:=  40.7:=  35.7:=  30.0:=  78.0:=  78.2
MICROPHONE= 140.0 DEG
:=   51.0:=  47.5:=  45.0:=  52.0:=  49.0:=  54.0:=  47.5:=  47.2
:=   59.7:=  53.5:=  58.5:=  57.5:=  60.2:=  69.5:=  63.2:=  62.7
:=   67.7:=  70.5:=  72.7:=  68.0:=  64.5:=  59.7:=  58.0:=  53.5
:=   53.5:=  47.0:=  43.5:=  39.7:=  33.2:=  30.0:=  77.7:=  78.0
MICROPHONE= 160.0 DEG
:=   50.2:=  46.7:=  45.5:=  54.0:=  49.5:=  54.2:=  47.2:=  47.2
:=   59.7:=  53.5:=  58.7:=  58.0:=  59.5:=  71.2:=  63.0:=  62.7
:=   67.5:=  69.7:=  71.5:=  69.7:=  65.7:=  60.2:=  56.2:=  53.5
:=   55.5:=  47.0:=  40.7:=  43.2:=  33.7:=  30.0:=  77.5:=  77.7


1/3 OCTAVE BAND PWL  DB RE 10:-13 WATT
=  80.0=  77.0=  70.5=  70.8=  69.7=  73.5=  67.9=  67.9
=  77.0=  73.4=  78.7=  77.0=  82.5=  95.6=  84.0=  84.3
=  91.3=  92.1=  91.9=  91.7=  88.7=  85.3=  83.3=  80.4
=  78.5=  75.1=  72.7=  70.2=  65.3=  56.8= 100.1= 100.7

FULL OCTAVE BAND PWL  DB RE 10:-13 WATT
=  82.1=  76.4=  78.0=  81.6=  96.1=  95.1
=  95.8=  88.2=  80.9=  71.5= 100.1= 100.7
*
```

3 BLADED AXIAL FAN NOISE DATA (CONCLUDED)

```
FAN NOISE DATA

TEST UNIT     : AXIAL FAN, MOTOR ONLY
CONDITION     :SHAFT END
MIKE RAD (IN):36

MICROPHONE=   0.0 DEG
:=  36.7:=  40.5:=  29.0:=  37.2:=  40.7:=  27.5:=  22.0:=  30.2
:=  20.0:=  22.0:=  21.0:=  19.7:=  22.0:=  32.7:=  42.2:=  48.5
:=  45.0:=  37.5:=  48.5:=  41.5:=  44.7:=  55.0:=  58.7:=  46.0
:=  45.7:=  42.0:=  38.2:=  32.5:=  27.0:=  25.7:=  61.7:=  61.2
MICROPHONE=  20.0 DEG
:=  33.5:=  41.0:=  30.2:=  41.2:=  37.2:=  26.2:=  22.0:=  30.5
:=  19.2:=  26.0:=  21.5:=  18.7:=  22.2:=  32.0:=  47.0:=  52.5
:=  51.5:=  43.5:=  43.2:=  47.2:=  45.5:=  49.5:=  51.2:=  45.7
:=  45.7:=  44.5:=  39.2:=  31.2:=  26.5:=  29.5:=  59.0:=  59.0
MICROPHONE=  40.0 DEG
:=  33.2:=  40.2:=  30.0:=  37.5:=  36.2:=  26.0:=  21.0:=  29.2
:=  19.2:=  32.2:=  23.7:=  20.0:=  25.5:=  33.5:=  47.0:=  52.7
:=  52.5:=  46.0:=  50.7:=  48.2:=  44.0:=  47.5:=  51.2:=  48.0
:=  50.0:=  49.2:=  40.0:=  31.0:=  25.0:=  27.0:=  60.5:=  60.7
MICROPHONE=  60.0 DEG
:=  35.5:=  41.0:=  31.0:=  35.5:=  33.5:=  25.0:=  19.7:=  26.2
:=  20.0:=  37.7:=  26.5:=  21.5:=  30.5:=  36.5:=  54.0:=  59.2
:=  53.2:=  45.5:=  50.5:=  47.7:=  42.7:=  47.2:=  50.0:=  48.0
:=  50.0:=  51.2:=  42.7:=  32.0:=  26.0:=  31.5:=  62.2:=  63.0
MICROPHONE=  80.0 DEG
:=  36.7:=  40.5:=  31.2:=  36.2:=  32.0:=  25.2:=  20.5:=  23.7
:=  22.0:=  42.5:=  29.2:=  22.0:=  32.0:=  36.0:=  54.0:=  59.5
:=  44.5:=  48.0:=  52.2:=  45.7:=  43.0:=  46.7:=  48.0:=  44.0
:=  45.0:=  45.2:=  41.0:=  31.2:=  24.7:=  28.0:=  62.0:=  62.5
MICROPHONE= 100.0 DEG
:=  39.0:=  39.2:=  30.5:=  39.5:=  38.2:=  27.5:=  23.2:=  30.7
:=  25.2:=  45.5:=  32.5:=  23.7:=  28.0:=  36.2:=  58.2:=  63.0
:=  49.2:=  51.0:=  55.5:=  51.0:=  42.2:=  45.5:=  49.5:=  39.0
:=  47.0:=  49.5:=  39.5:=  29.0:=  24.5:=  23.5:=  64.7:=  65.7
MICROPHONE= 120.0 DEG
:=  38.5:=  39.0:=  29.5:=  37.7:=  38.5:=  28.5:=  23.0:=  30.7
:=  26.2:=  46.5:=  33.7:=  25.0:=  33.2:=  35.7:=  54.7:=  59.7
:=  53.7:=  53.0:=  55.0:=  51.2:=  41.2:=  46.7:=  45.0:=  41.0
:=  47.5:=  42.7:=  36.7:=  27.7:=  21.5:=  20.5:=  63.2:=  63.7
MICROPHONE= 140.0 DEG
:=  36.2:=  34.2:=  27.5:=  36.0:=  38.7:=  29.5:=  24.0:=  32.7
:=  26.0:=  45.5:=  32.7:=  26.0:=  32.7:=  38.7:=  60.5:=  64.7
:=  56.0:=  52.0:=  58.0:=  50.0:=  37.0:=  42.7:=  46.0:=  35.2
:=  41.5:=  42.2:=  35.5:=  26.0:=  21.2:=  20.0:=  66.7:=  67.7
MICROPHONE= 160.0 DEG
:=  32.5:=  33.7:=  25.7:=  36.7:=  30.5:=  30.0:=  20.0:=  28.5
:=  21.0:=  36.5:=  27.0:=  25.5:=  26.5:=  40.5:=  53.0:=  59.5
:=  48.2:=  46.2:=  56.2:=  48.7:=  37.7:=  43.2:=  47.0:=  36.5
:=  39.7:=  43.5:=  33.0:=  22.0:=  16.7:=  11.5:=  62.5:=  63.0


1/3 OCTAVE BAND PWL  DB RE 10:-13 WATT
=  56.8=  59.5=  50.1=  57.7=  56.6=  47.4=  42.0=  49.6
=  43.6=  63.3=  50.6=  43.5=  50.7=  56.6=  75.9=  80.8
=  72.2=  69.8=  74.3=  69.3=  62.4=  66.7=  69.[illegible]=  64.4
=  67.3=  67.7=  59.8=  49.9=  44.2=  47.0=  83.4=  84.1

FULL OCTAVE BAND PWL  DB RE 10:-13 WATT
=  61.7=  60.5=  51.2=  63.6=  76.0=  81.6
=  75.7=  72.0=  70.9=  52.4=  83.4=  84.1
*
```

AXIAL FAN(MOTOR ONLY) NOISE DATA

```
FAN NOISE DATA

TEST UNIT      :SQUIRREL CAGE FAN
CONDITION      :INLET NOISE
MIKE RAD (IN):36

MICROPHONE=   0.0 DEG
:=  52.5:=  52.7:=  43.5:=  50.2:=  50.5:=  57.7:=  50.7:=  51.0
:=  58.7:=  59.2:=  62.2:=  60.5:=  58.5:=  59.2:=  65.0:=  68.5
:=  60.2:=  57.7:=  63.2:=  53.5:=  57.7:=  60.2:=  53.7:=  50.2
:=  54.7:=  51.2:=  45.5:=  41.0:=  37.0:=  31.0:=  72.0:=  73.5
MICROPHONE=  20.0 DEG
:=  52.5:=  53.7:=  42.2:=  49.5:=  50.7:=  56.7:=  48.5:=  53.2
:=  63.2:=  60.7:=  61.0:=  59.0:=  62.5:=  60.0:=  67.0:=  76.5
:=  65.0:=  59.2:=  62.0:=  56.2:=  59.2:=  64.5:=  58.0:=  55.5
:=  58.0:=  56.7:=  53.2:=  50.7:=  48.7:=  41.5:=  77.5:=  78.2
MICROPHONE=  40.0 DEG
:=  53.0:=  53.7:=  41.7:=  49.7:=  50.5:=  55.0:=  48.0:=  54.0
:=  65.5:=  61.2:=  59.7:=  60.0:=  63.0:=  61.0:=  65.5:=  74.5
:=  65.7:=  62.7:=  65.2:=  59.2:=  69.0:=  65.7:=  59.2:=  58.0
:=  60.2:=  59.2:=  58.0:=  55.0:=  52.2:=  45.2:=  77.5:=  78.2
MICROPHONE=  60.0 DEG
:=  52.0:=  52.5:=  41.5:=  51.0:=  50.5:=  52.5:=  48.7:=  54.2
:=  65.2:=  62.0:=  60.2:=  61.7:=  62.2:=  61.5:=  67.5:=  73.0
:=  66.0:=  64.5:=  65.5:=  61.0:=  69.0:=  67.5:=  62.0:=  58.2
:=  60.5:=  59.0:=  57.5:=  55.0:=  52.7:=  47.2:=  78.0:=  78.2
MICROPHONE=  80.0 DEG
:=  50.2:=  50.2:=  41.2:=  52.7:=  51.0:=  52.0:=  49.5:=  54.0
:=  65.2:=  61.5:=  61.0:=  62.5:=  62.7:=  62.0:=  67.0:=  72.5
:=  67.0:=  65.7:=  70.0:=  63.0:=  68.0:=  65.7:=  59.2:=  59.5
:=  59.5:=  58.5:=  56.7:=  55.0:=  51.5:=  47.0:=  78.0:=  78.2
MICROPHONE= 100.0 DEG
:=  49.0:=  46.7:=  41.2:=  54.5:=  52.5:=  55.5:=  50.5:=  53.7
:=  65.2:=  62.0:=  61.5:=  62.0:=  64.0:=  63.2:=  67.5:=  71.5
:=  66.5:=  65.5:=  71.5:=  64.5:=  68.7:=  65.0:=  60.5:=  59.7
:=  60.2:=  59.2:=  58.0:=  56.0:=  52.7:=  47.2:=  77.7:=  78.2
MICROPHONE= 120.0 DEG
:=  48.2:=  44.7:=  42.2:=  56.0:=  52.0:=  53.7:=  49.5:=  53.7
:=  66.2:=  62.5:=  61.5:=  61.5:=  64.0:=  62.7:=  68.7:=  70.0
:=  65.0:=  63.7:=  72.5:=  64.5:=  69.2:=  66.2:=  61.0:=  50.0
:=  61.2:=  60.2:=  59.2:=  58.0:=  56.2:=  50.7:=  78.2:=  78.7
MICROPHONE= 140.0 DEG
:=  48.0:=  39.7:=  40.5:=  54.5:=  51.2:=  54.5:=  49.7:=  53.0
:=  67.2:=  62.7:=  60.2:=  61.5:=  63.7:=  62.5:=  67.5:=  69.5
:=  64.0:=  62.0:=  66.0:=  60.5:=  66.5:=  65.0:=  60.5:=  58.0
:=  60.5:=  58.5:=  57.7:=  56.0:=  52.5:=  45.7:=  75.5:=  76.5
MICROPHONE= 160.0 DEG
:=  49.2:=  38.5:=  40.7:=  54.7:=  52.0:=  57.2:=  49.0:=  52.7
:=  66.5:=  61.5:=  60.5:=  59.7:=  61.5:=  62.0:=  69.2:=  75.2
:=  64.7:=  59.5:=  67.5:=  58.5:=  64.2:=  63.7:=  55.7:=  54.5
:=  57.0:=  54.2:=  52.7:=  51.0:=  48.2:=  41.2:=  77.2:=  78.2
MICROPHONE= 180.0 DEG
:=  47.7:=  38.0:=  41.5:=  55.5:=  53.7:=  58.7:=  49.5:=  50.5
:=  63.5:=  59.2:=  62.0:=  60.5:=  58.0:=  59.2:=  68.0:=  75.5
:=  63.7:=  58.2:=  66.7:=  58.7:=  68.7:=  59.7:=  54.7:=  53.0
:=  54.0:=  50.0:=  47.2:=  45.0:=  41.5:=  35.5:=  77.5:=  78.0
MICROPHONE=   0.0 DEG
:=  55.5:=  51.0:=  42.0:=  52.7:=  31.7:=  55.5:=  50.2:=  50.5
:=  58.2:=  58.0:=  62.0:=  59.2:=  57.0:=  59.5:=  64.5:=  78.5
:=  65.5:=  57.7:=  65.0:=  56.2:=  65.2:=  60.0:=  58.7:=  54.0
:=  55.7:=  51.0:=  45.7:=  42.5:=  38.7:=  32.7:=  78.7:=  79.7
MICROPHONE=  20.0 DEG
:=  55.2:=  52.5:=  41.7:=  52.2:=  51.2:=  52.2:=  49.2:=  52.0
:=  62.5:=  60.2:=  61.2:=  58.2:=  60.7:=  59.5:=  67.7:=  79.2
:=  66.2:=  58.2:=  59.7:=  56.5:=  65.0:=  62.7:=  58.5:=  56.2
:=  58.5:=  53.5:=  51.0:=  49.0:=  46.0:=  39.2:=  79.7:=  80.7
MICROPHONE=  40.0 DEG
:=  54.2:=  49.0:=  41.2:=  53.0:=  51.0:=  51.2:=  49.5:=  53.7
:=  64.0:=  60.7:=  59.2:=  60.2:=  62.5:=  60.2:=  67.7:=  78.5
:=  66.2:=  60.7:=  63.0:=  60.2:=  70.0:=  62.2:=  60.2:=  58.5
:=  63.5:=  59.2:=  57.0:=  54.2:=  51.7:=  44.5:=  79.5:=  80.0
```

SQUIRREL CAGE FAN NOISE DATA

```
MICROPHONE=  60.0 DEG
:=   52.7:=   49.5:=   41.2:=   53.2:=   50.7:=   50.0:=   50.0:=   54.0
:=   64.7:=   61.0:=   59.5:=   61.7:=   62.5:=   62.0:=   68.0:=   73.7
:=   65.2:=   63.7:=   69.0:=   64.0:=   74.0:=   66.0:=   61.0:=   59.0
:=   62.5:=   60.2:=   58.5:=   55.7:=   53.2:=   46.5:=   79.2:=   79.2
MICROPHONE=  80.0 DEG
:=   50.7:=   48.7:=   40.2:=   52.7:=   50.5:=   51.7:=   49.7:=   53.7
:=   65.2:=   61.2:=   61.0:=   62.0:=   63.5:=   62.7:=   67.7:=   70.7
:=   66.0:=   65.0:=   69.2:=   64.7:=   72.2:=   64.5:=   59.7:=   58.5
:=   60.7:=   58.5:=   57.5:=   55.5:=   52.5:=   47.2:=   77.7:=   78.5
MICROPHONE= 100.0 DEG
:=   49.0:=   48.2:=   40.0:=   53.5:=   51.0:=   53.0:=   49.5:=   53.5
:=   65.7:=   61.7:=   62.0:=   61.5:=   63.7:=   63.0:=   66.7:=   75.0
:=   66.5:=   65.5:=   68.7:=   64.0:=   65.2:=   66.5:=   60.5:=   60.2
:=   59.7:=   57.7:=   57.7:=   56.0:=   52.2:=   47.2:=   78.2:=   78.7
MICROPHONE= 120.0 DEG
:=   51.0:=   47.7:=   40.2:=   53.5:=   51.2:=   54.0:=   50.0:=   53.5
:=   66.5:=   62.7:=   60.7:=   61.5:=   64.0:=   62.2:=   67.0:=   77.0
:=   66.5:=   64.2:=   69.0:=   63.0:=   68.2:=   69.0:=   63.0:=   60.5
:=   60.7:=   60.0:=   58.5:=   57.0:=   54.2:=   48.5:=   79.5:=   80.0
MICROPHONE= 140.0 DEG
:=   52.2:=   47.7:=   40.5:=   54.0:=   51.0:=   55.0:=   49.0:=   53.0
:=   66.2:=   62.5:=   60.5:=   61.0:=   63.2:=   61.0:=   66.7:=   70.0
:=   63.0:=   61.2:=   69.5:=   61.2:=   67.7:=   68.0:=   61.2:=   59.0
:=   60.5:=   59.0:=   58.2:=   56.0:=   54.0:=   47.0:=   76.2:=   77.0
MICROPHONE= 160.0 DEG
:=   52.7:=   47.0:=   39.5:=   52.5:=   53.0:=   59.5:=   50.0:=   52.0
:=   65.0:=   60.5:=   61.5:=   60.2:=   62.5:=   61.7:=   67.2:=   71.7
:=   62.2:=   57.5:=   65.5:=   58.5:=   66.2:=   63.0:=   58.7:=   56.7
:=   57.5:=   55.2:=   53.0:=   50.5:=   48.0:=   41.2:=   75.5:=   76.2
MICROPHONE= 180.0 DEG
:=   53.0:=   48.5:=   40.7:=   53.7:=   54.0:=   59.5:=   51.0:=   49.2
:=   61.7:=   58.7:=   63.0:=   61.0:=   59.5:=   60.7:=   65.5:=   71.7
:=   61.5:=   56.7:=   71.5:=   59.7:=   68.7:=   63.2:=   58.2:=   55.2
:=   56.2:=   52.2:=   49.5:=   45.5:=   42.0:=   35.5:=   77.0:=   77.5


1/3 OCTAVE BAND PWL  DB RE 10:-13 WATT
=   69.4=   67.1=   58.3=   70.2=   68.7=   73.0=   66.5=   69.9
=   81.9=   78.2=   78.0=   77.6=   79.3=   78.2=   84.3=   92.3
=   81.9=   78.5=   84.4=   77.5=   84.9=   81.9=   76.6=   74.5
=   76.7=   74.4=   72.9=   70.7=   68.1=   61.8=   94.8=   95.5

FULL OCTAVE BAND PWL  DB RE 10:-13 WATT
=   71.6=   75.8=   82.3=   82.7=   86.3=   92.8
=   88.1=   83.6=   79.7=   72.9=   94.8=   95.5
*
```

SQUIRREL CAGE FAN NOISE (CONTINUED)

FAN NOISE DATA

