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Acoustic Test Results from a 36 Inch (0.914m) Statorless Lift Fan with Serrated and Unserrated Rotor Blades

by

D.L. Stimpert

GENERAL ELECTRIC COMPANY

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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16. Abstract

Tests of the LF336/E statorless lift fan with serrated and unserrated rotor leading edges indicated broadband noise reductions of 2 to 5 dB in the forward quadrant. Broadband noise levels near the blade passing frequency and above were reduced only from 80 to 100 degrees relative to the inlet.

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LF336/E Acoustics Statorless lift fan Lift fan Serrated rotor blades Rotor-alone noise	Unclassified - unlimited

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SECTION I

SUMMARY

The LF336/E statorless lift fan system was designed and tested with two sets of fan blades - one with serrated rotor leading edges and one with unserrated rotor leading edges.

Fan broadband noise reductions from 2 to 5 dB were achieved in the forward quadrant at frequencies from 100 to 2500 Hz. Broadband noise near and above the BPF was reduced only at angles of 80 to 100 degrees. BPF reductions were not achieved with serrations.

SECTION II

INTRODUCTION

The LF336/E statorless lift fan system was designed, fabricated, and tested under Contract NAS2-5462 which was sponsored by NASA Ames Research Center. Included in this program were two sets of fan blades - one with serrated rotor leading edges and one with unserrated rotor leading edges. Acoustic test results on the unserrated LF336/E were reported in Reference 1.

Serration geometry for the LF336/E statorless lift fan was selected based upon cascade tests of serrated leading edge blading at high subsonic speeds as reported in Reference 2.

This report compares the serrated and unserrated LF336/E statorless lift fan results from tests conducted at NASA Ames Research Center. Table I summarizes the test configurations and speed points investigated which are pertinent to this report.

SECTION III

TEST HARDWARE

The basic test propulsion system consisted of the LF336/E statorless fan, the J85-5 engine, and interconnecting ducting as shown in Figure 1. The system was installed in a test stand which provided for mounting the fan and engine system with the fan inlet oriented in a vertical plane. The fan inlet bellmouth was installed flush with a flat plane surface which simulated a wing upper surface of a fan-in-wing installation.

A. LF336/E Fan System

The LF336/E fan is a single stage statorless turbotip lift fan which is designed to operate without either inlet guide vanes or exit stator rows. The fan has a 36 inch (91.44 cm) diameter and incorporates 42 blades in a tip turbine driven, single stage rotor. The single stage rotor develops a fan pressure ratio of 1.25 at a fan design tip speed of 1060 feet per second (323 m per second). The design pressure ratio of 1.25 assumes no recovery of the exit swirl component. Accordingly, the overall total-to-total pressure ratio is 1.32 at design operating conditions.

A sketch of the fan is shown in Figure 2. Selected design parameters are presented in Table II. When the fan was tested, it was modified by the installation of tip turbine exit stators.

Serrated fan blade geometry for this test is presented in Figure 3. Cascade tests (Reference 2) had concluded that the best aerodynamic and acoustic performance was achieved with serrations that had a height greater than six percent of the blade chord and a height-to-spacing (H/S) ratio of 1.5 or less.

Both the serrated and unserrated statorless fans were tested with a circular inlet guide vane. This IGV is shown installed on the serrated statorless fan in Figure 4 and would be used to improve aerodynamic performance in crossflow. IGV-to-rotor spacing was approximately 0.25 inches (0.63 cm) or about 0.06 true IGV chords.

B. J85-5 Gas Generator

The fan tip turbine was driven by a J85-5 engine modified to a conventional turbojet engine configuration. The gas generator is shown in Figure 1 coupled to the lift fan. Also evident in this photograph is the acoustic suppressor which was installed on the J85-5 inlet to suppress gas generator inlet radiated noise. The engine exhaust is direct-coupled to the fan scroll inlet through a transition duct.