```
TEST UNIT      :SQUIRREL CAGE FAN
CONDITION      :OUTLET NOISE
MIKE RAD (IN):36


MICROPHONE=    0.0 DEG
:=  49.7:=  48.5:=  45.5:=  49.0:=  52.5:=  55.5:=  50.5:=  55.5
:=  60.2:=  60.2:=  62.0:=  59.7:=  57.0:=  59.0:=  62.0:=  66.0
:=  66.7:=  60.0:=  68.5:=  64.0:=  64.2:=  62.5:=  57.0:=  57.7
:=  53.7:=  52.2:=  48.0:=  43.5:=  37.7:=  27.5:=  74.5:=  75.2
MICROPHONE=   20.0 DEG
:=  50.5:=  49.5:=  45.5:=  50.7:=  53.2:=  54.7:=  51.5:=  58.7
:=  64.5:=  61.7:=  60.7:=  59.7:=  60.2:=  59.5:=  64.7:=  65.5
:=  67.0:=  62.7:=  67.0:=  63.2:=  61.5:=  63.2:=  58.0:=  56.0
:=  57.5:=  57.5:=  55.0:=  51.0:=  47.7:=  39.0:=  74.7:=  75.5
MICROPHONE=   40.0 DEG
:=  50.7:=  49.7:=  45.5:=  50.2:=  53.5:=  53.5:=  50.7:=  59.2
:=  66.2:=  61.2:=  59.5:=  60.7:=  61.0:=  60.2:=  64.7:=  71.0
:=  66.7:=  63.0:=  66.5:=  61.5:=  61.7:=  65.0:=  61.0:=  58.7
:=  59.0:=  59.7:=  59.5:=  57.5:=  53.5:=  45.7:=  75.5:=  77.0
MICROPHONE=   60.0 DEG
:=  56.2:=  53.5:=  48.0:=  50.7:=  53.5:=  53.2:=  51.0:=  59.5
:=  66.7:=  61.5:=  59.5:=  62.5:=  61.5:=  62.2:=  65.0:=  69.7
:=  65.5:=  62.2:=  64.2:=  61.7:=  62.7:=  64.0:=  62.7:=  59.7
:=  59.2:=  61.7:=  60.5:=  58.0:=  55.0:=  48.0:=  75.2:=  77.0
MICROPHONE=   80.0 DEG
:=  56.7:=  57.5:=  58.0:=  58.5:=  59.7:=  61.0:=  58.5:=  60.5
:=  65.5:=  62.0:=  59.7:=  62.2:=  60.5:=  62.5:=  65.2:=  71.2
:=  65.5:=  62.0:=  63.2:=  62.5:=  62.0:=  61.7:=  60.7:=  57.0
:=  57.2:=  58.2:=  57.0:=  54.2:=  49.0:=  41.0:=  75.0:=  77.2
MICROPHONE=  100.0 DEG
:=  51.5:=  49.0:=  46.2:=  51.2:=  54.2:=  56.2:=  51.5:=  57.5
:=  66.5:=  62.0:=  59.0:=  61.0:=  61.5:=  62.5:=  64.7:=  72.5
:=  65.7:=  61.7:=  63.7:=  62.5:=  62.2:=  64.5:=  62.5:=  59.2
:=  59.7:=  61.0:=  60.2:=  57.0:=  53.7:=  46.7:=  75.7:=  77.2
MICROPHONE=  120.0 DEG
:=  47.5:=  46.2:=  43.7:=  51.7:=  53.7:=  56.5:=  51.2:=  57.2
:=  67.0:=  62.5:=  58.2:=  61.0:=  61.5:=  62.5:=  65.0:=  73.0
:=  65.2:=  60.7:=  62.5:=  60.5:=  62.2:=  64.0:=  61.0:=  58.5
:=  60.0:=  60.5:=  59.5:=  57.5:=  52.7:=  45.2:=  75.7:=  77.5
MICROPHONE=  140.0 DEG
:=  45.5:=  43.2:=  43.5:=  51.2:=  53.5:=  58.2:=  50.2:=  56.2
:=  66.7:=  61.7:=  58.0:=  61.2:=  60.5:=  61.5:=  65.2:=  74.5
:=  66.2:=  61.7:=  62.5:=  57.5:=  58.5:=  62.5:=  59.7:=  58.0
:=  58.7:=  58.2:=  56.7:=  54.0:=  50.7:=  43.5:=  76.0:=  77.5
MICROPHONE=  160.0 DEG
:=  43.2:=  42.2:=  43.7:=  51.7:=  52.5:=  58.5:=  49.5:=  55.2
:=  65.5:=  60.2:=  59.0:=  59.0:=  59.7:=  60.7:=  65.0:=  69.2
:=  65.5:=  62.7:=  63.5:=  59.2:=  60.7:=  58.7:=  54.0:=  53.0
:=  56.0:=  55.5:=  53.2:=  50.7:=  46.5:=  38.2:=  73.7:=  75.0
MICROPHONE=  180.0 DEG
:=  44.7:=  43.5:=  45.2:=  53.2:=  61.5:=  59.7:=  49.5:=  53.2
:=  63.0:=  59.2:=  60.7:=  59.2:=  56.7:=  60.5:=  63.0:=  71.2
:=  65.2:=  62.2:=  63.2:=  60.2:=  62.2:=  62.2:=  59.7:=  55.0
:=  56.7:=  56.2:=  51.0:=  46.0:=  40.5:=  33.0:=  74.5:=  75.2
MICROPHONE=    0.0 DEG
:=  49.7:=  43.7:=  42.0:=  49.0:=  51.7:=  57.7:=  51.0:=  55.0
:=  62.2:=  59.0:=  61.2:=  59.2:=  55.5:=  58.2:=  62.2:=  71.2
:=  64.5:=  60.0:=  64.0:=  57.2:=  58.7:=  58.2:=  56.0:=  52.0
:=  54.0:=  52.5:=  48.7:=  46.5:=  40.0:=  32.0:=  73.5:=  75.0
```

SQUIRREL CAGE FAN NOISE DATA (CONTINUED)

```
MICROPHONE=  20.0 DEG
:=   50.0:=   44.2:=   42.7:=   49.7:=   52.0:=   56.0:=   50.7:=   57.0
:=   65.0:=   60.7:=   59.7:=   58.0:=   59.5:=   59.0:=   65.5:=   75.7
:=   67.2:=   61.7:=   66.0:=   59.2:=   61.0:=   62.2:=   60.5:=   54.5
:=   56.2:=   54.7:=   52.2:=   50.2:=   48.0:=   40.2:=   77.5:=   78.2
MICROPHONE=  40.0 DEG
:=   50.5:=   45.2:=   43.2:=   50.2:=   52.5:=   54.5:=   50.2:=   58.0
:=   66.5:=   62.0:=   58.2:=   59.7:=   60.7:=   61.0:=   66.0:=   76.2
:=   68.0:=   63.0:=   65.2:=   60.5:=   58.5:=   61.0:=   58.7:=   58.7
:=   59.2:=   59.5:=   58.5:=   55.5:=   52.0:=   44.2:=   78.0:=   79.0
MICROPHONE=  60.0 DEG
:=   64.0:=   60.5:=   56.0:=   56.2:=   55.7:=   54.7:=   52.5:=   58.5
:=   66.2:=   62.0:=   59.5:=   61.2:=   61.0:=   62.0:=   65.7:=   75.0
:=   67.0:=   62.0:=   64.0:=   60.2:=   60.2:=   61.5:=   61.2:=   57.2
:=   57.5:=   57.5:=   58.5:=   54.7:=   49.5:=   42.5:=   76.7:=   79.0
MICROPHONE=  80.0 DEG
:=   62.5:=   64.0:=   65.2:=   65.7:=   63.7:=   63.2:=   63.7:=   64.7
:=   65.5:=   63.2:=   62.0:=   62.7:=   61.0:=   62.2:=   65.5:=   75.2
:=   66.7:=   61.5:=   63.7:=   60.2:=   58.0:=   62.5:=   59.2:=   54.5
:=   54.0:=   53.2:=   49.7:=   43.5:=   37.7:=   31.7:=   76.5:=   79.0
MICROPHONE= 110.0 DEG
:=   66.7:=   64.2:=   61.5:=   59.7:=   58.2:=   57.5:=   56.0:=   59.7
:=   66.5:=   62.5:=   59.7:=   62.5:=   61.2:=   62.5:=   64.2:=   69.2
:=   63.7:=   61.2:=   65.7:=   62.0:=   61.2:=   62.0:=   60.7:=   56.7
:=   59.0:=   59.0:=   57.2:=   55.2:=   50.7:=   42.5:=   74.5:=   78.2
MICROPHONE= 120.0 DEG
:=   51.5:=   50.2:=   45.2:=   50.0:=   53.5:=   55.2:=   50.5:=   59.2
:=   67.2:=   62.5:=   59.2:=   62.0:=   61.5:=   61.5:=   64.7:=   68.5
:=   63.0:=   61.5:=   66.0:=   61.7:=   61.2:=   62.5:=   60.7:=   57.5
:=   59.5:=   59.5:=   58.2:=   55.5:=   51.7:=   44.2:=   74.2:=   75.0
MICROPHONE= 140.0 DEG
:=   51.7:=   49.2:=   43.5:=   48.7:=   53.0:=   56.0:=   50.2:=   59.5
:=   67.2:=   62.0:=   58.7:=   61.5:=   62.0:=   61.0:=   64.2:=   68.5
:=   62.0:=   60.5:=   65.5:=   60.2:=   59.5:=   62.5:=   59.0:=   56.2
:=   58.2:=   59.7:=   56.7:=   54.2:=   50.2:=   42.2:=   73.7:=   75.7
MICROPHONE= 160.0 DEG
:=   50.7:=   48.2:=   42.7:=   48.7:=   53.2:=   57.2:=   50.5:=   58.7
:=   66.2:=   61.0:=   60.5:=   59.2:=   60.7:=   61.0:=   65.0:=   71.5
:=   63.2:=   59.2:=   64.2:=   58.7:=   57.7:=   59.7:=   56.0:=   53.2
:=   55.2:=   56.0:=   53.0:=   50.7:=   46.0:=   38.5:=   74.0:=   75.7
MICROPHONE= 180.0 DEG
:=   50.2:=   47.2:=   42.7:=   47.0:=   53.2:=   58.5:=   51.5:=   56.2
:=   63.0:=   59.7:=   61.7:=   60.0:=   57.0:=   60.7:=   63.5:=   67.5
:=   61.5:=   58.0:=   59.2:=   57.5:=   59.5:=   61.5:=   54.2:=   51.0
:=   52.0:=   52.5:=   50.0:=   44.2:=   38.5:=   30.0:=   71.7:=   73.5


1/3 OCTAVE BAND PWL  DB RE 10:-13 WATT
=  72.4=  70.6=  69.2=  70.8=  72.3=  74.2=  69.8=  75.3
=  82.7=  78.3=  76.9=  77.4=  77.3=  77.9=  81.8=  89.3
=  82.8=  78.7=  82.0=  77.7=  77.8=  79.3=  76.3=  73.6
=  74.5=  74.9=  73.3=  70.6=  66.8=  59.2=  92.4=  93.8

FULL OCTAVE BAND PWL  DB RE 10:-13 WATT
=  75.7=  77.4=  83.6=  82.4=  84.2=  90.5
=  84.5=  81.8=  79.1=  72.4=  92.4=  93.8
+
```

SQUIRREL CAGE FAN NOISE DATA (CONCLUDED)

```
FAN NOISE DATA

TEST UNIT      :SQUIRREL CAGE FAN
CONDITION      :MOTOR ONLY
MIKE RAD (IN):36


MICROPHONE=   0.0 DEG
:=  39.0:=  40.2:=  30.0:=  37.7:=  39.0:=  32.0:=  30.0:=  30.7
:=  35.7:=  35.7:=  31.2:=  41.5:=  40.0:=  34.2:=  46.7:=  62.5
:=  52.0:=  57.5:=  77.2:=  66.2:=  65.7:=  62.0:=  61.5:=  55.2
:=  54.0:=  53.7:=  48.7:=  41.7:=  40.5:=  36.5:=  79.0:=  78.2
MICROPHONE=  20.0 DEG
:=  39.7:=  41.7:=  30.0:=  37.7:=  38.7:=  32.0:=  30.0:=  31.0
:=  35.7:=  35.7:=  31.5:=  39.5:=  42.5:=  36.5:=  51.2:=  69.0
:=  57.0:=  56.7:=  76.5:=  66.0:=  67.5:=  61.5:=  62.5:=  55.2
:=  55.5:=  63.5:=  52.5:=  45.0:=  42.2:=  39.2:=  79.0:=  78.5
MICROPHONE=  40.0 DEG
:=  39.7:=  39.7:=  30.0:=  37.5:=  37.5:=  32.0:=  30.0:=  31.0
:=  36.0:=  36.0:=  31.5:=  39.7:=  43.0:=  35.7:=  53.7:=  68.7
:=  57.0:=  54.2:=  74.7:=  63.2:=  66.0:=  64.5:=  59.7:=  51.2
:=  53.5:=  56.7:=  47.7:=  42.7:=  40.5:=  35.0:=  77.7:=  77.0
MICROPHONE=  60.0 DEG
:=  38.7:=  41.2:=  30.0:=  38.0:=  37.7:=  32.5:=  30.0:=  31.0
:=  36.0:=  36.0:=  31.5:=  39.7:=  39.7:=  37.7:=  57.0:=  73.0
:=  60.5:=  51.5:=  71.7:=  59.7:=  63.0:=  59.0:=  56.2:=  52.0
:=  52.2:=  51.7:=  51.2:=  42.0:=  36.2:=  31.0:=  76.2:=  76.2
MICROPHONE=  80.0 DEG
:=  36.0:=  41.0:=  30.2:=  38.2:=  38.2:=  32.7:=  30.0:=  30.7
:=  36.2:=  36.0:=  31.5:=  41.0:=  41.2:=  38.7:=  56.5:=  74.5
:=  61.5:=  46.5:=  64.5:=  55.2:=  62.0:=  54.0:=  55.5:=  48.7
:=  53.2:=  53.7:=  49.7:=  44.0:=  37.5:=  33.2:=  75.0:=  75.5
MICROPHONE= 100.0 DEG
:=  33.0:=  39.0:=  30.0:=  37.5:=  36.0:=  32.5:=  30.0:=  30.7
:=  36.0:=  36.0:=  31.0:=  39.5:=  42.5:=  39.2:=  55.7:=  74.5
:=  61.0:=  47.2:=  63.7:=  54.2:=  50.7:=  55.2:=  49.2:=  47.0
:=  48.2:=  48.5:=  45.2:=  37.0:=  33.7:=  31.5:=  74.5:=  75.0
MICROPHONE= 120.0 DEG
:=  34.7:=  39.0:=  30.0:=  37.0:=  35.0:=  32.5:=  30.0:=  31.0
:=  36.0:=  36.0:=  31.5:=  39.0:=  43.5:=  37.5:=  54.0:=  70.5
:=  58.2:=  43.0:=  60.7:=  55.5:=  59.0:=  61.7:=  51.7:=  46.5
:=  46.0:=  48.2:=  39.0:=  33.2:=  32.2:=  30.0:=  72.0:=  72.5
MICROPHONE= 140.0 DEG
:=  36.7:=  37.7:=  30.0:=  36.7:=  33.7:=  32.0:=  30.0:=  30.7
:=  35.7:=  36.2:=  31.2:=  40.2:=  41.0:=  37.0:=  51.0:=  71.2
:=  58.2:=  43.7:=  61.7:=  59.0:=  59.5:=  65.7:=  51.2:=  48.0
:=  43.2:=  44.0:=  38.0:=  33.2:=  32.7:=  30.0:=  73.2:=  73.2
MICROPHONE= 160.0 DEG
:=  36.7:=  35.7:=  23.2:=  29.2:=  26.5:=  24.7:=  21.2:=  24.7
:=  26.7:=  26.7:=  25.0:=  40.2:=  38.2:=  34.0:=  49.2:=  69.2
:=  56.0:=  45.7:=  63.0:=  61.7:=  58.7:=  66.5:=  54.0:=  50.7
:=  44.0:=  47.5:=  38.0:=  31.7:=  30.7:=  24.5:=  72.5:=  72.5
MICROPHONE= 180.0 DEG
:=  37.2:=  36.0:=  23.5:=  29.2:=  27.0:=  25.2:=  22.0:=  24.7
:=  27.0:=  26.7:=  24.0:=  41.0:=  39.7:=  31.2:=  41.0:=  61.5
:=  48.2:=  46.7:=  66.0:=  61.7:=  58.2:=  53.7:=  49.2:=  47.5
:=  40.0:=  41.2:=  38.7:=  28.7:=  24.7:=  20.2:=  69.0:=  68.5


1/3 OCTAVE BAND PWL  DB RE 10:-13 WATT
=  57.1=  59.9=  49.8=  57.4=  56.7=  52.2=  49.8=  50.7
=  55.8=  55.8=  51.2=  60.0=  61.9=  57.7=  74.9=  92.5
=  79.6=  70.4=  90.0=  80.0=  82.3=  81.9=  76.2=  70.2
=  71.2=  74.5=  67.9=  60.9=  56.9=  52.9=  95.4=  95.4

FULL OCTAVE BAND PWL  DB RE 10:-13 WATT
=  62.0=  60.7=  57.7=  61.8=  75.2=  92.7
=  91.0=  83.2=  76.8=  62.8=  95.4=  95.4
*
```

SQUIRREL CAGE FAN (MOTOR ONLY) NOISE DATA

PUMP NOISE DATA

NO. OF TEST POINTS:20
MIKE RADIUS (IN) :36
TEST CONDITION :PUMP AND MOTOR

```
MICROPHONE=    1.0
:=  36.7:=  32.0:=  20.7:=  25.7:=  30.0:=  22.7:=  19.0:=  18.7
:=  19.5:=  18.5:=  14.0:=  21.0:=  22.0:=  24.2:=  24.5:=  25.7
:=  30.7:=  34.7:=  37.2:=  43.2:=  45.2:=  29.0:=  29.7:=  33.5
:=  34.2:=  36.0:=  35.5:=  32.2:=  26.2:=  15.5:=  49.5:=  49.2
MICROPHONE=    2.0
:=  34.7:=  42.2:=  30.5:=  27.7:=  31.7:=  23.7:=  18.0:=  25.5
:=  23.5:=  22.0:=  16.0:=  20.2:=  22.0:=  23.0:=  22.7:=  24.5
:=  27.7:=  33.7:=  36.0:=  41.5:=  45.7:=  29.5:=  31.7:=  35.5
:=  34.5:=  35.2:=  33.0:=  30.7:=  28.0:=  20.5:=  49.2:=  49.5
MICROPHONE=    3.0
:=  37.5:=  36.2:=  19.0:=  25.7:=  32.7:=  22.5:=  19.0:=  19.7
:=  20.7:=  19.5:=  17.2:=  25.0:=  26.5:=  26.0:=  26.0:=  28.7
:=  35.5:=  33.0:=  35.7:=  41.0:=  47.0:=  29.5:=  28.0:=  33.7
:=  33.0:=  35.5:=  33.5:=  32.7:=  29.7:=  23.7:=  49.5:=  49.5
MICROPHONE=    4.0
:=  31.0:=  38.7:=  23.5:=  26.2:=  34.2:=  21.0:=  19.0:=  28.0
:=  29.7:=  27.0:=  20.2:=  25.0:=  24.7:=  26.5:=  24.2:=  28.7
:=  33.0:=  31.2:=  33.0:=  42.7:=  45.0:=  29.2:=  31.2:=  35.2
:=  32.2:=  35.2:=  32.0:=  31.2:=  32.0:=  22.0:=  49.5:=  49.5
MICROPHONE=    5.0
:=  37.0:=  38.5:=  37.5:=  32.0:=  29.0:=  25.2:=  23.7:=  29.7
:=  26.2:=  24.0:=  13.5:=  25.0:=  24.7:=  27.5:=  25.2:=  27.7
:=  29.7:=  32.2:=  34.5:=  40.5:=  46.0:=  30.5:=  30.7:=  33.2
:=  33.2:=  34.7:=  32.7:=  32.2:=  31.7:=  23.0:=  48.7:=  49.5
MICROPHONE=    6.0
:=  27.2:=  30.2:=  24.7:=  26.5:=  30.0:=  24.0:=  18.2:=  23.7
:=  25.7:=  24.2:=  16.5:=  24.0:=  24.5:=  23.5:=  24.7:=  29.7
:=  33.2:=  32.2:=  35.7:=  40.7:=  45.2:=  28.7:=  31.7:=  35.5
:=  34.2:=  36.2:=  34.7:=  35.5:=  30.7:=  24.7:=  48.7:=  49.2
MICROPHONE=    7.0
:=  38.7:=  38.0:=  20.0:=  25.0:=  33.0:=  21.2:=  16.7:=  23.7
:=  20.7:=  20.0:=  21.2:=  16.7:=  20.7:=  23.7:=  25.7:=  28.2
:=  33.0:=  31.0:=  35.5:=  36.7:=  41.0:=  31.0:=  30.7:=  29.2
:=  34.0:=  36.2:=  33.0:=  29.7:=  28.0:=  20.7:=  46.0:=  47.2
MICROPHONE=    8.0
:=  35.0:=  42.5:=  26.5:=  31.5:=  36.7:=  24.0:=  23.5:=  23.2
:=  22.0:=  20.5:=  13.0:=  18.5:=  20.5:=  20.0:=  25.5:=  31.0
:=  33.2:=  31.7:=  35.2:=  40.2:=  43.5:=  31.2:=  31.0:=  32.0
:=  35.2:=  36.5:=  29.7:=  30.5:=  23.7:=  15.0:=  47.7:=  49.0
MICROPHONE=    9.0
:=  35.0:=  37.7:=  22.5:=  23.0:=  26.7:=  19.5:=  18.2:=  29.7
:=  22.0:=  20.7:=  17.5:=  16.0:=  18.0:=  26.2:=  24.7:=  29.0
:=  33.0:=  33.2:=  37.5:=  40.0:=  44.2:=  31.2:=  32.5:=  31.5
:=  37.7:=  32.5:=  29.7:=  31.0:=  24.7:=  11.5:=  48.2:=  48.5
MICROPHONE=   10.0
:=  28.0:=  28.5:=  20.5:=  24.7:=  27.0:=  20.7:=  16.0:=  23.7
:=  24.5:=  22.7:=  19.2:=  18.2:=  18.2:=  25.7:=  24.0:=  28.2
:=  32.7:=  33.0:=  36.0:=  41.2:=  43.7:=  31.0:=  31.2:=  32.5
:=  34.2:=  34.5:=  31.0:=  27.7:=  23.0:=  13.5:=  48.2:=  48.5
MICROPHONE=   11.0
:=  32.2:=  35.5:=  29.0:=  28.5:=  35.2:=  23.7:=  25.5:=  27.0
:=  34.0:=  27.7:=  22.0:=  32.7:=  29.7:=  33.0:=  28.0:=  35.0
:=  39.2:=  31.0:=  29.2:=  43.2:=  48.0:=  28.2:=  25.0:=  28.7
:=  30.0:=  31.7:=  29.0:=  26.2:=  17.2:=  10.7:=  51.0:=  51.0
MICROPHONE=   12.0
:=  28.5:=  34.2:=  24.2:=  26.0:=  31.5:=  25.2:=  19.7:=  27.5
:=  25.0:=  20.2:=  14.2:=  30.7:=  27.0:=  25.2:=  24.5:=  27.2
:=  29.0:=  29.7:=  30.0:=  43.5:=  48.0:=  28.7:=  28.5:=  30.5
:=  27.2:=  28.0:=  27.0:=  20.7:=  15.2:=  14.5:=  51.0:=  50.5
```

PUMP NOISE DATA

```
MICROPHONE=   13.0
:=   28.0:=  34.0:=  21.0:=  26.5:=  31.7:=  23.7:=  20.5:=  27.7
:=   25.5:=  22.0:=  17.0:=  20.5:=  22.7:=  26.2:=  27.2:=  27.7
:=   28.0:=  28.0:=  29.7:=  41.2:=  41.7:=  27.7:=  29.2:=  30.7
:=   30.0:=  23.5:=  19.5:=  15.2:=  12.2:=  13.0:=  46.7:=  46.7
MICROPHONE=   14.0
:=   34.0:=  37.7:=  21.5:=  28.0:=  36.7:=  24.5:=  20.7:=  24.0
:=   27.0:=  23.7:=  20.7:=  24.5:=  26.0:=  29.5:=  27.5:=  25.5
:=   30.5:=  27.0:=  28.7:=  37.2:=  42.0:=  26.7:=  26.7:=  25.5
:=   28.5:=  29.0:=  25.7:=  25.5:=  19.5:=  11.7:=  45.7:=  46.7
MICROPHONE=   15.0
:=   39.2:=  34.7:=  20.0:=  25.2:=  34.5:=  23.5:=  18.5:=  22.0
:=   30.0:=  27.0:=  15.7:=  20.7:=  20.7:=  27.7:=  28.5:=  27.7
:=   34.0:=  29.2:=  33.5:=  41.0:=  43.0:=  30.2:=  29.7:=  30.7
:=   29.0:=  29.5:=  27.0:=  27.0:=  21.7:=  13.2:=  47.5:=  49.0
MICROPHONE=   16.0
:=   35.5:=  40.0:=  24.5:=  23.0:=  27.7:=  18.7:=  15.7:=  25.0
:=   20.0:=  19.7:=  14.7:=  20.7:=  20.0:=  20.2:=  25.2:=  28.0
:=   33.2:=  30.2:=  33.7:=  42.2:=  43.2:=  31.0:=  31.0:=  30.7
:=   34.0:=  33.2:=  32.5:=  30.2:=  28.0:=  15.7:=  48.0:=  48.2
MICROPHONE=   17.0
:=   37.5:=  37.0:=  20.5:=  26.5:=  35.2:=  22.7:=  18.0:=  23.2
:=   30.2:=  26.2:=  21.0:=  21.5:=  22.2:=  26.5:=  27.7:=  27.0
:=   30.7:=  29.7:=  32.0:=  41.0:=  42.5:=  27.5:=  30.0:=  29.2
:=   30.5:=  30.5:=  29.5:=  27.5:=  22.5:=  12.0:=  46.5:=  47.5
MICROPHONE=   18.0
:=   37.0:=  43.2:=  36.2:=  30.5:=  37.0:=  21.5:=  20.2:=  27.2
:=   25.5:=  23.5:=  21.5:=  20.5:=  21.0:=  27.5:=  25.7:=  27.0
:=   32.0:=  28.7:=  32.2:=  41.0:=  43.2:=  31.0:=  30.2:=  29.0
:=   33.0:=  31.0:=  31.2:=  28.7:=  23.0:=  15.2:=  47.5:=  49.2
MICROPHONE=   19.0
:=   32.7:=  36.0:=  24.0:=  24.0:=  31.7:=  25.2:=  19.7:=  30.2
:=   25.5:=  24.5:=  17.2:=  21.2:=  21.2:=  26.5:=  26.0:=  27.2
:=   29.5:=  31.5:=  34.2:=  41.7:=  41.5:=  31.0:=  31.7:=  32.7
:=   34.2:=  32.0:=  32.0:=  31.0:=  28.0:=  19.5:=  47.7:=  48.0
MICROPHONE=   20.0
:=   35.7:=  32.2:=  25.2:=  28.2:=  34.2:=  24.7:=  22.2:=  24.0
:=   27.2:=  25.7:=  18.2:=  19.0:=  21.0:=  24.7:=  26.0:=  27.5
:=   32.7:=  29.5:=  33.0:=  41.0:=  41.0:=  26.7:=  29.7:=  29.0
:=   29.0:=  31.0:=  30.5:=  30.2:=  29.0:=  19.7:=  46.2:=  47.7


1/3 OCTAVE BAND PWL  DB RE 10:-13 WATT
=   55.4=  58.1=  48.8=  47.5=  53.4=  43.3=  40.5=  46.3
=   47.0=  43.9=  38.5=  44.7=  43.8=  46.7=  46.0=  48.8
=   53.0=  51.5=  54.4=  61.4=  64.6=  49.8=  50.4=  52.3
=   53.2=  53.7=  51.6=  50.3=  47.2=  39.0=  68.5=  68.9

FULL OCTAVE BAND PWL  DB RE 10:-13 WATT
=   60.3=  54.7=  50.2=  47.8=  50.4=  56.2
=   66.6=  55.7=  57.7=  52.2=  68.5=  68.9
*
```

PUMP NOISE DATA (CONCLUDED)

PUMP NOISE DATA

```
TEST UNIT       :SSD PUMP MOTOR
CONDITION       :MOTOR ONLY (ORIGINAL MOTOR)
MIKE RAD (IN):36

MICROPHONE=    0.0 DEG
:=   34.5:=  40.0:=  22.7:=  23.5:=  30.2:=  19.5:=  17.2:=  28.0
:=   18.0:=  27.2:=  16.5:=  12.7:=  24.5:=  17.5:=  39.7:=  30.7
:=   22.7:=  21.2:=  22.0:=  30.0:=  34.5:=  17.5:=  13.2:=  14.0
:=   17.7:=  23.0:=  17.0:=   9.7:=   6.2:=   1.5:=  41.0:=  44.5
MICROPHONE=   22.5 DEG
:=   36.7:=  38.7:=  23.5:=  24.0:=  26.2:=  20.5:=  17.2:=  27.5
:=   17.5:=  28.2:=  15.2:=  11.0:=  25.5:=  19.0:=  41.2:=  31.5
:=   23.5:=  25.5:=  21.5:=  31.2:=  36.2:=  19.5:=  24.2:=  25.2
:=   18.5:=  22.0:=  21.7:=  16.7:=  14.7:=  12.0:=  42.5:=  46.0
MICROPHONE=   45.0 DEG
:=   31.2:=  32.7:=  21.2:=  23.0:=  21.7:=  19.0:=  18.7:=  31.0
:=   17.2:=  25.5:=  13.0:=  10.7:=  21.2:=  13.2:=  28.0:=  18.0
:=   19.7:=  23.5:=  22.0:=  28.0:=  33.0:=  19.7:=  23.2:=  24.0
:=   20.7:=  28.0:=  19.5:=  12.2:=   9.2:=   5.0:=  37.2:=  40.5
MICROPHONE=   67.5 DEG
:=   32.0:=  30.2:=  25.7:=  29.7:=  33.2:=  34.5:=  24.7:=  31.2
:=   20.0:=  26.5:=  17.0:=  11.7:=  17.7:=  11.2:=  25.7:=  16.7
:=   19.7:=  24.0:=  22.5:=  30.5:=  33.5:=  22.2:=  22.7:=  26.7
:=   23.0:=  25.2:=  20.2:=   9.2:=   6.0:=   0.5:=  38.5:=  42.7
MICROPHONE=   90.0 DEG
:=   27.5:=  23.7:=  18.5:=  22.7:=  21.2:=  21.2:=  18.7:=  29.0
:=   17.2:=  29.5:=  20.0:=  11.2:=  15.0:=  10.5:=  23.7:=  17.7
:=   20.2:=  23.2:=  24.2:=  33.2:=  36.0:=  24.2:=  24.0:=  28.0
:=   29.2:=  28.2:=  22.5:=   9.2:=   3.0:=   0.0:=  40.2:=  41.5
MICROPHONE=  112.5 DEG
:=   21.7:=  19.0:=  18.2:=  22.2:=  25.7:=  24.0:=  19.0:=  27.7
:=   17.7:=  30.0:=  19.2:=  12.2:=  27.0:=  14.5:=  22.5:=  18.2
:=   21.0:=  22.5:=  23.2:=  33.0:=  36.7:=  23.5:=  22.0:=  29.2
:=   27.0:=  32.0:=  22.2:=  10.7:=   2.0:=   0.0:=  41.0:=  42.0
MICROPHONE=  135.0 DEG
:=   21.7:=  19.2:=  16.7:=  22.2:=  23.7:=  19.5:=  16.5:=  25.7
:=   17.2:=  30.2:=  17.5:=  12.5:=  30.2:=  16.7:=  23.5:=  19.0
:=   20.7:=  20.5:=  20.2:=  34.2:=  39.5:=  24.7:=  22.7:=  28.5
:=   21.2:=  29.0:=  18.5:=   8.7:=   1.2:=   0.0:=  42.2:=  42.5


1/3 OCTAVE BAND PWL  DB RE 10↑-13 WATT
=   50.1=  50.7=  41.5=  45.1=  47.7=  48.0=  40.3=  49.1
=   38.0=  48.9=  37.9=  31.8=  45.9=  34.7=  51.4=  42.5
=   40.7=  43.1=  42.6=  52.5=  56.7=  43.2=  43.1=  47.7
=   45.4=  48.8=  40.9=  31.1=  27.1=  23.9=  60.6=  62.5

FULL OCTAVE BAND PWL  DB RE 10↑-13 WATT
=   53.7=  51.9=  49.9=  49.3=  52.5=  47.0
=   58.2=  50.0=  50.9=  33.1=  60.6=  62.5
*
```

PUMP NOISE DATA (MOTOR ONLY)

PART III - MODIFIED VERIFICATION HARDWARE TEST DATA

```
FAN NOISE DATA

TEST UNIT     :   SQUIRREL CAGE FAN (DAYTON MOTOR)
CONDITION     :EXHAUST NOISE
MIKE RAD (IN):36

MICROPHONE=   0.0 DEG
:=  44.5:=  39.5:=  36.2:=  48.5:=  56.0:=  58.7:=  51.2:=  62.2
:=  62.7:=  58.7:=  66.0:=  62.2:=  56.2:=  58.5:=  55.7:=  58.2
:=  56.5:=  55.5:=  53.0:=  48.5:=  47.5:=  46.7:=  46.0:=  45.0
:=  44.2:=  43.7:=  42.5:=  38.0:=  32.2:=  24.0:=  65.5:=  71.7
MICROPHONE=  20.0 DEG
:=  47.0:=  39.7:=  38.2:=  49.5:=  56.2:=  58.0:=  49.7:=  60.2
:=  65.2:=  59.7:=  66.0:=  61.7:=  58.7:=  60.0:=  55.7:=  57.5
:=  56.5:=  55.7:=  53.5:=  52.0:=  51.0:=  49.0:=  48.7:=  48.0
:=  46.2:=  46.5:=  46.5:=  43.2:=  38.2:=  32.2:=  66.2:=  72.0
MICROPHONE=  40.0 DEG
:=  46.2:=  41.7:=  38.7:=  48.2:=  54.7:=  57.2:=  48.0:=  58.0
:=  66.5:=  60.0:=  65.5:=  61.2:=  60.7:=  59.2:=  56.2:=  58.2
:=  56.5:=  56.0:=  55.7:=  54.5:=  52.5:=  50.7:=  52.0:=  50.2
:=  49.5:=  49.7:=  49.7:=  46.7:=  42.0:=  34.2:=  67.5:=  72.0
MICROPHONE=  60.0 DEG
:=  45.7:=  41.7:=  39.2:=  48.5:=  53.5:=  57.0:=  48.2:=  55.7
:=  66.0:=  59.5:=  67.0:=  60.7:=  61.0:=  60.7:=  56.7:=  58.0
:=  56.7:=  57.7:=  58.5:=  57.0:=  54.2:=  52.7:=  53.5:=  52.2
:=  51.7:=  52.0:=  52.0:=  48.5:=  44.0:=  35.7:=  68.2:=  72.2
MICROPHONE=  80.0 DEG
:=  61.7:=  59.5:=  54.7:=  55.5:=  55.0:=  57.5:=  50.7:=  55.2
:=  65.2:=  60.0:=  68.5:=  62.0:=  61.0:=  61.7:=  57.2:=  58.5
:=  57.2:=  59.2:=  59.5:=  57.5:=  54.7:=  53.5:=  54.5:=  53.7
:=  54.0:=  54.0:=  54.0:=  50.0:=  45.2:=  37.0:=  68.7:=  75.0
MICROPHONE= 100.0 DEG
:=  76.2:=  73.5:=  70.7:=  67.7:=  69.7:=  65.7:=  62.5:=  61.0
:=  66.5:=  61.2:=  69.2:=  63.5:=  60.5:=  61.2:=  58.5:=  60.0
:=  58.7:=  58.7:=  59.0:=  57.0:=  55.0:=  54.7:=  55.5:=  55.0
:=  54.0:=  54.5:=  55.2:=  51.5:=  46.2:=  40.7:=  69.7:=  83.2
MICROPHONE= 120.0 DEG
:=  54.0:=  50.0:=  44.5:=  47.7:=  49.7:=  53.5:=  49.5:=  57.0
:=  65.7:=  60.7:=  69.0:=  63.7:=  60.5:=  61.2:=  58.2:=  60.7
:=  60.2:=  58.5:=  59.7:=  57.5:=  54.7:=  55.7:=  55.7:=  55.2
:=  53.7:=  53.2:=  54.2:=  49.5:=  44.5:=  35.5:=  69.7:=  74.2
MICROPHONE= 140.0 DEG
:=  47.2:=  44.5:=  39.0:=  47.0:=  49.5:=  53.0:=  49.2:=  57.2
:=  66.0:=  60.2:=  68.0:=  62.0:=  61.0:=  59.7:=  58.2:=  60.2
:=  60.5:=  59.7:=  60.0:=  56.7:=  52.0:=  52.5:=  54.2:=  53.2
:=  52.5:=  52.7:=  52.7:=  49.5:=  44.5:=  35.7:=  69.5:=  73.2
MICROPHONE= 160.0 DEG
:=  48.5:=  45.0:=  38.7:=  47.2:=  49.2:=  54.2:=  48.2:=  56.5
:=  64.7:=  61.0:=  68.5:=  60.2:=  60.0:=  58.7:=  56.5:=  59.0
:=  59.7:=  59.0:=  60.0:=  56.2:=  53.0:=  51.0:=  50.0:=  48.7
:=  49.5:=  49.5:=  48.5:=  44.7:=  39.0:=  31.5:=  68.2:=  72.7
MICROPHONE= 180.0 DEG
:=  47.7:=  45.2:=  39.2:=  47.2:=  49.2:=  55.2:=  49.0:=  54.7
:=  62.7:=  61.2:=  70.2:=  60.2:=  56.7:=  59.2:=  55.0:=  54.5
:=  57.2:=  56.2:=  56.2:=  54.0:=  50.5:=  49.5:=  49.2:=  47.7
:=  45.7:=  45.0:=  43.0:=  39.0:=  34.0:=  30.0:=  67.2:=  72.5
MICROPHONE=  00.0 DEG
:=  42.5:=  39.5:=  39.7:=  51.0:=  55.7:=  58.7:=  49.5:=  55.5
:=  64.2:=  59.7:=  67.2:=  62.5:=  56.2:=  58.0:=  53.7:=  55.5
:=  55.5:=  55.0:=  56.0:=  54.0:=  50.5:=  48.7:=  47.0:=  45.2
:=  46.0:=  44.7:=  43.0:=  39.0:=  34.5:=  31.0:=  65.7:=  71.7
MICROPHONE=  20.0 DEG
:=  42.5:=  39.5:=  40.0:=  50.7:=  54.7:=  57.2:=  47.7:=  53.5
:=  66.5:=  61.0:=  67.0:=  61.5:=  58.5:=  58.5:=  56.5:=  57.7
:=  58.5:=  58.5:=  58.5:=  55.2:=  52.0:=  51.0:=  49.0:=  47.7
:=  48.2:=  47.0:=  47.2:=  44.7:=  39.0:=  32.5:=  67.7:=  72.5
MICROPHONE=  40.0 DEG
:=  42.2:=  39.5:=  40.0:=  50.5:=  53.2:=  56.5:=  48.0:=  54.0
:=  67.5:=  60.5:=  66.5:=  61.5:=  60.5:=  59.7:=  57.0:=  59.5
:=  59.5:=  59.5:=  59.5:=  55.7:=  51.5:=  51.0:=  50.5:=  51.7
:=  53.0:=  51.5:=  52.5:=  48.7:=  42.5:=  34.0:=  68.5:=  72.7
MICROPHONE=  60.0 DEG
:=  45.0:=  42.0:=  41.0:=  50.2:=  53.2:=  56.2:=  49.5:=  54.5
:=  66.5:=  60.0:=  68.2:=  61.2:=  60.7:=  61.0:=  58.0:=  59.7
:=  59.2:=  59.7:=  59.7:=  56.5:=  53.2:=  54.7:=  54.0:=  53.7
:=  53.7:=  53.7:=  54.2:=  49.5:=  43.7:=  35.5:=  69.2:=  73.2
```

SQUIRREL CAGE FAN NOISE DATA