SECTION IV

NASA AMES RESEARCH CENTER OUTDOOR TEST SITE

LF336/E statorless lift fan testing was conducted at an outdoor test site located at NASA Ames Research Center. An aerial view of the test site is presented in Figure 5. As the photograph shows, the acoustic path to any given microphone was in some places asphalt and concrete, and in others short grass and asphalt. The microphone layout for the unserrated test is given in Figure 6 and the serrated test in Figure 7. Far field microphones were on a 150-foot (45.7 m) arc in ten degree increments from 0 to 160 degrees relative to the fan inlet. For both tests Runs 1 and 2 had the near field microphones on a 20-foot (6.1 m) arc located in 20 degree increments from 30 to 150 degrees. All successive runs had the seven 20 foot (6.1 m) arc microphones located at 90, 110, 130, 150, 210, 230 and 250 degrees. This latter arrangement duplicated the near field microphone layout used when the unserrated statorless fan was tested in the NASA Ames 40' by 80' (12.2 m x 24.4 m) wind tunnel.

SECTION V

SOUND DATA ACQUISITION AND PROCESSING

A. Data Acquisition

All data acquisition for the near and far sound fields was made using Bruel-Kjaer model 4133 microphone systems in conjunction with a Honeywell Model 7600 tape recorder operated at thirty inches per second (76 centimeters per second). Figure 8 includes a schematic of the data acquisition system and photographs of the equipment and the General Electric Mobile Sound Evaluation Unit.

All far field microphones were oriented to point at the test vehicle and had Bruel-Kjaer UA0237 windscreens installed on the microphone heads. The near field microphones were oriented to point in the same direction as the J85 inlet and used Bruel-Kjaer model UA0052 nose cones.

The free field frequency response of each microphone head is derived from a pressure response curve recorded automatically by the electro-static actuator method traceable to the Bureau of Standards. The free field characteristics for various angles of incidence for microphones with protecting grid, nose cones, and windscreens are given by the microphone manufacturer. Individual microphone head sensitivities are determined by the insertion of a Bruel-Kjaer pistonphone on the cartridge mounted to a standard microphone system. Both the pistonphone and standard microphone system are traceable to the Bureau of Standards.

Prior to initiation of testing, a frequency response of each data channel (minus microphone head) was made by the insertion of a Hewlett-Packard Pseudo-Random Pink Noise Generator into each cathode follower and recorded on magnetic tape.

Prior to and subsequent to each day's testing, an absolute calibration was made by the insertion of a pistonphone on each microphone and recorded on tape. Any microphone whose voltage output with the pistonphone applied was found to deviate more than ± 1.5 dB from the laboratory calibration was replaced.

During test operations, sound was recorded continuously for a minimum of two minutes to allow enough sample length for data processing. All acoustic data was taken at wind speeds below 5 mph (8 km/hour).

B. Data Processing

1. 1/3 Octave Bands

All 1/3 octave band data processing was performed at the General Electric Edwards Flight Test Center facilities using a General Radio real time analyzer in conjunction with a Honeywell 316 and SDS930 computer. Thirty-two second averaging time was used for data processing with data for each angle sampled from the same period of time for each data point.

Before data processing could be initiated, the total data acquisition and reduction system frequency response characteristics had to be determined and made available in the computer for final data processing. The first step in this process was to analyze the Pink Noise calibration tapes for each data channel, and determine the response characteristics for the total system as referenced to 250 Hz (frequency of the pistonphone) at each 1/3 octave band. Final one-third octave data processing was made by determining absolute sound pressure levels, for the 150 foot (45.7 m) arc and 200, 500 foot (61 m, 151 m) sidelines, corrected to standard day (59° F (15 ° C), 70% relative humidity) conditions as per Reference 3 and for ground attenuation effects as per Reference 4.

2. <u>20 Hz Narrowbands</u>

All narrowband analysis was made at the General Electric Edwards Flight Test Center facilities using a Federal Scientific Ubiquitous Spectrum Analyzer and a 139B Digital Averager. All data was processed using a 20 Hz bandwidth filter and an averaging time of 12.8 seconds. No corrections for humidity or acquisition/processing responses were included in the narrowband plots.