```
MICROPHONE=  80.0 DEG
:=   76.7:=   75.0:=   73.5:=   73.2:=   69.2:=   68.0:=   64.0:=   62.7
:=   66.5:=   62.5:=   69.7:=   63.0:=   61.2:=   61.7:=   58.5:=   59.5
:=   58.7:=   59.2:=   59.7:=   57.0:=   54.0:=   55.0:=   53.7:=   53.2
:=   53.2:=   53.5:=   53.7:=   49.5:=   45.5:=   40.7:=   70.0:=   84.5
MICROPHONE= 100.0 DEG
:=   68.0:=   64.5:=   61.0:=   61.2:=   56.7:=   60.7:=   56.7:=   58.5
:=   66.0:=   61.5:=   69.7:=   63.0:=   60.7:=   61.7:=   58.2:=   59.2
:=   57.5:=   58.7:=   60.5:=   58.0:=   55.0:=   53.7:=   53.7:=   52.7
:=   52.7:=   51.2:=   50.7:=   45.7:=   38.7:=   31.7:=   69.7:=   77.2
MICROPHONE= 120.0 DEG
:=   48.5:=   46.5:=   41.7:=   49.2:=   52.0:=   54.7:=   49.2:=   58.2
:=   66.2:=   60.5:=   68.7:=   62.7:=   61.0:=   61.0:=   57.7:=   59.5
:=   57.7:=   57.5:=   59.5:=   58.7:=   54.7:=   53.0:=   54.7:=   53.0
:=   53.0:=   52.7:=   53.0:=   49.2:=   43.7:=   35.0:=   69.2:=   73.7
MICROPHONE= 140.0 DEG
:=   47.2:=   45.7:=   40.7:=   48.5:=   52.0:=   54.7:=   49.7:=   59.5
:=   65.7:=   60.5:=   68.2:=   62.2:=   61.2:=   60.0:=   58.2:=   60.0
:=   58.0:=   56.2:=   57.2:=   56.5:=   54.5:=   51.5:=   53.2:=   51.2
:=   51.0:=   51.0:=   50.7:=   48.0:=   43.0:=   34.7:=   68.5:=   73.0
MICROPHONE= 160.0 DEG
:=   47.2:=   46.0:=   38.7:=   44.7:=   50.7:=   56.0:=   49.5:=   60.5
:=   64.5:=   60.5:=   69.5:=   61.0:=   59.5:=   59.2:=   57.2:=   59.0
:=   57.7:=   56.7:=   54.7:=   52.5:=   52.5:=   50.2:=   50.0:=   48.5
:=   47.2:=   46.7:=   46.5:=   41.5:=   34.7:=   30.2:=   67.2:=   73.2
MICROPHONE= 180.0 DEG
:=   47.0:=   44.2:=   38.2:=   45.0:=   51.5:=   57.7:=   50.2:=   60.2
:=   62.0:=   60.7:=   70.0:=   61.0:=   57.5:=   57.7:=   56.2:=   59.2
:=   58.2:=   56.2:=   55.2:=   51.2:=   49.7:=   48.2:=   48.0:=   46.2
:=   45.0:=   44.2:=   43.2:=   38.2:=   32.2:=   22.2:=   66.5:=   72.7


1/3 OCTAVE BAND PWL  DB RE 10↑-13 WATT
=   79.0=   76.7=   74.6=   74.2=   73.9=   74.8=   68.9=   75.3
=   82.6=   77.5=   85.1=   78.8=   76.9=   76.8=   74.0=   75.9
=   75.3=   74.8=   75.1=   72.5=   69.7=   68.7=   69.0=   68.0
=   67.6=   67.4=   67.5=   63.8=   58.5=   50.9=   85.1=   91.3

FULL OCTAVE BAND PWL  DB RE 10↑-13 WATT
=   81.9=   79.1=   83.5=   86.6=   80.8=   80.1
=   77.7=   73.3=   72.3=   65.1=   85.1=   91.3
*
```

SQUIRREL CAGE FAN NOISE DATA (CONTINUED)

```
FAN NOISE DATA

TEST UNIT     :SQUIRREL CAGE FAN (DAYTON MOTOR)
CONDITION     :INLET NOISE
MIKE RAD (IN):36


MICROPHONE=   0.0 DEG
:=  56.0:=  53.2:=  40.5:=  49.2:=  50.5:=  59.5:=  54.2:=  58.7
:=  59.2:=  57.2:=  65.5:=  63.2:=  61.2:=  59.5:=  59.0:=  59.0
:=  62.5:=  64.0:=  63.7:=  62.2:=  56.0:=  54.7:=  55.0:=  55.7
:=  54.2:=  52.7:=  53.2:=  50.7:=  46.0:=  39.5:=  71.7:=  74.2
MICROPHONE=  20.0 DEG
:=  56.0:=  52.5:=  40.7:=  48.0:=  50.7:=  57.5:=  52.5:=  56.5
:=  62.0:=  59.0:=  63.7:=  61.5:=  61.0:=  61.2:=  57.5:=  58.5
:=  62.5:=  62.5:=  63.0:=  61.5:=  57.7:=  55.2:=  54.7:=  54.7
:=  53.5:=  53.7:=  54.2:=  52.0:=  48.0:=  40.7:=  71.0:=  73.0
MICROPHONE=  40.0 DEG
:=  55.5:=  53.0:=  39.7:=  48.2:=  51.2:=  55.7:=  49.5:=  55.2
:=  63.2:=  59.7:=  62.2:=  59.7:=  61.7:=  59.7:=  57.7:=  57.7
:=  60.2:=  60.7:=  60.0:=  60.2:=  58.5:=  54.7:=  55.5:=  55.2
:=  54.0:=  54.0:=  53.7:=  50.5:=  45.5:=  37.5:=  70.0:=  72.2
MICROPHONE=  60.0 DEG
:=  54.7:=  53.2:=  39.0:=  52.2:=  53.0:=  55.0:=  48.0:=  56.2
:=  64.2:=  60.2:=  60.7:=  59.5:=  62.0:=  58.5:=  57.2:=  58.0
:=  58.0:=  58.0:=  56.2:=  56.2:=  55.7:=  53.2:=  53.0:=  54.2
:=  52.7:=  53.5:=  53.5:=  50.0:=  45.5:=  37.0:=  68.0:=  71.7
MICROPHONE=  80.0 DEG
:=  52.2:=  50.5:=  38.7:=  54.2:=  53.0:=  54.0:=  48.0:=  56.5
:=  63.0:=  59.2:=  60.0:=  59.0:=  60.2:=  58.7:=  54.5:=  57.2
:=  57.0:=  55.7:=  52.5:=  52.5:=  50.7:=  48.5:=  48.5:=  48.2
:=  47.5:=  46.7:=  46.7:=  43.0:=  38.2:=  29.2:=  65.2:=  70.0
MICROPHONE= 100.0 DEG
:=  49.7:=  48.0:=  39.5:=  54.7:=  53.5:=  53.0:=  48.5:=  56.2
:=  63.0:=  58.5:=  59.2:=  58.5:=  59.5:=  56.2:=  53.2:=  54.7
:=  55.2:=  54.5:=  50.7:=  49.5:=  47.2:=  44.7:=  43.7:=  43.2
:=  42.0:=  40.7:=  40.0:=  36.5:=  30.5:=  23.5:=  63.5:=  69.0
MICROPHONE= 120.0 DEG
:=  51.0:=  48.2:=  40.0:=  56.2:=  52.7:=  52.5:=  47.7:=  54.5
:=  63.0:=  58.2:=  58.2:=  57.5:=  59.2:=  54.7:=  52.7:=  52.5
:=  52.5:=  52.2:=  50.2:=  49.5:=  46.5:=  43.0:=  41.2:=  40.7
:=  39.5:=  37.7:=  36.5:=  32.5:=  27.2:=  21.2:=  62.2:=  69.0
MICROPHONE= 140.0 DEG
:=  51.7:=  48.2:=  39.5:=  55.2:=  51.7:=  52.5:=  46.7:=  51.7
:=  63.0:=  57.7:=  59.2:=  56.5:=  59.2:=  57.2:=  53.0:=  50.0
:=  50.2:=  47.0:=  47.0:=  47.7:=  45.7:=  42.5:=  42.5:=  39.7
:=  38.0:=  36.5:=  34.2:=  30.7:=  26.5:=  21.2:=  61.5:=  68.0
MICROPHONE= 160.0 DEG
:=  52.5:=  46.0:=  38.5:=  54.7:=  51.0:=  55.0:=  47.2:=  50.2
:=  61.0:=  56.2:=  60.5:=  57.0:=  56.2:=  56.7:=  53.5:=  52.0
:=  51.7:=  50.2:=  46.7:=  47.0:=  44.0:=  39.7:=  39.2:=  38.2
:=  36.5:=  35.2:=  33.0:=  29.2:=  24.7:=  20.2:=  61.5:=  67.7
MICROPHONE= 180.0 DEG
:=  52.2:=  46.5:=  38.7:=  55.2:=  51.2:=  57.7:=  49.7:=  50.0
:=  57.2:=  53.5:=  60.7:=  59.5:=  56.2:=  54.2:=  56.0:=  52.0
:=  54.2:=  53.2:=  50.0:=  47.0:=  42.7:=  39.0:=  40.2:=  36.5
:=  34.7:=  33.2:=  32.7:=  28.7:=  24.2:=  20.7:=  62.2:=  67.7


1/3 OCTAVE BAND PWL  DB RE 10↑-13 WATT
=  74.1=  70.9=  59.7=  73.4=  71.7=  76.1=  70.1=  75.0
=  82.2=  78.3=  81.9=  79.7=  80.1=  78.6=  76.2=  76.2
=  78.7=  79.1=  78.7=  77.7=  74.5=  71.7=  71.8=  71.9
=  70.6=  70.5=  70.6=  67.9=  63.5=  56.0=  87.9=  91.0

FULL OCTAVE BAND PWL  DB RE 10↑-13 WATT
=  75.9=  78.9=  83.2=  85.0=  83.3=  82.9
=  82.1=  76.6=  75.4=  69.4=  87.9=  91.0
*
```

SQUIRREL CAGE FAN NOISE DATA (CONCLUDED)

FAN NOISE DATA

```
TEST UNIT     :SQUIRREL CAGE FAN (DAYTON MOTOR)
CONDITION     :MOTOR ONLY
MIKE RAD (IN):36

MICROPHONE=   0.0 DEG
:=   35.5:=   26.2:=   20.5:=   23.5:=   25.7:=   18.5:=   24.2:=   36.2
:=   16.2:=   15.0:=   17.2:=   26.0:=   29.5:=   21.0:=   23.7:=   26.5
:=   19.7:=   20.2:=   20.0:=   26.0:=   30.0:=   23.5:=   34.2:=   28.7
:=   32.5:=   17.5:=   11.5:=   11.0:=    7.7:=    3.0:=   39.2:=   43.2
MICROPHONE=  20.0 DEG
:=   35.0:=   29.2:=   19.0:=   22.5:=   24.0:=   17.2:=   23.7:=   36.2
:=   17.0:=   17.0:=   17.5:=   32.2:=   36.5:=   22.2:=   22.2:=   23.0
:=   18.7:=   20.2:=   19.2:=   25.7:=   27.7:=   23.7:=   30.7:=   26.5
:=   19.7:=   18.5:=   13.5:=   11.5:=    8.5:=    3.5:=   38.0:=   43.5
MICROPHONE=  40.0 DEG
:=   35.5:=   31.0:=   19.0:=   24.7:=   28.2:=   17.2:=   23.5:=   35.7
:=   18.0:=   18.5:=   19.0:=   36.0:=   40.5:=   24.7:=   23.2:=   20.0
:=   18.0:=   20.0:=   18.5:=   22.0:=   34.5:=   26.0:=   32.7:=   31.7
:=   19.7:=   15.5:=   12.7:=   11.0:=    8.0:=    3.5:=   41.0:=   45.2
MICROPHONE=  60.0 DEG
:=   32.0:=   30.2:=   20.5:=   25.5:=   32.5:=   19.7:=   22.5:=   34.5
:=   19.2:=   20.2:=   21.7:=   36.5:=   40.5:=   27.7:=   23.2:=   21.2
:=   18.5:=   20.7:=   23.0:=   29.2:=   31.2:=   24.7:=   33.7:=   32.2
:=   19.7:=   18.0:=   14.2:=   13.2:=    9.2:=    3.5:=   41.2:=   45.2
MICROPHONE=  80.0 DEG
:=   31.0:=   32.5:=   22.2:=   27.0:=   33.5:=   19.0:=   21.7:=   33.7
:=   19.2:=   19.7:=   21.5:=   35.0:=   38.7:=   27.0:=   24.0:=   23.0
:=   18.5:=   21.0:=   23.7:=   28.5:=   35.7:=   25.0:=   33.5:=   28.5
:=   21.0:=   18.7:=   15.5:=   12.7:=    9.0:=    3.5:=   41.5:=   45.0
MICROPHONE= 100.0 DEG
:=   27.0:=   31.5:=   21.5:=   28.0:=   33.2:=   17.0:=   18.5:=   29.7
:=   18.0:=   19.5:=   21.2:=   35.2:=   39.2:=   26.5:=   26.0:=   27.2
:=   18.2:=   19.0:=   23.7:=   29.0:=   32.5:=   22.7:=   29.5:=   27.7
:=   18.5:=   16.0:=   16.5:=   14.0:=    8.7:=    4.0:=   40.2:=   43.7
MICROPHONE= 120.0 DEG
:=   29.5:=   32.7:=   22.5:=   25.0:=   29.5:=   16.5:=   19.0:=   29.7
:=   18.5:=   19.0:=   19.0:=   34.7:=   38.5:=   24.5:=   25.7:=   28.0
:=   17.0:=   20.0:=   21.5:=   29.5:=   32.5:=   23.0:=   36.0:=   31.5
:=   18.0:=   18.5:=   18.0:=   14.7:=   10.2:=    4.5:=   41.7:=   44.2
MICROPHONE= 140.0 DEG
:=   32.0:=   31.2:=   24.0:=   30.7:=   25.5:=   17.7:=   21.0:=   32.7
:=   17.0:=   16.7:=   18.5:=   32.7:=   36.0:=   22.5:=   25.5:=   28.5
:=   17.0:=   21.0:=   21.5:=   23.7:=   29.7:=   21.5:=   34.0:=   29.0
:=   20.0:=   20.7:=   21.7:=   16.0:=   11.0:=    6.5:=   39.2:=   42.7
MICROPHONE= 160.0 DEG
:=   33.2:=   31.7:=   21.0:=   21.5:=   23.5:=   17.0:=   22.7:=   34.0
:=   16.2:=   15.5:=   20.7:=   28.7:=   32.2:=   21.5:=   25.5:=   28.2
:=   19.0:=   18.7:=   21.5:=   24.5:=   31.0:=   22.0:=   33.5:=   29.0
:=   22.0:=   20.0:=   21.2:=   16.2:=   11.7:=    6.5:=   39.0:=   42.2
MICROPHONE= 180.0 DEG
:=   33.5:=   32.2:=   23.0:=   27.2:=   29.5:=   19.5:=   24.0:=   35.5
:=   18.0:=   17.5:=   21.5:=   30.2:=   33.5:=   21.0:=   26.0:=   28.7
:=   20.0:=   20.2:=   21.7:=   24.5:=   32.0:=   24.0:=   32.2:=   28.5
:=   20.5:=   20.0:=   19.0:=   16.2:=   12.7:=    6.2:=   39.5:=   43.0


1/3 OCTAVE BAND PWL  DB RE 10:-13 WATT
=  53.7=  51.0=  41.5=  46.1=  48.4=  37.9=  42.8=  54.7
=  37.6=  37.8=  39.8=  53.4=  57.4=  43.9=  44.6=  46.5
=  38.6=  40.2=  41.2=  46.2=  51.7=  43.8=  53.4=  49.8
=  44.0=  38.9=  38.2=  34.3=  30.2=  25.0=  60.0=  63.8

FULL OCTAVE BAND PWL  DB RE 10:-13 WATT
=  55.7=  50.7=  55.1=  53.7=  57.8=  47.9
=  53.1=  55.3=  46.0=  36.1=  60.0=  63.8
*
```

SQUIRREL CAGE FAN NOISE DATA (MOTOR ONLY)

```
FAN NOISE DATA

TEST UNIT     :AXIAL FAN (MODIFIED)
CONDITION     :INLET NOISE
MIKE RAD (IN):36


MICROPHONE=    0.0 DEG
:=   57.7:=   58.7:=   52.0:=   59.7:=   55.0:=   52.2:=   47.0:=   48.2
:=   50.7:=   50.7:=   54.2:=   58.0:=   62.5:=   64.7:=   67.0:=   68.0
:=   68.5:=   66.5:=   67.0:=   67.0:=   66.5:=   63.2:=   61.5:=   66.5
:=   60.0:=   59.7:=   55.7:=   54.2:=   50.0:=   40.2:=   77.0:=   77.2
MICROPHONE=   20.0 DEG
:=   58.0:=   59.2:=   52.7:=   59.7:=   54.2:=   50.5:=   45.5:=   47.2
:=   52.7:=   52.7:=   54.2:=   56.5:=   63.2:=   66.5:=   65.7:=   68.2
:=   68.2:=   65.7:=   67.0:=   66.7:=   66.5:=   63.7:=   62.0:=   63.0
:=   60.7:=   58.7:=   55.2:=   54.0:=   50.0:=   40.7:=   76.5:=   76.5
MICROPHONE=   40.0 DEG
:=   58.2:=   59.0:=   51.2:=   60.2:=   54.5:=   52.2:=   45.2:=   49.0
:=   54.7:=   52.7:=   54.0:=   56.0:=   64.7:=   65.7:=   65.2:=   67.2
:=   67.0:=   64.5:=   66.0:=   65.2:=   64.5:=   62.7:=   60.5:=   59.0
:=   57.0:=   55.7:=   54.7:=   52.5:=   49.0:=   41.0:=   75.2:=   76.0
MICROPHONE=   60.0 DEG
:=   56.5:=   57.2:=   50.0:=   59.7:=   55.7:=   53.5:=   45.5:=   51.0
:=   55.7:=   50.5:=   53.0:=   55.5:=   64.2:=   62.5:=   63.7:=   66.0
:=   65.2:=   62.0:=   65.0:=   61.5:=   61.0:=   58.7:=   56.7:=   55.5
:=   54.2:=   53.2:=   52.2:=   50.5:=   47.0:=   40.0:=   73.5:=   74.5
MICROPHONE=   80.0 DEG
:=   56.2:=   56.7:=   47.7:=   59.7:=   56.2:=   55.2:=   46.7:=   52.0
:=   55.7:=   50.2:=   53.5:=   55.0:=   62.5:=   61.7:=   61.0:=   63.5
:=   61.5:=   59.7:=   62.2:=   59.0:=   56.2:=   55.0:=   52.0:=   52.5
:=   48.7:=   47.2:=   46.2:=   43.5:=   38.0:=   32.0:=   70.0:=   72.0
MICROPHONE=  100.0 DEG
:=   55.7:=   53.5:=   46.2:=   60.7:=   57.0:=   56.7:=   47.0:=   52.2
:=   55.7:=   52.0:=   54.7:=   54.7:=   62.0:=   61.0:=   61.2:=   61.7
:=   60.0:=   57.5:=   60.5:=   57.5:=   54.5:=   52.0:=   49.0:=   50.7
:=   46.2:=   43.0:=   39.7:=   38.5:=   34.7:=   30.7:=   68.5:=   71.0
MICROPHONE=  120.0 DEG
:=   52.0:=   48.5:=   45.7:=   61.7:=   59.0:=   58.5:=   48.7:=   51.5
:=   56.0:=   56.2:=   56.2:=   53.2:=   61.7:=   61.0:=   60.5:=   60.5
:=   57.5:=   54.0:=   55.0:=   53.5:=   52.5:=   51.5:=   47.0:=   47.2
:=   44.7:=   39.2:=   36.2:=   34.0:=   30.0:=   24.7:=   66.7:=   70.5
MICROPHONE=  140.0 DEG
:=   51.0:=   47.0:=   46.5:=   61.7:=   59.0:=   58.7:=   51.5:=   53.0
:=   57.5:=   57.0:=   54.7:=   55.0:=   60.0:=   62.2:=   60.5:=   60.7
:=   59.2:=   55.0:=   56.0:=   50.7:=   48.0:=   46.7:=   44.5:=   45.0
:=   40.2:=   39.0:=   36.2:=   33.2:=   28.2:=   23.0:=   67.0:=   70.7
MICROPHONE=  160.0 DEG
:=   50.5:=   45.5:=   46.7:=   62.7:=   59.5:=   60.2:=   52.5:=   54.5
:=   56.2:=   55.5:=   55.2:=   56.7:=   59.5:=   62.2:=   61.5:=   61.7
:=   60.5:=   57.5:=   59.0:=   54.5:=   52.0:=   48.5:=   42.7:=   39.5
:=   36.7:=   35.5:=   32.7:=   31.0:=   26.0:=   21.0:=   68.0:=   71.5
MICROPHONE=  180.0 DEG
:=   50.0:=   45.0:=   48.0:=   63.0:=   60.2:=   59.5:=   53.7:=   55.0
:=   57.0:=   54.5:=   55.5:=   57.0:=   60.0:=   61.0:=   63.2:=   61.7
:=   61.7:=   58.2:=   58.5:=   54.0:=   51.5:=   47.5:=   41.2:=   39.7
:=   37.0:=   35.5:=   33.0:=   30.7:=   26.7:=   21.0:=   68.2:=   71.2


1/3 OCTAVE BAND PWL   DB RE 10↑-13 WATT
=  75.6=  76.0=  69.9=  81.3=  77.7=  77.1=  69.8=  72.0
=  75.6=  74.3=  74.7=  76.2=  82.4=  83.9=  83.9=  85.4
=  85.1=  82.5=  83.9=  82.8=  82.3=  79.7=  77.8=  79.4
=  75.8=  74.4=  71.6=  70.0=  66.1=  57.5=  93.3=  94.3

FULL OCTAVE BAND PWL   DB RE 10↑-13 WATT
=  79.4=  83.9=  77.9=  79.9=  88.2=  89.3
=  87.8=  83.8=  79.0=  71.7=  93.3=  94.3
*
```

AXIAL FAN NOISE DATA

```
FAN NOISE DATA

TEST UNIT     : AXIAL FAN (MODIFIED)
CONDITION     : OUTLET NOISE
MIKE RAD (IN):36


MICROPHONE=   0.0 DEG
:=  75.0:=  70.2:=  64.0:=  58.5:=  56.5:=  51.7:=  52.0:=  52.2
:=  55.2:=  54.7:=  54.5:=  58.0:=  68.5:=  74.5:=  72.7:=  71.0
:=  71.0:=  70.7:=  72.0:=  69.0:=  67.5:=  63.5:=  62.2:=  59.7
:=  59.0:=  57.0:=  53.2:=  50.7:=  47.7:=  41.2:=  80.0:=  83.5
MICROPHONE=  20.0 DEG
:=  74.2:=  70.5:=  63.7:=  59.2:=  56.0:=  52.0:=  51.5:=  52.2
:=  55.0:=  54.7:=  54.7:=  58.0:=  68.7:=  74.0:=  73.0:=  70.7
:=  71.0:=  70.7:=  71.7:=  69.0:=  67.2:=  63.2:=  62.2:=  59.7
:=  58.7:=  57.0:=  53.0:=  51.0:=  47.5:=  41.5:=  79.7:=  83.5
MICROPHONE=  40.0 DEG
:=  56.2:=  54.2:=  49.7:=  52.7:=  53.2:=  48.0:=  48.7:=  52.7
:=  55.7:=  54.0:=  54.2:=  57.2:=  67.0:=  72.5:=  71.5:=  70.2
:=  70.0:=  68.7:=  71.2:=  69.7:=  69.0:=  65.5:=  63.2:=  61.2
:=  58.5:=  57.7:=  54.5:=  53.2:=  49.0:=  42.5:=  80.0:=  80.7
MICROPHONE=  60.0 DEG
:=  52.2:=  51.2:=  47.0:=  52.2:=  53.2:=  48.7:=  49.2:=  53.5
:=  56.7:=  54.0:=  56.7:=  57.5:=  66.0:=  72.0:=  69.7:=  70.0
:=  68.5:=  67.0:=  69.0:=  67.0:=  65.7:=  63.0:=  61.5:=  59.2
:=  57.2:=  56.5:=  54.5:=  53.2:=  47.7:=  39.7:=  78.0:=  78.5
MICROPHONE=  80.0 DEG
:=  51.2:=  51.2:=  46.5:=  52.2:=  52.5:=  49.5:=  48.7:=  53.2
:=  57.0:=  54.7:=  57.2:=  58.7:=  65.0:=  71.2:=  67.0:=  68.0
:=  65.7:=  64.5:=  66.5:=  64.0:=  61.5:=  58.5:=  56.7:=  54.2
:=  51.7:=  50.7:=  47.7:=  47.7:=  42.2:=  36.0:=  75.2:=  76.2
MICROPHONE= 100.0 DEG
:=  50.5:=  50.0:=  46.5:=  52.5:=  52.7:=  50.0:=  49.0:=  53.0
:=  57.7:=  55.2:=  57.5:=  58.5:=  65.0:=  69.7:=  64.7:=  66.0
:=  63.2:=  61.5:=  64.0:=  62.0:=  58.7:=  54.7:=  53.2:=  49.7
:=  47.5:=  45.7:=  42.5:=  40.5:=  36.5:=  32.2:=  73.2:=  75.2
MICROPHONE= 120.0 DEG
:=  49.2:=  47.7:=  45.2:=  53.7:=  52.2:=  51.7:=  48.5:=  53.0
:=  58.2:=  55.7:=  56.7:=  58.0:=  65.0:=  69.2:=  65.0:=  65.0
:=  61.2:=  58.0:=  60.0:=  58.7:=  56.7:=  54.0:=  51.0:=  47.2
:=  44.2:=  42.0:=  41.0:=  41.0:=  34.5:=  31.0:=  71.5:=  73.7
MICROPHONE= 140.0 DEG
:=  48.0:=  45.7:=  45.0:=  54.5:=  52.0:=  52.5:=  48.7:=  51.7
:=  57.5:=  55.2:=  56.2:=  58.7:=  64.0:=  69.0:=  65.7:=  63.2
:=  61.5:=  57.7:=  59.0:=  55.5:=  52.2:=  49.7:=  49.0:=  45.2
:=  43.0:=  40.7:=  38.7:=  37.0:=  32.7:=  30.0:=  70.7:=  73.5
MICROPHONE= 160.0 DEG
:=  47.2:=  44.7:=  44.2:=  53.7:=  52.2:=  54.5:=  47.7:=  49.7
:=  56.7:=  52.7:=  55.0:=  60.2:=  63.7:=  71.7:=  66.2:=  65.2
:=  63.5:=  60.7:=  62.7:=  58.7:=  54.5:=  50.5:=  47.0:=  43.5
:=  42.2:=  40.2:=  37.5:=  36.0:=  32.2:=  30.0:=  73.0:=  75.2
MICROPHONE= 180.0 DEG
:=  49.5:=  48.7:=  46.2:=  55.0:=  52.2:=  54.2:=  47.7:=  49.2
:=  57.0:=  51.5:=  54.5:=  61.7:=  63.0:=  70.7:=  67.2:=  65.2
:=  62.5:=  61.0:=  61.2:=  58.5:=  55.2:=  51.7:=  47.0:=  44.5
:=  41.5:=  37.0:=  34.5:=  34.0:=  31.7:=  30.0:=  72.5:=  75.0


1/3 OCTAVE BAND PWL   DB RE 10:-13 WATT
=  88.6=  84.5=  78.1=  75.7=  73.8=  72.2=  69.6=  72.0
=  76.6=  74.3=  75.5=  78.9=  86.3=  92.1=  89.9=  88.5
=  87.9=  87.0=  88.5=  86.2=  84.7=  81.1=  79.4=  77.1
=  75.4=  74.1=  70.8=  69.2=  65.0=  58.7=  97.2=  99.7

FULL OCTAVE BAND PWL   DB RE 10:-13 WATT
=  90.3=  78.9=  78.5=  81.5=  94.8=  92.6
=  91.5=  84.3=  78.6=  70.8=  97.2=  99.7
*
```

AXIAL FAN NOISE DATA (CONCLUDED)

MICROPUMP NOISE DATA

```
NO. OF TEST POINTS:20
MIKE RADIUS (IN)   :36
TEST CONDITION     :26 PSI INLET


MICROPHONE=    1.0
:=  19.0:=  19.7:=  21.2:=  35.5:=  43.7:=  23.7:=  23.5:=  29.5
:=  31.5:=  26.0:=  19.7:=  16.7:=  18.5:=  28.2:=  24.7:=  23.0
:=  26.2:=  24.0:=  18.5:=  24.7:=  21.5:=  17.2:=  23.2:=  22.2
:=  18.2:=  15.2:=  14.0:=  12.0:=   9.0:=   3.2
MICROPHONE=    2.0
:=  21.0:=  27.5:=  26.2:=  36.0:=  44.0:=  22.7:=  23.0:=  28.5
:=  31.5:=  24.5:=  17.0:=  15.2:=  16.7:=  22.5:=  18.7:=  18.2
:=  23.7:=  17.7:=  15.2:=  28.5:=  22.0:=  19.2:=  25.2:=  21.0
:=  19.2:=  13.2:=  14.5:=  10.7:=   8.5:=   3.7
MICROPHONE=    3.0
:=  22.0:=  22.5:=  18.5:=  34.7:=  43.0:=  23.2:=  24.2:=  29.7
:=  31.0:=  30.2:=  19.5:=  16.5:=  18.5:=  25.2:=  23.7:=  26.7
:=  28.0:=  20.2:=  15.5:=  23.0:=  20.7:=  18.0:=  19.7:=  22.0
:=  18.7:=  20.5:=  18.2:=  13.2:=   9.2:=   5.2
MICROPHONE=    4.0
:=  19.2:=  28.0:=  19.7:=  35.2:=  43.0:=  24.7:=  22.7:=  28.2
:=  34.0:=  33.2:=  20.0:=  17.2:=  18.7:=  30.2:=  22.2:=  23.0
:=  30.0:=  21.5:=  14.5:=  27.5:=  23.7:=  18.5:=  28.0:=  15.7
:=  17.5:=  13.2:=  13.0:=  11.5:=   9.7:=   5.2
MICROPHONE=    5.0
:=  21.0:=  24.0:=  18.2:=  34.7:=  43.2:=  20.5:=  21.5:=  28.2
:=  28.7:=  25.5:=  16.7:=  14.7:=  19.2:=  21.7:=  22.5:=  22.5
:=  28.0:=  24.5:=  16.5:=  28.0:=  22.7:=  13.5:=  15.0:=  11.2
:=  15.0:=   8.5:=   9.5:=   7.5:=   7.7:=   4.0
MICROPHONE=    6.0
:=  13.0:=  17.2:=  17.5:=  34.5:=  43.0:=  20.5:=  20.2:=  27.7
:=  30.0:=  23.5:=  16.2:=  15.2:=  16.7:=  26.2:=  23.5:=  22.0
:=  21.5:=  20.2:=  17.0:=  25.5:=  26.7:=  15.2:=  20.7:=  17.5
:=  12.5:=   8.5:=   9.2:=   7.7:=   7.0:=   3.2
MICROPHONE=    7.0
:=  20.7:=  25.7:=  17.7:=  35.0:=  43.2:=  24.5:=  25.2:=  30.7
:=  33.0:=  29.7:=  20.7:=  17.0:=  19.0:=  34.2:=  29.0:=  27.0
:=  32.2:=  26.2:=  27.5:=  35.2:=  32.0:=  25.0:=  26.2:=  21.5
:=  18.5:=  15.7:=  14.5:=   9.5:=   8.0:=   3.7
MICROPHONE=    8.0
:=  21.0:=  28.5:=  24.5:=  44.2:=  52.7:=  30.2:=  31.7:=  33.0
:=  38.0:=  33.7:=  24.2:=  24.5:=  23.2:=  31.0:=  28.0:=  28.0
:=  29.2:=  26.7:=  26.2:=  38.0:=  32.5:=  29.7:=  34.7:=  25.5
:=  22.0:=  18.0:=  16.0:=  12.2:=  10.7:=   8.0
MICROPHONE=    9.0
:=  19.5:=  24.0:=  16.2:=  28.5:=  35.0:=  23.0:=  27.5:=  31.0
:=  29.0:=  23.5:=  18.5:=  19.0:=  18.7:=  20.2:=  17.5:=  16.7
:=  22.7:=  22.7:=  14.7:=  25.5:=  19.2:=  13.7:=  16.5:=  12.5
:=  12.7:=  12.5:=   9.5:=   8.2:=   9.2:=   4.5
MICROPHONE=   10.0
:=  12.0:=  17.7:=  16.7:=  34.2:=  43.0:=  22.2:=  23.2:=  30.0
:=  25.0:=  17.5:=  18.5:=  19.0:=  17.7:=  23.0:=  15.7:=  19.5
:=  30.0:=  22.5:=  14.0:=  26.5:=  18.5:=  12.5:=  17.7:=  14.7
:=  17.2:=  13.2:=  10.2:=   9.0:=   9.5:=   5.2
MICROPHONE=   11.0
:=  19.7:=  28.7:=  17.5:=  34.2:=  43.0:=  22.7:=  22.5:=  27.5
:=  27.5:=  17.5:=  19.7:=  13.5:=  16.2:=  25.2:=  21.7:=  21.0
:=  20.2:=  19.2:=  17.7:=  30.2:=  19.7:=  15.7:=  19.2:=  18.7
:=  16.0:=  10.2:=  10.5:=  10.7:=  10.0:=   6.0
MICROPHONE=   12.0
:=  15.5:=  22.0:=  19.0:=  34.7:=  42.7:=  21.0:=  21.2:=  25.7
:=  28.5:=  19.0:=  17.7:=  15.7:=  16.2:=  23.0:=  25.5:=  19.5
:=  24.0:=  22.2:=  23.5:=  36.0:=  26.0:=  21.5:=  21.5:=  17.2
:=  14.0:=   9.5:=   9.5:=   9.0:=   9.2:=   6.0
MICROPHONE=   13.0
:=  20.7:=  20.5:=  22.0:=  34.2:=  42.7:=  24.0:=  25.5:=  29.7
:=  31.0:=  26.2:=  21.0:=  28.5:=  29.0:=  17.5:=  19.5:=  23.0
:=  26.0:=  23.0:=  19.2:=  28.2:=  25.2:=  21.7:=  23.7:=  16.0
:=  23.2:=  14.2:=  14.2:=  10.5:=   8.2:=   4.5
MICROPHONE=   14.0
:=  20.0:=  28.2:=  19.7:=  34.5:=  42.7:=  22.7:=  22.7:=  28.5
:=  24.0:=  23.5:=  22.2:=  25.0:=  27.0:=  24.0:=  21.2:=  22.0
:=  23.2:=  20.2:=  18.7:=  25.0:=  24.2:=  20.5:=  23.0:=  17.2
:=  17.0:=  12.7:=  13.5:=   9.7:=   8.5:=   4.7
MICROPHONE=   15.0
:=  20.0:=  21.7:=  16.5:=  33.7:=  42.7:=  24.0:=  23.7:=  29.2
:=  33.5:=  33.0:=  18.0:=  24.2:=  25.5:=  27.0:=  24.5:=  26.0
:=  21.7:=  25.5:=  28.5:=  28.7:=  25.7:=  21.0:=  24.0:=  21.5
:=  24.5:=  15.0:=  14.0:=  11.0:=   9.0:=   6.2
```

MICROPUMP NOISE DATA