SECTION VI

RESULTS AND COMPARISONS

A. Serrated to Unserrated Statorless Lift Fan

Serrations reduced the perceived noise level (PNL) by 2 to 4 PNdB primarily from 80 to 100 degrees (relative to the fan inlet on a 200 foot (61 m) sideline as shown in Figure 9 at 6000, 5300, and 4800 rpm. At forward angles, however, the use of PNL is somewhat deceiving since it weights the 1/3 octave band which contains the BPF most heavily and in the forward angles the BPF not fan broadband noise controls the spectra. Figure 10 presents a comparison of serrated and unserrated sound power levels (re 10^{-13} watts) at three fan speeds. Serrations clearly reduced fan broadband power levels from 630 Hz to the BPF by 1 to 2 dB. Above the band containing the BPF, there was little or no reduction due to serrations. The region of the spectrum around 315 Hz is influenced by the ground null; however, lower frequencies down to 100 Hz show lower sound power levels with the serrated rotor. There are two possible reasons for the reduction at these low frequencies. One is that the fan is performing differently with the serrated rotor and jet velocities are reduced thus lowering these low frequency levels. A second possibility is that these low frequencies which are usually associated with jet noise are in fact fan broadband noise which has been reduced by serrations. Figure 11 indicates that the second possibility is correct. Here the serrated and unserrated 160 Hz sound pressure levels (SPL's) at three fan speeds are compared at acoustic angles on a 200 foot (61 m) sideline. The SPL's from 30 to 100 degrees have been reduced by serrations by 2 to 5 dB. However, aft angles show little change with serrations as one would expect if these angles are controlled by jet noise not fan broadband noise. Similar results are available for 100 and 125 Hz SPL's.

At higher fan broadband levels, e.g., at 1600 Hz in Figure 12, the effect of serrations can be seen at angles of 30 degrees rearward at 4800, 5300, and 6000 rpm. For some reason, which is not clear at this time, the 110 degree level was not reduced by serrations. The reductions range from 2 to 4 dB. Similar results are observed for the 2500 Hz SPL's in Figure 13. Again the 110 degree SPL's with serrations are the same as the unserrated levels.

Serrated and unserrated SPL's of the 1/3 octave bands which contain the BPF for 6000, 5300, and 4800 rpm are compared in Figure 14. At forward angles up to 80 degrees the SPL's at the two lower fan speeds show no effect due to serrations and the 6000 rpm SPL's only show about a 1 dB drop due to serrations. The forward SPL's which contain the BPF are controlled by the BPF and the BPF is not affected by serrations or are slightly increased as the narrowband SPL's in Figure 15 indicate. Note that Figure 15 compares both 1/3 octave band BPF and 20 Hz narrowband BPF on a 150 foot (45.7 m) arc. Typical 120 Hz narrowband spectra are shown in Figure 16 for 60 degrees and 120 degrees. The aft spectra BPF is only 4 dB above the broadband noise which accounts for the difference between the aft quadrant 1/3 octave band BPF and 20 Hz BPF levels in Figure 15.

At frequencies above the BPF, serrations do not achieve a reduction except at 80, 90, and 100 degrees. Figure 17 is a typical frequency, 8000 Hz, at three fan speeds.

B. Serrated Fan with and without Circular IGV

Tests on the LF336/E statorless lift fan both serrated and unserrated included configurations with and without a circular inlet guide vane. As shown in Figure 4, the inlet guide vane is a 180 degree turning vane positioned near the fan inlet bellmouth and is located less than 0.1 rotor chords forward of the rotor leading edge. This device is intended to improve fan performance in crossflow with little change at static fan operation.

Installation of the circular IGV effected an increase in perceived noise level as shown in Figure 18 at 6000 and 5300 rpm. Figure 19 indicates that at 40 and 50 degrees there is no difference attributable to the circular IGV at low speeds. At 60 and 70 degrees the configuration with the circular IGV is 1 to 2 PNdB higher over the entire speed regime.

Installation of the circular IGV also increased the 1/3 octave band which contains the BPF. This is shown in Figure 20 at 6000 and 5300 rpm. 20 Hz narrowband directivity on a 150 foot (45.7 m) arc is shown in Figure 21 and indicates a change in the forward quadrant BPF with circular IGV. Figure 22 compares 20 Hz narrowband spectra at 50 degrees and 60 degrees and shows that the circular IGV affects only the BPF and not fan broadband noise. Similar results were observed when the circular IGV was installed on the unserrated rotor (Reference 1).

C. Serrated and Unserrated Fan with Circular IGV

With the circular IGV installed, the serrated rotor reduced the forward quadrant PNL's at 6000 rpm by 4 PNdB at 60 and 70 degrees as shown in Figure 23. At 5300 rpm the reduction due to serrations was 1 to 4 PNdB from 30 to 100 degrees. As indicated by Figure 24, these forward quadrant PNL reductions with the IGV installed are generally 2 to 3 PNdB down to 3000 rpm where the effects are minimal.