```
MICROPHONE=   19.Ø
:=   18.2:=   22.7:=   18.2:=   34.2:=   43.Ø:=   25.7:=   25.5:=   28.5
:=   45.5:=   38.Ø:=   2Ø.7:=   26.5:=   22.5:=   31.Ø:=   29.2:=   27.5
:=   29.2:=   27.Ø:=   22.Ø:=   32.2:=   26.Ø:=   16.7:=   25.Ø:=   2Ø.2
:=   23.5:=   13.Ø:=   15.Ø:=    9.7:=    8.Ø:=    4.7
MICROPHONE=   2Ø.Ø
:=   17.2:=   25.Ø:=   19.Ø:=   35.Ø:=   43.Ø:=   22.5:=   21.7:=   26.5
:=   34.Ø:=   29.7:=   15.5:=   17.2:=   16.7:=   22.2:=   19.5:=   2Ø.7
:=   32.7:=   28.2:=   27.5:=   36.Ø:=   28.5:=   21.2:=   24.5:=   19.7
:=   24.7:=   13.2:=   13.5:=   1Ø.Ø:=    8.7:=    5.5

1/3 OCTAVE BAND PWL  DB RE 1Ø↑-13 WATT
=  39.2=  44.8=  4Ø.2=  56.Ø=  64.4=  43.8=  44.6=  49.2
=  55.Ø=  49.8=  39.5=  41.8=  42.2=  47.2=  44.Ø=  43.6
=  47.9=  44.2=  42.9=  51.6=  46.3=  41.4=  45.8=  39.7
=  4Ø.8=  34.4=  33.7=  3Ø.6=  28.9=  25.1
FULL OCTAVE BAND PWL  DB RE 1Ø↑-13 WATT
=  46.9=  65.1=  56.3=  5Ø.8=  49.7=  5Ø.5
=  53.2=  47.8=  42.3=  33.5
71Ø AT  Ø.ØØ
*
MICROPHONE=   16.Ø
:=   16.7:=   23.2:=   19.Ø:=   34.5:=   42.7:=   22.2:=   23.Ø:=   28.5
:=   23.7:=   19.2:=   18.7:=   24.2:=   25.2:=   25.7:=   24.5:=   22.5
:=   26.7:=   26.7:=   22.5:=   3Ø.5:=   27.Ø:=   24.Ø:=   29.7:=   18.7
:=   18.5:=   15.Ø:=   16.Ø:=   14.5:=    9.7:=    5.Ø
MICROPHONE=   17.Ø
:=   18.2:=   23.5:=   19.2:=   34.2:=   42.7:=   2Ø.5:=   21.5:=   28.Ø
:=   24.7:=   24.Ø:=   16.Ø:=   19.5:=   21.Ø:=   21.Ø:=   18.5:=   21.Ø
:=   3Ø.Ø:=   25.7:=   25.5:=   33.Ø:=   27.Ø:=   18.7:=   16.7:=   16.Ø
:=   24.7:=   12.Ø:=   1Ø.7:=    8.7:=    8.2:=    5.2
MICROPHONE=   18.Ø
:=   13.2:=   17.5:=   19.5:=   34.Ø:=   43.Ø:=   2Ø.5:=   2Ø.7:=   27.5
:=   28.5:=   28.Ø:=   15.Ø:=   18.7:=   18.Ø:=   16.7:=   16.7:=   19.2
:=   24.5:=   21.2:=   23.Ø:=   24.2:=   2Ø.7:=   16.Ø:=   2Ø.5:=   18.2
:=   23.7:=   12.5:=   12.5:=    7.5:=    7.7:=    4.2
```

MICROPUMP NOISE DATA (CONTINUED)

```
PUMP NOISE DATA

TEST UNIT      :MODIFIED MICROPUMP  (INLET PRESSURE STUDY)
CONDITION      : 26 PSI INLET
MIKE RAD (IN):36

MICROPHONE=   0.0 DEG
:=  31.0:=  35.2:=  32.5:=  35.5:=  40.5:=  29.7:=  26.2:=  27.0
:=  28.5:=  31.5:=  22.7:=  21.7:=  21.7:=  29.0:=  26.0:=  34.2
:=  36.5:=  37.5:=  29.5:=  26.5:=  25.0:=  23.7:=  28.5:=  18.5
:=  18.0:=  14.5:=  15.2:=  11.5:=   9.7:=   6.0:=  47.7:=  47.2
MICROPHONE=  20.0 DEG
:=  27.2:=  33.7:=  20.5:=  32.5:=  39.5:=  27.7:=  25.0:=  26.5
:=  25.7:=  28.0:=  22.2:=  24.5:=  28.7:=  25.0:=  23.0:=  28.2
:=  30.7:=  36.5:=  28.7:=  30.7:=  33.0:=  25.7:=  27.5:=  22.0
:=  22.2:=  14.7:=  13.5:=   9.5:=   8.5:=   6.7:=  46.7:=  46.2
MICROPHONE=  40.0 DEG
:=  27.2:=  35.5:=  20.7:=  32.0:=  38.5:=  21.7:=  22.0:=  27.2
:=  23.5:=  25.5:=  20.0:=  25.5:=  29.5:=  25.5:=  26.7:=  31.5
:=  27.5:=  31.5:=  24.0:=  37.5:=  37.5:=  33.2:=  31.2:=  24.7
:=  21.5:=  17.5:=  16.5:=  11.2:=   8.5:=   6.0:=  49.0:=  48.0
MICROPHONE=  60.0 DEG
:=  23.7:=  31.5:=  18.5:=  29.2:=  35.2:=  19.2:=  20.5:=  28.2
:=  22.7:=  24.2:=  20.5:=  24.0:=  28.2:=  26.2:=  23.5:=  27.0
:=  23.2:=  26.5:=  20.2:=  27.0:=  29.2:=  26.5:=  28.0:=  25.0
:=  21.5:=  15.7:=  16.0:=  12.0:=   7.7:=   2.5:=  42.5:=  42.2
MICROPHONE=  80.0 DEG
:=  24.7:=  33.0:=  18.5:=  27.7:=  32.5:=  19.2:=  20.5:=  29.0
:=  24.0:=  25.7:=  19.0:=  18.2:=  21.5:=  23.2:=  23.5:=  28.2
:=  31.5:=  28.0:=  20.5:=  25.0:=  29.7:=  25.2:=  20.5:=  18.0
:=  17.5:=  12.7:=  13.7:=  11.2:=   8.0:=   3.2:=  43.0:=  42.5
MICROPHONE= 100.0 DEG
:=  23.0:=  29.7:=  21.5:=  27.5:=  30.5:=  19.0:=  21.5:=  30.7
:=  23.0:=  24.0:=  17.0:=  19.7:=  24.2:=  23.5:=  20.0:=  25.2
:=  26.0:=  26.7:=  24.0:=  30.2:=  29.2:=  26.2:=  22.7:=  21.0
:=  16.5:=  13.2:=  13.7:=  11.0:=   7.2:=   1.7:=  42.5:=  42.0
MICROPHONE= 120.0 DEG
:=  18.7:=  26.0:=  19.2:=  27.0:=  32.2:=  19.5:=  21.7:=  31.5
:=  23.7:=  26.2:=  18.0:=  20.2:=  24.7:=  19.2:=  20.2:=  30.5
:=  27.7:=  28.5:=  28.0:=  34.5:=  33.0:=  28.7:=  22.5:=  18.2
:=  14.2:=   9.2:=   8.5:=   6.0:=   4.5:=- 0.3:=  46.2:=  45.2
MICROPHONE= 140.0 DEG
:=  16.7:=  22.2:=  17.7:=  27.0:=  33.0:=  19.2:=  21.2:=  31.2
:=  21.5:=  21.5:=  20.2:=  21.0:=  24.7:=  17.7:=  21.0:=  28.0
:=  24.2:=  30.5:=  23.5:=  26.5:=  29.5:=  22.5:=  27.7:=  14.0
:=  13.5:=   9.5:=   8.2:=   6.5:=   5.0:=   0.5:=  42.5:=  41.7
MICROPHONE= 160.0 DEG
:=  17.5:=  15.5:=  17.0:=  26.7:=  33.0:=  21.0:=  21.5:=  30.5
:=  21.2:=  21.2:=  21.5:=  21.5:=  26.0:=  22.0:=  20.2:=  23.7
:=  21.7:=  32.2:=  25.7:=  27.5:=  31.5:=  27.5:=  28.5:=  15.0
:=  13.2:=   9.0:=   8.2:=   6.5:=   5.2:=   0.0:=  44.2:=  43.7
MICROPHONE= 180.0 DEG
:=  16.7:=  19.7:=  18.7:=  27.5:=  33.5:=  22.5:=  22.2:=  30.2
:=  23.2:=  24.5:=  21.0:=  24.2:=  28.7:=  16.7:=  16.5:=  29.0
:=  28.0:=  27.0:=  28.7:=  30.5:=  32.2:=  28.7:=  25.2:=  15.5
:=  12.5:=   8.7:=   8.2:=   6.0:=   5.7:=   0.5:=  44.5:=  43.7


1/3 OCTAVE BAND PWL   DB RE 10↑-13 WATT
=  43.8=  51.4=  40.2=  49.0=  54.8=  41.2=  41.7=  49.9
=  43.4=  45.1=  39.7=  42.1=  46.3=  43.7=  42.9=  48.6
=  48.1=  50.3=  44.9=  51.9=  52.3=  48.0=  46.7=  41.4
=  38.6=  33.7=  33.6=  30.2=  27.1=  23.0=  65.0=  64.2

FULL OCTAVE BAND PWL   DB RE 10↑-13 WATT
=  52.3=  56.0=  51.3=  47.6=  49.3=  53.9
=  55.5=  50.9=  40.8=  32.4=  65.0=  64.2

?10 AT   0.00
*
```

MICROPUMP NOISE DATA (CONTINUED)

```
PUMP NOISE DATA

TEST UNIT      :MODIFIED MICROPUMP (INLET PRESSURE STUDY)
CONDITION      :10 PSI INLET
MIKE RAD (IN):36


MICROPHONE=   0.0 DEG
:=  40.5:=  43.0:=  42.2:=  45.0:=  48.2:=  38.2:=  35.0:=  34.7
:=  32.7:=  33.2:=  32.0:=  29.0:=  31.7:=  27.7:=  31.0:=  38.2
:=  38.7:=  46.2:=  42.0:=  37.2:=  37.5:=  34.0:=  43.0:=  41.5
:=  39.0:=  32.2:=  29.5:=  25.5:=  18.2:=  15.2:=  57.2:=  56.7
MICROPHONE=  20.0 DEG
:=  40.5:=  42.5:=  43.2:=  46.5:=  48.5:=  39.5:=  37.2:=  37.0
:=  34.0:=  33.0:=  33.2:=  30.0:=  31.2:=  26.7:=  28.2:=  34.2
:=  36.5:=  43.2:=  40.5:=  41.0:=  43.5:=  37.0:=  41.2:=  42.5
:=  39.5:=  29.5:=  24.7:=  20.0:=  18.0:=  15.0:=  57.2:=  56.5
MICROPHONE=  40.0 DEG
:=  35.5:=  38.2:=  39.0:=  43.2:=  48.5:=  35.0:=  32.2:=  33.7
:=  30.5:=  29.7:=  31.5:=  27.5:=  27.2:=  25.5:=  27.2:=  33.0
:=  32.0:=  35.5:=  38.7:=  40.7:=  42.2:=  39.7:=  43.0:=  44.7
:=  41.7:=  34.5:=  32.2:=  27.0:=  20.5:=  15.2:=  57.2:=  56.2
MICROPHONE=  60.0 DEG
:=  34.2:=  37.7:=  37.2:=  43.0:=  48.0:=  36.7:=  32.5:=  32.2
:=  28.5:=  29.0:=  29.5:=  25.0:=  24.5:=  23.7:=  25.7:=  33.0
:=  33.2:=  36.2:=  36.2:=  34.0:=  37.7:=  35.2:=  40.2:=  43.7
:=  43.7:=  34.0:=  29.5:=  30.7:=  21.2:=  16.0:=  55.2:=  54.7
MICROPHONE=  80.0 DEG
:=  29.5:=  34.0:=  32.2:=  35.0:=  38.5:=  28.7:=  26.5:=  30.2
:=  25.5:=  28.5:=  25.0:=  23.2:=  27.7:=  21.2:=  24.7:=  29.7
:=  31.2:=  36.7:=  35.7:=  31.7:=  33.7:=  30.5:=  38.5:=  41.0
:=  37.7:=  28.5:=  27.7:=  28.5:=  17.7:=   9.2:=  52.5:=  52.0
MICROPHONE= 100.0 DEG
:=  31.0:=  32.2:=  32.0:=  35.5:=  39.5:=  28.2:=  25.7:=  31.0
:=  25.0:=  28.0:=  25.7:=  26.2:=  31.0:=  23.0:=  23.5:=  31.5
:=  30.7:=  34.5:=  34.5:=  37.0:=  36.7:=  38.7:=  40.2:=  43.0
:=  39.2:=  30.0:=  25.5:=  22.2:=  15.5:=  10.0:=  54.2:=  53.7
MICROPHONE= 120.0 DEG
:=  24.5:=  28.0:=  26.7:=  32.7:=  38.0:=  23.5:=  22.7:=  30.7
:=  23.0:=  25.2:=  28.5:=  28.0:=  29.7:=  22.5:=  24.0:=  31.5
:=  29.0:=  32.7:=  36.0:=  40.0:=  37.2:=  33.0:=  33.2:=  33.5
:=  27.5:=  19.0:=  16.7:=  14.0:=  10.5:=   6.5:=  51.2:=  50.5
MICROPHONE= 140.0 DEG
:=  23.5:=  29.0:=  32.7:=  42.0:=  39.7:=  32.7:=  26.0:=  30.7
:=  22.7:=  23.5:=  30.7:=  29.2:=  26.5:=  23.2:=  25.0:=  32.7
:=  30.2:=  36.0:=  34.2:=  33.5:=  36.2:=  29.7:=  29.5:=  30.5
:=  31.2:=  21.5:=  16.2:=  13.0:=   9.7:=   6.0:=  49.2:=  48.7
MICROPHONE= 160.0 DEG
:=  21.5:=  22.0:=  22.0:=  32.0:=  38.5:=  26.7:=  22.2:=  29.5
:=  21.5:=  20.2:=  29.7:=  29.7:=  26.0:=  22.7:=  25.7:=  28.2
:=  28.5:=  34.2:=  31.2:=  32.0:=  33.7:=  28.5:=  28.0:=  29.5
:=  28.2:=  18.5:=  15.0:=  13.7:=  12.5:=   5.7:=  47.7:=  47.0
MICROPHONE= 180.0 DEG
:=  23.0:=  23.5:=  23.5:=  33.0:=  39.0:=  26.2:=  23.5:=  29.7
:=  21.7:=  20.2:=  28.0:=  27.5:=  29.7:=  25.0:=  22.5:=  30.5
:=  28.7:=  36.5:=  34.0:=  35.2:=  33.5:=  28.5:=  27.2:=  27.2
:=  29.5:=  20.2:=  16.0:=  13.0:=  11.5:=   6.0:=  49.0:=  48.2


1/3 OCTAVE BAND PWL  DB RE 10↑-13 WATT
=  53.0=  55.8=  55.9=  60.7=  64.4=  53.4=  50.1=  52.1
=  47.6=  48.3=  49.3=  47.3=  48.7=  43.6=  45.5=  52.1
=  51.9=  56.8=  56.4=  57.4=  58.3=  55.8=  59.2=  61.5
=  59.3=  50.4=  47.2=  46.0=  37.6=  32.2=  74.1=  73.4

FULL OCTAVE BAND PWL  DB RE 10↑-13 WATT
=  59.9=  66.2=  55.1=  53.1=  51.2=  59.0
=  62.2=  64.2=  60.1=  46.8=  74.1=  73.4
```

MICROPUMP NOISE DATA (CONCLUDED)

```
FAN NOISE DATA

TEST UNIT      : MICROPUMP MOTOR (REPLACEMENT MOTOR)
CONDITION      : AS RECEIVED (BALL BEARINGS)
MIKE RAD (IN):36


MICHOPHONE=   0.0 DEG
:=   36.2:=   32.0:=   18.2:=   23.2:=   29.7:=   21.5:=   22.0:=   32.2
:=   19.7:=   25.0:=   18.0:=   11.5:=   24.0:=   19.7:=   33.2:=   35.2
:=   29.7:=   32.0:=   34.2:=   32.5:=   43.2:=   25.2:=   22.7:=   25.0
:=   27.5:=   26.2:=   19.7:=   17.0:=   12.0:=    7.2:=   46.2:=   47.0
MICROPHONE=  20.0 DEG
:=   37.0:=   33.0:=   18.7:=   24.2:=   28.2:=   19.5:=   21.5:=   32.0
:=   19.7:=   33.0:=   21.0:=   10.0:=   24.7:=   20.0:=   37.5:=   37.2
:=   36.2:=   36.2:=   39.0:=   33.5:=   42.7:=   26.0:=   27.2:=   29.2
:=   29.7:=   28.0:=   21.2:=   16.7:=   16.5:=    9.0:=   47.2:=   48.7
MICROPHONF=  40.0 DEG
:=   36.2:=   34.0:=   20.5:=   26.2:=   28.0:=   19.5:=   20.2:=   31.2
:=   20.5:=   39.5:=   25.2:=   14.0:=   34.5:=   23.7:=   38.5:=   34.7
:=   35.0:=   41.2:=   43.5:=   38.2:=   40.2:=   28.0:=   30.0:=   31.5
:=   36.2:=   29.2:=   22.0:=   18.0:=   13.7:=    7.5:=   48.7:=   49.5
MICROPHONE=  60.0 DEG
:=   32.0:=   33.5:=   20.5:=   26.0:=   28.0:=   19.2:=   19.2:=   29.5
:=   20.0:=   41.2:=   27.2:=   15.0:=   36.0:=   24.7:=   40.5:=   36.0
:=   38.0:=   40.7:=   46.0:=   43.5:=   40.5:=   29.7:=   31.2:=   34.5
:=   38.7:=   30.5:=   20.5:=   18.5:=   14.7:=    5.2:=   50.5:=   51.0
MICROPHONE=  80.0 DEG
:=   30.7:=   36.7:=   23.7:=   30.0:=   25.0:=   21.2:=   19.7:=   27.5
:=   20.7:=   41.7:=   27.5:=   17.2:=   38.7:=   27.2:=   43.7:=   40.7
:=   41.0:=   41.2:=   46.7:=   44.5:=   40.7:=   35.5:=   33.2:=   39.0
:=   44.5:=   34.7:=   28.7:=   26.0:=   22.2:=   13.2:=   52.7:=   53.0
MICROPHONE= 100.0 DEG
:=   29.7:=   37.2:=   23.2:=   28.2:=   25.7:=   22.5:=   19.2:=   25.5
:=   22.0:=   43.0:=   29.0:=   18.2:=   39.7:=   28.7:=   44.2:=   39.2
:=   39.7:=   45.2:=   49.2:=   46.2:=   40.2:=   32.0:=   32.5:=   40.2
:=   43.5:=   35.0:=   28.7:=   27.0:=   22.7:=   12.2:=   55.0:=   55.2
MICROPHONE= 120.0 DEG
:=   31.2:=   37.2:=   24.0:=   26.7:=   27.5:=   20.7:=   19.0:=   25.0
:=   21.2:=   41.2:=   27.2:=   18.0:=   39.7:=   27.5:=   41.5:=   40.2
:=   38.5:=   37.0:=   44.7:=   43.2:=   37.7:=   31.5:=   30.7:=   41.5
:=   43.7:=   36.0:=   29.0:=   29.7:=   25.0:=   15.0:=   51.5:=   52.0
MICROPHONE= 140.0 DEG
:=   33.2:=   39.5:=   25.5:=   26.7:=   29.0:=   20.0:=   19.0:=   24.2
:=   19.7:=   39.5:=   25.5:=   18.5:=   41.2:=   28.5:=   36.2:=   34.7
:=   35.7:=   34.7:=   41.5:=   39.2:=   38.2:=   29.5:=   31.0:=   39.7
:=   39.5:=   35.0:=   29.2:=   27.5:=   21.0:=   15.0:=   49.0:=   50.2
MICROPHONE= 160.0 DEG
:=   33.0:=   38.5:=   23.7:=   24.5:=   23.0:=   17.7:=   17.5:=   23.2
:=   18.2:=   36.7:=   22.5:=   15.5:=   36.5:=   24.7:=   37.5:=   36.5
:=   33.2:=   35.0:=   40.2:=   38.5:=   38.2:=   25.2:=   27.2:=   36.7
:=   32.5:=   31.2:=   23.2:=   22.7:=   17.0:=   10.7:=   46.5:=   48.0
MICROPHONE= 180.0 DEG
:=   32.7:=   37.5:=   24.2:=   24.2:=   29.2:=   21.5:=   19.0:=   23.7
:=   17.7:=   32.0:=   18.2:=   12.2:=   30.0:=   20.5:=   32.0:=   30.5
:=   29.0:=   20.5:=   32.0:=   33.0:=   37.5:=   24.7:=   25.0:=   28.7
:=   30.0:=   34.2:=   27.0:=   21.0:=   18.0:=   11.7:=   42.5:=   44.5