Sound power level (re 10^{-13} watts) reductions were achieved with the serrated rotor as evidenced by Figure 25. Fan broadband PWL's from 500 to the BPF and above the BPF are reduced 1 to 3 dB. For this configuration the 1/3 octave band which contains the BPF shows a 2.5 dB reduction. When compared as a function of acoustic angle, the 1/3 octave BPF band shows as much as 5 dB reduction in SPL with serrations at forward angles while the aft angles show slight reductions. This is shown in Figure 26 at two fan speeds. Typical forward and aft narrowband comparisons at 6000 rpm are shown in Figure 27. Note that the serrated rotor with the circular IGV installed has reduced not only the fan broadband noise but also the BPF and its harmonics. This is in contrast to the case without the IGV where serrations had no effect on the BPF.

Low frequency fan broadband SPL's are decreased by the serrated rotor by 2 to 3 dB in the forward quadrant as shown in Figure 28. In the aft quadrant, jet noise is dominant and no serration effect is visible. Similar results at these low frequencies were observed for the fan without the IGV and further confirms that fan broadband noise is present and that serrations reduce this fan broadband noise. Figures 29 and 30 present fan broadband SPL's at 1600 and 2500 Hz below the BPF. Serration reductions of 2 to 5 dB are present over the entire sideline. Reduction is also evident above the BPF as shown in Figure 31; however, the angles reduced are from 30 to 120 degrees.

SECTION VII

CONCLUSIONS

The 1/3-octave band SPL's from 100 Hz to 2500 Hz (excluding bands influenced by the ground null) show reductions due to serrations of 2 to 5 dB in the forward quadrant. Bands close to and above the BPF show reduction due to serrations only at angles of 80 to 100 degrees.

BPF reductions were not achieved with serrations. The reduction in broadband noise and not tones is consistent with rotor alone analyses and cascade tests which indicated that serrations primarily effect fluctuating pressure on the rotor and thus broadband noise generation.

Installation of a circular IGV resulted in a 1 to 2 PNdB increase at forward angles. This circular IGV increases the BPF at forward angles from 3 to 7 dB.

SECTION VIII

NOMENCLATURE

Symbol or Abbreviation	Definition	Units
BPF	Blade Passing Frequency	Hz
C	Blade Chord	inches (cm)
f	Frequency	Hz
H	Serration height	inches (cm)
IGV	Inlet guide vane	---
L	Peak-to-Peak Spacing of Serrations	inches (cm)
OGV	Outlet guide vane	---
PNL	Perceived Noise Level	PNdB
PWL	Sound Power Level, re 10^{-13} watts	dB
R	Radius	inches (cm)
S	Serration Spacing	inches (cm)
SPL	Sound pressure level re: 0.0002 dynes/cm^2	dB

SECTION IX

REFERENCES

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2. Smith, E.G.; and Sowers, H.D.; "Cascade Tests of Serrated Leading Edge Blading at High Subsonic Speeds", General Electric Company Technical Information Series R74AEG283, December 1974, NASA CR2472.

3. Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity for Use in Evaluating Aircraft Flyover Noise. S.A.E. ARP866, August 31, 1964.

4. Method of Calculating the Attenuation of Aircraft Ground to Ground Noise Propagation During Takeoff and Landing. Aerospace Information Report 923, Society of Automotive Engineers, Inc., August 15, 1966.

TABLE I. LF336/E Acoustic Test Summary.

- Unsuppressed Fan
- Test Site - NASA Ames Research Center

Run	Configuration	Date	Nominal Fan Speed (F' M)						
			3000	3375	4050	4200	4800	5410	6000
1	Unserrated	3-26-73	1*	1	1	1	1	1	1
2	Unserrated With Circular IGV	3-22-73	1	-	-	1	1	2	2
3	Unserrated	3-22-73	1	1	1				
1	Serrated	12-3-73	2	-	-	2	2	2	2
2	Serrated	12-3-73	1	-	-	1	1	1	1
3	Serrated With Circular IGV	12-3-73	1	-	-	1	1	1	1

*Denotes number of data points at each speed.

Table II. LF336/E Lift Fan Design Parameters.