1/3 OCTAVE BAND PWL   DB RE 10:-13 WATT
=   54.5=   56.7=   42.8=   45.8=   47.9=   40.1=   39.9=   49.1
=   39.8=   58.5=   44.6=   35.5=   56.8=   45.1=   58.7=   56.7
=   56.0=   58.1=   62.7=   60.0=   60.4=   48.7=   49.4=   56.5
=   58.2=   52.5=   45.7=   44.1=   39.3=   31.5=   69.0=   69.9

FULL OCTAVE BAND PWL   DB RE 10:-13 WATT
=   58.8=   50.4=   50.0=   58.7=   61.0=   61.8
=   66.0=   57.9=   59.4=   45.5=   69.0=   69.9
*
```

MICROPUMP MOTOR (BALL BEARINGS) NOISE DATA

```
FAN NOISE DATA

TEST UNIT      : MICROPUMP MOTOR
CONDITION      : BRONZE BUSHINGS
MIKE RAD (IN):36


MICROPHONE=   0.0 DEG
:=  40.0:=  43.5:=  30.5:=  29.5:=  32.5:=  23.0:=  23.5:=  31.2
:=  22.0:=  37.0:=  23.5:=  12.5:=  25.7:=  17.5:=  26.2:=  26.7
:=  19.0:=  23.0:=  18.7:=  19.0:=  19.5:=  13.0:=  11.2:=   9.7
:=  10.0:=  11.5:=   9.2:=   8.7:=   8.0:=   3.7:=  32.5:=  46.7
MICROPHONE=  20.0 DEG
:=  31.0:=  34.7:=  19.0:=  24.7:=  27.2:=  17.5:=  18.5:=  28.7
:=  18.5:=  37.5:=  22.7:=  10.0:=  25.2:=  14.7:=  29.0:=  30.5
:=  22.0:=  25.0:=  21.2:=  19.0:=  24.0:=  19.5:=  12.7:=  10.0
:=  11.0:=  24.2:=  15.2:=  15.7:=   8.2:=   4.7:=  35.5:=  42.0
MICROPHONE=  40.0 DEG
:=  32.5:=  36.5:=  21.5:=  26.7:=  27.2:=  19.2:=  18.0:=  27.0
:=  19.0:=  37.5:=  23.5:=  12.5:=  32.5:=  20.2:=  28.7:=  28.0
:=  21.5:=  26.0:=  23.5:=  22.0:=  26.2:=  23.0:=  14.2:=   8.5
:=  10.0:=  10.0:=   9.2:=   9.0:=   8.5:=   5.2:=  36.2:=  42.7
MICROPHONE=  60.0 DEG
:=  31.0:=  37.0:=  21.5:=  26.0:=  26.7:=  18.0:=  18.0:=  26.2
:=  19.7:=  39.0:=  24.7:=  13.0:=  33.0:=  20.0:=  27.2:=  27.7
:=  21.5:=  24.5:=  22.0:=  21.2:=  25.0:=  23.7:=  12.7:=   8.0
:=   9.0:=   9.5:=   9.2:=   8.7:=   8.0:=   5.0:=  36.0:=  42.7
MICROPHONE=  80.0 DEG
:=  29.5:=  33.5:=  21.0:=  25.5:=  27.7:=  21.5:=  18.7:=  25.5
:=  20.0:=  40.7:=  26.7:=  13.0:=  32.5:=  19.5:=  27.2:=  29.7
:=  21.0:=  25.5:=  23.2:=  19.0:=  20.0:=  19.0:=  10.5:=   8.2
:=   9.5:=   9.0:=  10.0:=   9.0:=   9.0:=   5.5:=  36.2:=  43.5
MICROPHONE= 100.0 DEG
:=  27.5:=  34.0:=  21.2:=  26.7:=  29.5:=  22.2:=  18.7:=  26.5
:=  20.0:=  41.0:=  26.7:=  14.5:=  34.7:=  21.5:=  28.7:=  27.5
:=  21.0:=  27.0:=  23.5:=  19.0:=  23.0:=  19.2:=  10.7:=   8.0
:=   9.5:=   9.2:=   9.5:=   9.2:=   9.0:=   5.7:=  36.5:=  43.7
MICROPHONE= 120.0 DEG
:=  26.7:=  31.0:=  25.0:=  33.7:=  30.5:=  25.5:=  20.7:=  27.2
:=  20.2:=  41.2:=  26.0:=  15.2:=  36.0:=  22.5:=  27.2:=  27.7
:=  19.5:=  20.2:=  22.2:=  21.0:=  25.7:=  20.2:=  11.0:=   8.7
:=  10.0:=   9.5:=   9.7:=   9.5:=   9.5:=   6.2:=  36.5:=  44.5
MICROPHONE= 140.0 DEG
:=  26.0:=  27.0:=  17.7:=  24.0:=  28.7:=  18.0:=  17.7:=  27.7
:=  24.2:=  46.0:=  31.2:=  14.5:=  32.0:=  20.5:=  34.2:=  31.0
:=  25.2:=  22.5:=  22.5:=  20.0:=  23.5:=  20.0:=  11.2:=   8.7
:=  13.0:=  12.0:=  10.2:=  10.0:=   9.7:=   6.5:=  39.0:=  47.0
MICROPHONE= 160.0 DEG
:=  25.0:=  22.7:=  18.7:=  22.5:=  28.0:=  19.0:=  18.7:=  28.0
:=  22.5:=  44.0:=  29.0:=  21.2:=  27.7:=  29.2:=  40.2:=  39.2
:=  30.2:=  23.5:=  22.0:=  26.0:=  28.0:=  22.7:=  15.0:=  12.7
:=  14.5:=  15.0:=  11.0:=  10.0:=   9.7:=   7.2:=  43.2:=  47.2
MICROPHONE= 180.0 DEG
:=  25.2:=  21.5:=  18.7:=  22.5:=  27.0:=  20.5:=  19.5:=  28.7
:=  22.7:=  44.0:=  29.7:=  28.0:=  22.5:=  31.2:=  33.2:=  36.2
:=  31.2:=  29.7:=  24.0:=  23.5:=  21.0:=  18.2:=  12.0:=  11.0
:=  11.5:=  10.2:=  10.2:=  10.2:=  10.2:=   7.5:=  40.0:=  46.0


1/3 OCTAVE BAND PWL  DB RE 10↑-13 WATT
=  52.2=  55.9=  43.1=  47.3=  48.7=  40.6=  39.5=  48.2
=  41.5=  62.2=  47.5=  39.7=  51.2=  45.1=  54.3=  53.7
=  46.2=  45.1=  42.4=  42.2=  45.1=  41.1=  32.9=  30.1
=  31.8=  37.5=  31.4=  31.4=  29.1=  26.0=  58.9=  65.3

FULL OCTAVE BAND PWL  DB RE 10↑-13 WATT
=  57.6=  51.5=  49.5=  62.3=  56.3=  54.9
=  48.2=  42.0=  39.3=  34.1=  58.9=  65.3
*
```

MICROPUMP MOTOR (BRONZE BUSHINGS) NOISE DATA

APPENDIX C

PLAN OF TEST FOR APOLLO FAN AND PUMP NOISE EVALUATION

HS F-927 6/56

TEST NO. 1

HAMILTON STANDARD

PLAN OF TEST

JOB: Fan and Pump Noise Control Test Program

PLAN PREPARED BY: T. Ganger 3/15/72

B.M.

PROJECT & ORDER: B85-100-200A

APPROVED BY: J. Misoda, Program Engineer

INSTRUCTION:

TEST ENGINEER: T. Ganger

TIME PERIOD: March, 1972 TO April, 1972

1. WHAT IS ITEM BEING TESTED?

2. WHY IS TEST BEING RUN? WHAT WILL RESULTS SHOW OR BE USED FOR?

3. DESCRIBE TEST SET UP INCLUDING INSTRUMENTATION. ATTACH SKETCH OF INSTALLATION.

4. ITEMIZE RUNS TO BE MADE GIVING LENGTH OF EACH AND READINGS TO BE TAKEN.

5. SPECIAL INSTRUCTIONS: SAFETY PRECAUTIONS FOR OPERATORS AND HANDLING EQUIPMENT. OBSERVATIONS BY SIGHT, FEEL, OR HEARING. LIST POINTS OF OBSERVATION WHICH MIGHT CONTRIBUTE TO ANALYSIS OF (A) PERFORMANCE OF UNITS, (B) INCIPIENT TROUBLE BEFORE IT OCCURS, AND (C) CAUSE OF FAILURE.

6. HOW WILL DATA BE USED OR FINALLY PRESENTED? GIVE SAMPLE PLOT, CURVE, OR TABULATION AS IT WILL BE FINALLY PRESENTED.

NUMBER ENTRY AS LISTED ABOVE AND DESCRIBE BELOW

1.0 Description of Test Items (GFE)

The test items consist of the following spacecraft fans and pumps:

LM Suit Fan	P/N SV 737732	S/N 00001 (U/N 121)
LM Cabin Fan	SV 715543	S/N 86-R1; 86-R2
CSM Suit Compressor	P/N 826000-2-2	S/N 107-171
LM Pump	P/N SV 737656	S/N 00002 (U/N 117)
CSM Pump	P/N 850024-6-1	S/N 95-114

2.0 Purpose of Tests

These tests are being conducted to identify and quantify noise sources and causes in present spacecraft fans and pumps. The test data will be used for correlation with empirical and theoretical fan and pump noise estimating procedures to develop design criteria for Space Shuttle applications.

3.0 Test Instrumentation and Set Up

3.1 Acoustic Instrumentation

The following instrumentation will be used for acoustic data acquisition:

Microphones: Bruel & Kjaer Type 4133

Tape Recorder: Nagra III

Sound Level Meter: Bruel & Kjaer Type 2203

3.1 (Con't)

Microphone Calibrator: Bruel & Kjaer Type 4230

Microphone Power Supply: HS 12 channel power supply

Microphone Preamps: Bruel & Kjaer Type 2619

Associated Cables

3.2 Performance Instrumentation

Suitable rig instrumentation will be supplied to measure system pressures, temperatures, flow, speed, and power as described on Tables 1 and 2 for the spacecraft fans and pumps.

3.3 Test Set Up

3.3.1 Fans

The test fans and instrumentation will be set up in Rig 14 of the Space Systems Department (SSD) laboratory as shown in Figure 1. A bellmouth will be installed on the fan inlet to insure uniform fan inflow.

3.3.2 Pumps

The test pumps and instrumentation will be set up in Rig 14 of the SSD laboratory as shown in Figure 2.

4.0 Description of Tests

4.1 Fans

Performance data, i.e., temperatures, pressures, flow, rpm (if possible), and power will be recorded with the fan operating near the design point. All instrumentation (static and total pressure probes) will then be removed from the fan flow stream. A 30 second recording will then be made for each microphone position of Figure 1 with the fan continuing to operate near the design point.

These tests will be conducted on the fan inlet with the exhaust noise isolated, and the exhaust with the inlet noise isolated. The ambient pressure will be maintained at either 5 or 14.7 psia for performance and acoustic tests.

4.2 Pumps

Performance data, i.e., temperature, pressures, flow, rpm, and power will be recorded with the pump operating near the design point. In addition, a 30 second recording will be made for each microphone position of Figure 2.

Since pump noise is body radiated, there will be no isolation of the inlet and outlet noise. The ambient pressure will be maintained at 14.7 psia for performance and acoustic tests.

5.0 Special Instructions

1. Background noise and use standardize recordings will be made for all tests. This information will be used to correct the acoustic data if necessary.

2. Each microphone will be calibrated prior to each test.

3. Microphones will be allowed to warm up for 30 minutes prior to testing to ensure stability.

6.0 Data Reduction

6.1 Performance Data

Performance data will be used to monitor test hardware performance and to ensure design point operation.

6.2 Acoustic Data Reduction

The acoustic data will be analyzed for each microphone location using a GR type 1921 1/3 octave band real time analyzer with a 16 second integration time. This analysis will permit the calculation of acoustic power level (PWL db re 10^{-13} watt) for each fan (inlet and exhaust) and pump tested. In addition, narrow band analyses will be made to determine the tone content of the source.

The acoustic data will be presented in both tabular and graphic form.

7.0 Data Accuracy

The data accuracy based on the rig performance instrumentation and the acoustic data acquisition/data reduction equipment is as follows:

temperature ±3°
delta pressure ±0.2" H_2O
pressure ±0.5% full scale
gas flow ±5% full scale
liquid flow ±5% full scale
speed ±2% full scale
voltage ±1% full scale
amperage ±1% full scale
acoustic noise ±1.5 dB

TABLE 1

HARDWARE DESIGN POINTS

FANS

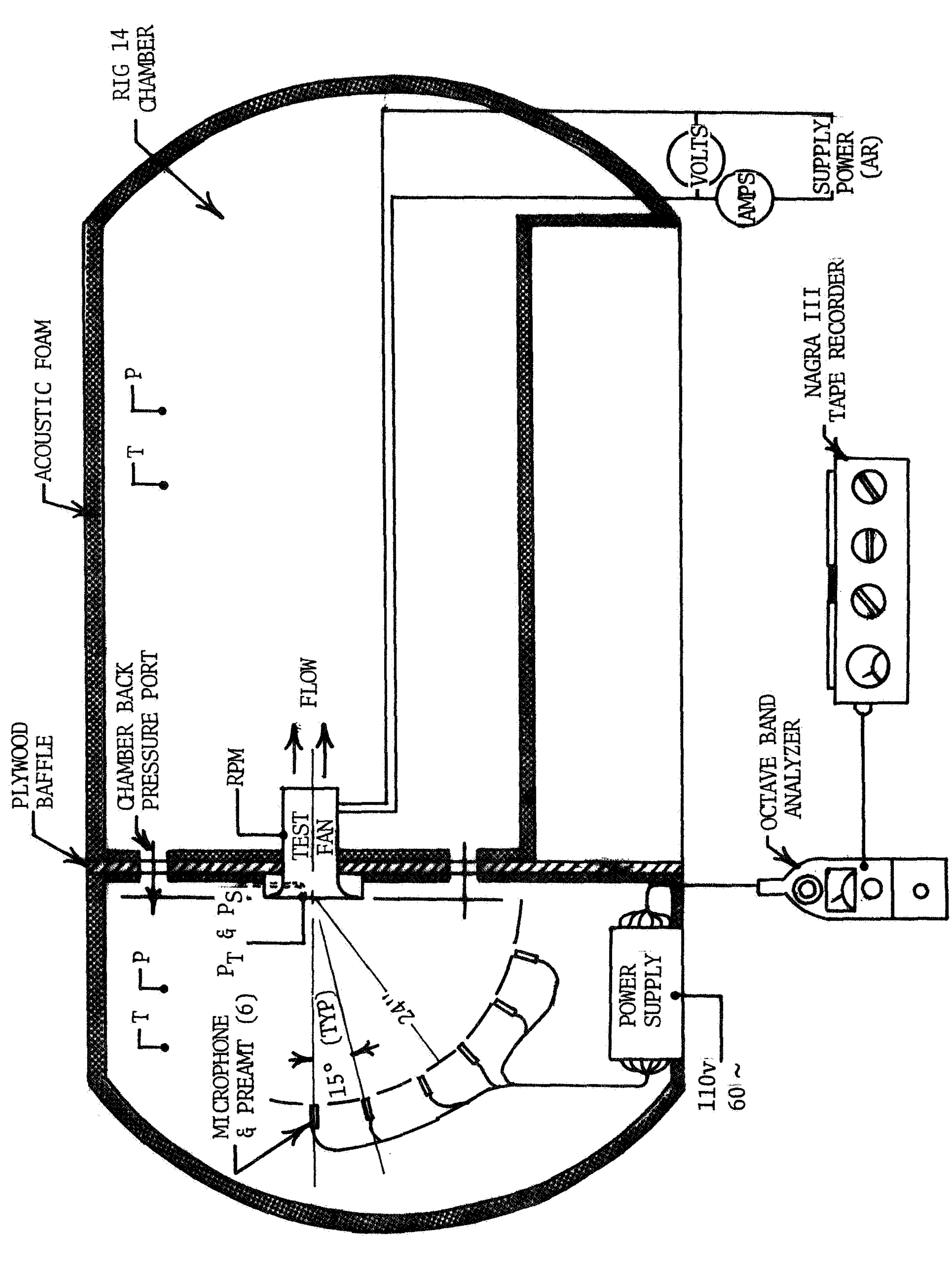
	LM SUIT	LM CABIN	CSM SUIT	CSM CABIN
Fluid	Air	Air	Air	Air
Flow (#/Min) (CFM)	.74 27	5.0 183	.93 35	2.5 86
ΔP ("h_2O)	15	0.4	10	0.4
Pin (psia)	5.0	5.0	5.0	5.0
Power (Watts)	160	30	85	20
Speed rpm	25,000	13,000	22,000	11,000
Power Source	28V DC	28V DC	115/200V 3Ø 400 cps	115/200V 3Ø 400 cps

TABLE 2

HARDWARE DESIGN POINTS

PUMPS

	LM	CSM
Fluid	Glycol/Water 62 1/2/37 1/2	Glycol/Water 62 1/2/37 1/2
Pin (psia)	14.7	14.7
Flow #/Hr	222	200
ΔP psi	30	36
Power Watts	25	52
Speed rpm	5500	22000
Power Source	28V DC	115/200V 3ϕ 400 cps

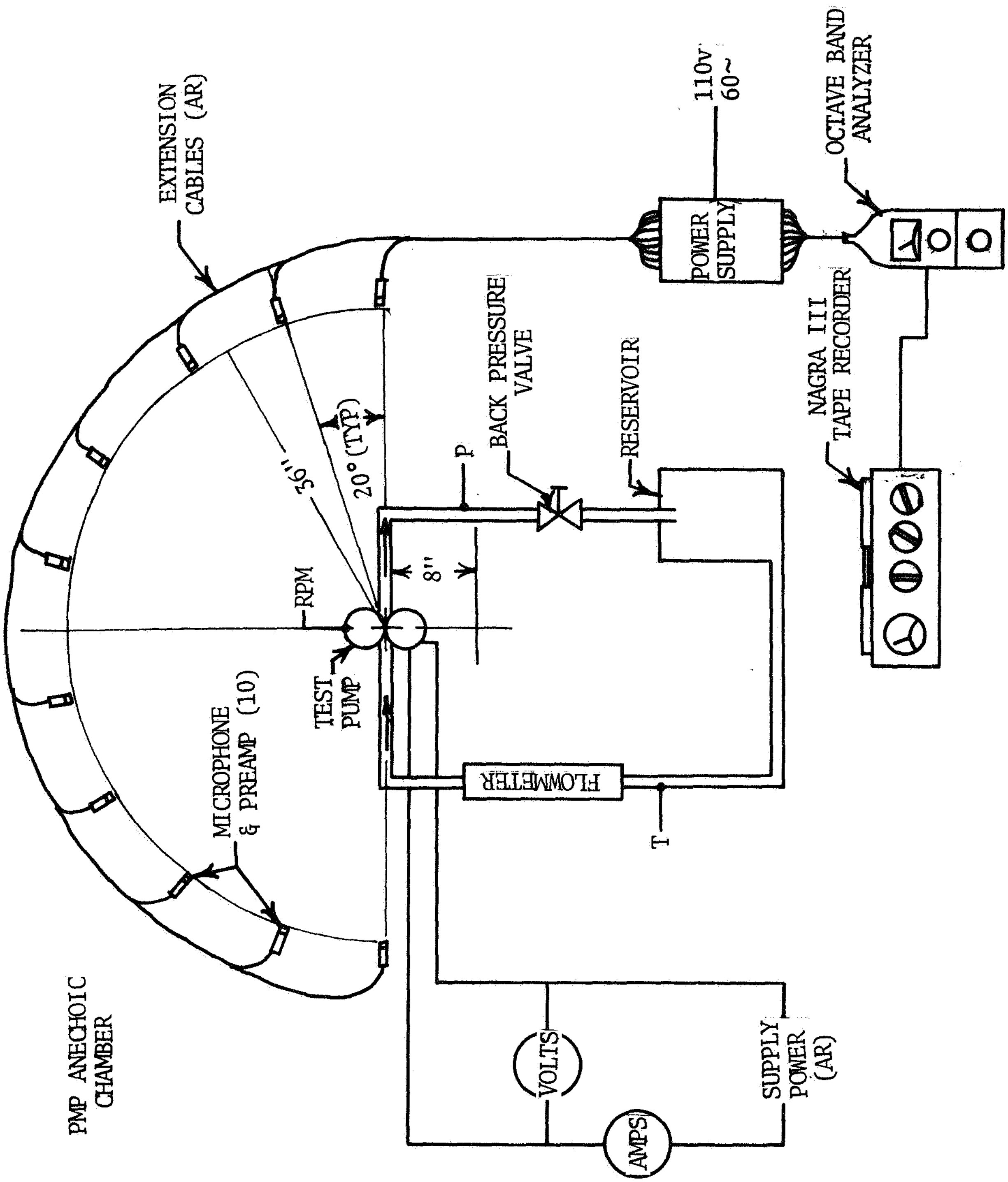


T = TEMPERATURE
P = PRESSURE

FAN NOISE TEST SETUP

FIGURE 1

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP



PUMP NOISE TEST SETUP

FIGURE 2

APPENDIX D

FAN AND PUMP NOISE CONTROL

MASTER TEST PLAN

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

Revision A
June 16, 1972

FAN AND PUMP NOISE CONTROL

MASTER TEST PLAN

PREPARED UNDER CONTRACT NAS 9-12457

by

HAMILTON STANDARD

DIVISION OF UNITED AIRCRAFT CORPORATION

WINDSOR LOCKS, CONNECTICUT

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Prepared by John Mrsrda
Program Engineer

Approved by Fred H. Greenwood
Program Manager

1.0 DESCRIPTION OF TEST ITEMS

The items to be tested shall consist of two (2) fans and one (1) pump. These items are those which are selected as the most favorable concepts based on consideration of weight, volume, power consumption, existing noise level, and potential noise level reduction. These fans and pump will be off-the-shelf hardware purchased for this program.

2.0 PURPOSE OF TESTS

The purpose of this testing is to demonstrate that the noise reduction techniques which are to be formulated in the course of this program accomplish reductions in noise level. However, since modified commercial hardware is being utilized as test models, these tests are not intended to demonstrate ability to meet the NC-30 design goals.

3.0 TEST AND INSTRUMENTATION

3.1 Test

All testing will be done at atmospheric pressure in Hamilton Standard's test facility by Hamilton Standard personnel.

3.1.1 Test Facility

3.1.1.1 Description

The tests will be conducted in Hamilton Standard's anechoic chamber. This chamber has a volume of approximately 3000 cubic feet and provides an essentially free-field environment at distances up to five feet from the source for frequencies over the range of 90 to 5,600 Hz as shown in Figure 1.

3.1.1.2 Background Noise

The background noise in the test environment is below 17 dB over the frequency range 90 to 11,200 Hz as measured by octave bands. As this level is 10 dB or more below the octave band levels of the design goal of NC-30, background noise levels in the best environment are not considered a problem.

3.1.2 Test Set-Up

3.1.2.1 Test Item Location

The test items shall be located in the approximate center of the test chamber, approximately 3 feet above the floor.

3.1.2.2 Measurement Locations

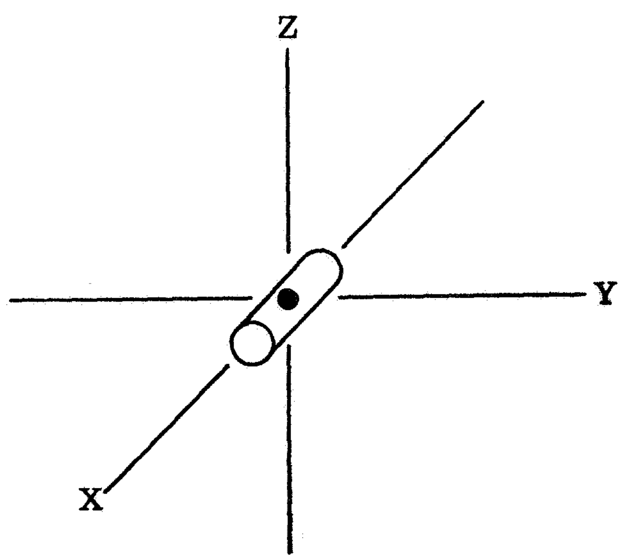
All measurements shall be made at 3 feet from the source. If the test item exhibits acoustic noise radiation symmetry (i.e., such as an axial fan), the microphone locations shall be at 20 degree increments from 0 to 160 degrees as shown in Figure 2. If the test item does not exhibit acoustic noise radiation symmetry, measurements will be made at 20 points equally spaced on a sphere centered on the center of the source as defined in Table I. The measurements will first be made at 12 points on a hemisphere above the test item. The test item will then be inverted and the noise measurements repeated. The four measurement locations common to both hemispheres will be weighted by a factor of 1/2 in power.

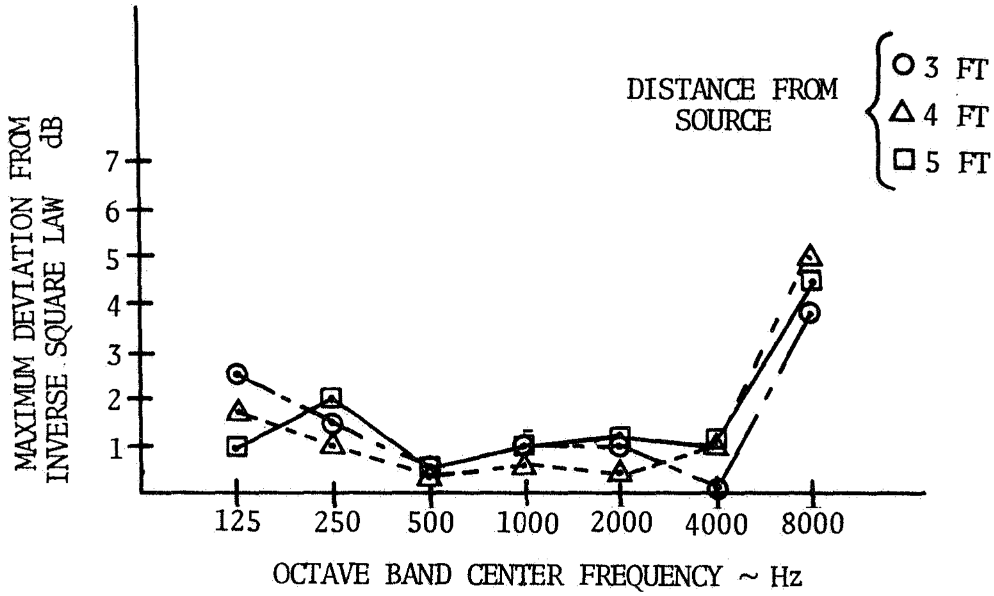
TABLE I

Cartesian Coordinates of Microphone Locations

For Measuring Noise From a Source Which Does Not Exhibit Symmetry

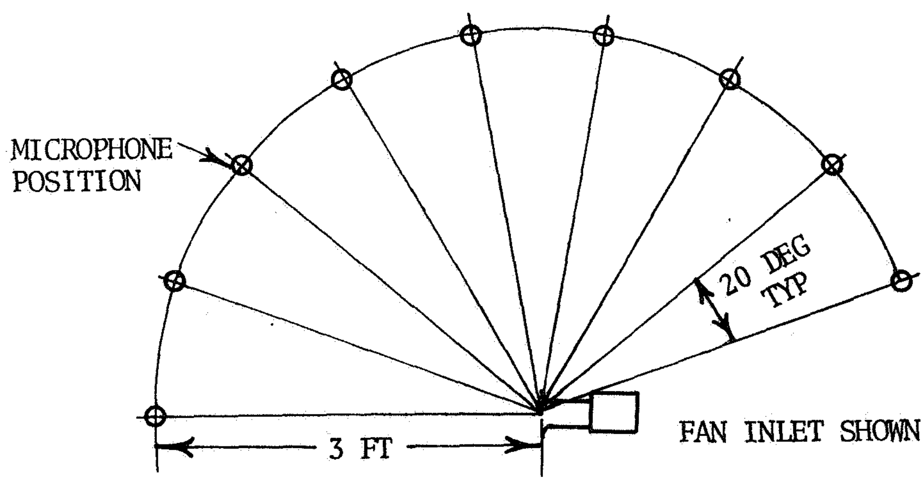
X	Y	Z
0 ft.	2.79 ft.	1.08
1.74	1.74	1.74
2.79	1.08	0
1.08	0	2.79
2.79	-1.08	0
1.74	-1.74	1.74
0	-2.79	1.08
-1.74	-1.74	1.74
-2.79	-1.08	0
-1.08	0	2.79
-2.79	1.08	0
-1.74	1.74	1.74





FREE - FIELD CHARACTERISTICS OF ANECHOIC CHAMBER

FIGURE 1



MICROPHONE POSITIONS FOR MEASURING NOISE FROM A SOURCE HAVING AXIAL SYMMETRY

FIGURE 2

3.1.2.3 Ancillary Equipment Locations

Ancillary test equipment which is likely to make noise, such as power supplies, control valves, etc., will be located outside the test chamber.

3.2 Instrumentation

3.2.1 Acoustic Instrumentation

3.2.1.1 Description

The following instrumentation will be used for acoustic data acquisition:

a) Bruel & Kjaer (B & K) type 4131 one-inch condenser microphones.

b) B & K type 2613 cathode followers.

c) B & K type 2801 power supplies.

d) B & K type A00028 30 ft. extension cable.

e) B & K type 2203 precision sound level meter.

f) Kudelshi NAGRA III magnetic tape recorder.

g) B & K type 4230 microphone calibrator.

The following equipment will be used for data playback and analysis:

a) Ampex Model AG-500 magnetic tape recorder.

b) General Radio type 1921 real time 1/3 octave band analyzer.

c) Spectral Dynamics type 301B frequency analyzer.

The tape recorder will be operated at 15 inches per second.

3.2.1.2 Measurement Accuracy

The B & K type 4230 microphone calibrator has an accuracy of ± .5 dB. This calibrator will be used to provide a calibration signal for the entire data acquisition/analysis system. The overall system accuracy is ± 1.5 dB over the frequency range 20 to 16,000 Hz. Dynamic range, measured by 1/3 octave bands, is better than 60 dB.

3.2.2 Performance Instrumentation

3.2.2.1 Description

The instrumentation used to measure fan and pump performance will be as follows:

3.2.2.1.1 Fan Tests

Flow: Total pressure gage and delta pressure manometer.
Pressure Rise: Delta pressure manometer.
Ambient Temperature: Thermometer.
Rotational Speed: Magnetic pickup or strobotac.
Input Power: Voltmeter and ammeter or wattmeter.

3.2.2.1.2 Pump Tests

Flow: Glass tube flow meter.
Pressure Rise: Delta pressure gage.
Fluid temperature: Thermometer.
Pump inlet (outlet) pressure: Pressure gage.
Speed: Magnetic pickup.
Power input: Voltmeter and ammeter or wattmeter.

3.2.2.2 Performance Measurement Accuracy

The accuracy of the instrumentation used for the performance measurements is as follows:

Temperature	$\pm$ 3 degrees
Pressure rise (fan)	$\pm$ 0.2 inches H_2O
Pressure rise (pump)	$\pm$ 0.5% full scale
Ambient pressure (fan)	$\pm$ 0.5% full scale
Inlet pressure (pump)	$\pm$ 0.5% full scale
Gas flow	$\pm$ 5% full scale
Liquid flow	$\pm$ 5% full scale
Speed	$\pm$ 2% full scale
Voltage	$\pm$ 1% full scale
Current	$\pm$ 1% full scale

4.0 DESCRIPTION OF TESTS

4.1 Background-Test Philosophy

The tests will be conducted on two fans and one pump which will be commercial off-the-shelf hardware. These items will be tested for noise and performance "as-is" for the purpose of establishing base levels. These items will be selected on the basis of their minimum noise levels and good potential for further noise reduction by the modifications evolved as a result of a performance/noise characteristics optimization. Each unit will be modified and tested at least one time to demonstrate the noise reduction techniques. The purpose of these tests will be the verification of the noise level reduction predicted from the optimization study. A

4.2 Test Procedures

4.2.1 Fan Tests

4.2.1.1 Fan Installation

Since separate evaluation of noise levels from the inlet and exhaust ports of the fans is planned, the inlet and exhausts will be acoustically isolated. During inlet noise testing, the exhaust from the fan will be ducted into a muffler to eliminate fan exhaust noise. Flow rate will be controlled by means of a throttling valve at the inlet to the muffler. To insure uniform inflow to the fan, a bellmouth will be used at the fan inlet.

For the measurement of exhaust noise levels, the fan will be reversed so that it draws from the muffler. Again, flow rate will be controlled by a throttle valve, but now located at the muffler exit. To insure uniform inflow to the fan, flow straightening devices, such as capillary tube bundles, may be installed at the fan inlet. This will be done to insure that turbulence generated in the muffler and duct wall boundary layer turbulence do not cause non-uniform inflow to the fan roter.

4.2.1.2 Performance Testing

The fans will be tested at atmospheric pressure. Performance data, i.e., temperatures, pressures, flow, rpm (if possible), and power, will be recorded with the fan operating near the design point. All instrumentation will be removed from the air flow stream after the design point operating condition is achieved.

4.2.1.3 Acoustic Noise Testing

Each fan configuration will be tested at its design condition. The operating condition will be held constant for the duration of each set of measurements. Each modification to the fans will be tested at the initial design flowrate condition, if possible. Recordings of approximately 30 seconds duration will be made at each of the locations defined in 3.1.2.2 for inlet noise and exhaust noise. A

4.2.2 Pump Testing

Noise and performance testing shall be conducted simultaneously. A similar procedure to that described in 4.2.1.3 will be used, except that total body radiated noise will be measured rather than inlet and exhaust noise. Each pump modification will be tested at the initial design flowrate, if possible. A

4.2.3 Special Test Considerations

4.2.3.1 Use-Standardize Recordings

Several recordings of use-standardize mode will be performed during the course of testing of each item. These measurements are made using the same recording gain settings used during the test item noise recordings, the only difference being that the test item is not operating. The purpose of these measurements is to determine the total noise, both in acoustic and electrical, which is inherent to the installation. This procedure ensures that the noise levels determined for the test item are free from interference from other unwanted sources.

4.2.3.2 Microphone Calibration

Each microphone shall be calibrated prior to each test using the microphone calibrator defined in 3.2.1.1. Also, the calibration signal from at least one microphone (if several are used) shall be recorded on magnetic tape. This signal will then be used as an absolute calibration signal for the entire data acquisition/playback/analysis system.

4.2.3.3 System Warm-Up

Items requiring warm-up, such as microphone preamplifiers and power supplies, shall be allowed to warm up for at least 30 minutes prior to calibration to ensure stability.

4.3 Data Reduction and Analysis

4.3.1 Performance Data

The performance instrumentation will be used to set the hardware

4.3.1 (Continued)

at the design point with respect to flow and pressure rise. Once this is achieved power and speed will be measured to assure design point operation. At this stage the pumps will be evaluated for noise. On the fans, however, removal of the delta pressure manometer and the total pressure gage from the air stream will be done prior to testing for noise.

4.3.2 Acoustic Data

The acoustic data will be analyzed using a General Radio type 1921 analyzer or its equivalent with 16 seconds integration time. One-third octave bands of center frequencies 50 to 10000 Hz will be used for the analysis.

The data from each microphone will then be integrated to calculate the sound power level (PWL) for each item at each operating condition. The intent of the PWL calculation is to better define the acoustic energy reduction achieved by the design modifications.

Also, the 1/3 octave band levels for the loudest microphone location will be summed to octave band levels for comparison with the design goal of NC-30.

Narrow band (50 Hz or less) analyses of selected recordings will be made to more clearly define the frequency distribution of the noise generated.

4.4 Data Presentation

The data will be presented in tabular form showing the measured 1/3 octave band levels at each measurement locations. Each operating condition will be presented on a separate table.

In addition, selected samples of data will be presented in graphical form where this leads to a better understanding of the noise characteristics.