	Design Point		Mechanical Limit Speed	
Fan pressure ratio	1.25		1.196	
Fan flow, lbm/sec (kg/sec)	172	(78)	152	(69.4)
Fan tip speed, ft/sec (m/sec)	1060	(323)	950	(290)
Fan speed, rpm	6748		6048	
Blade number	42			
Fan tip diameter, inches (cm)	36	(91.44)		
Radius ratio (rotor inlet)	0.554			

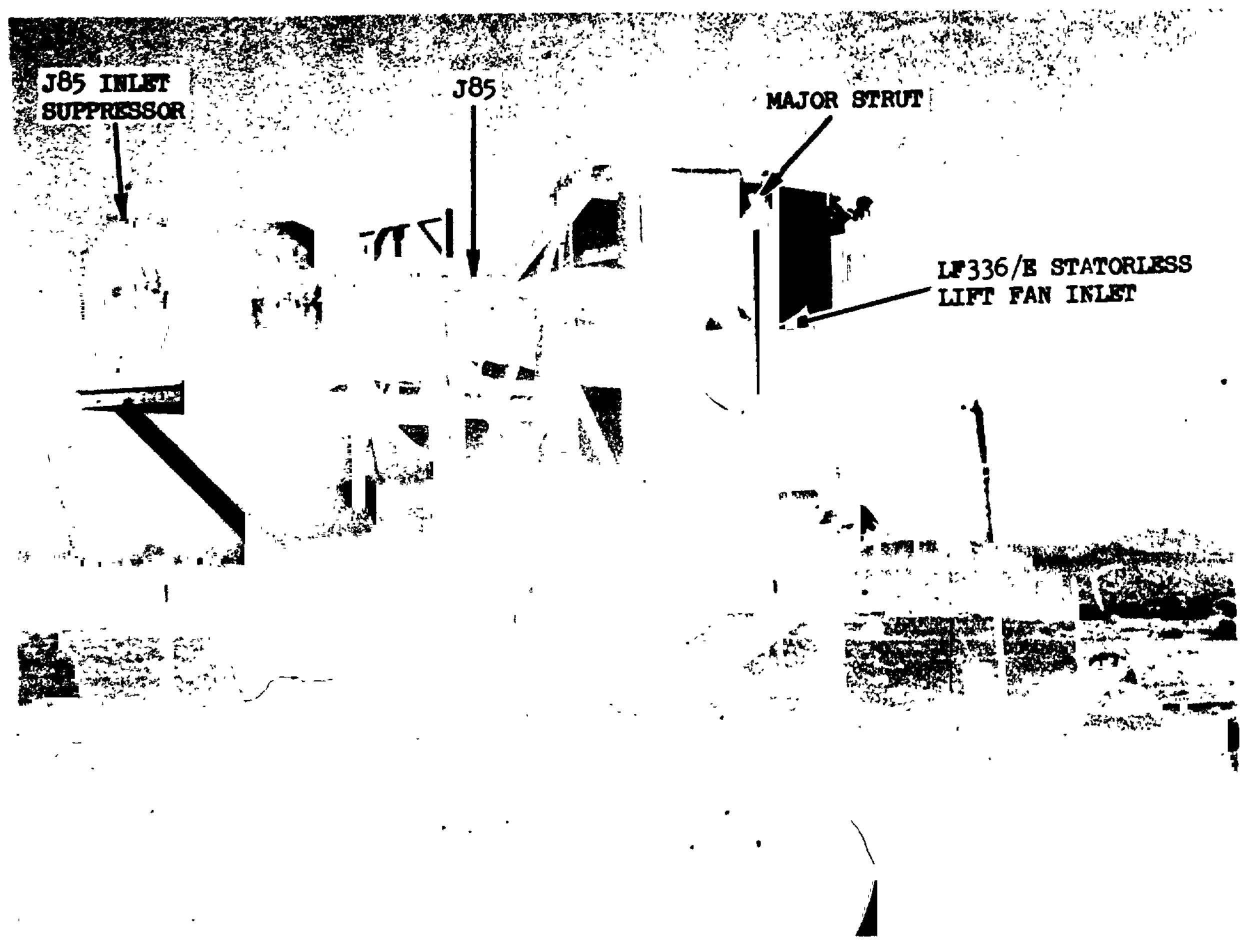


FIGURE 1 PHOTOGRAPH OF THE LF336/E STATORLESS LIFT FAN

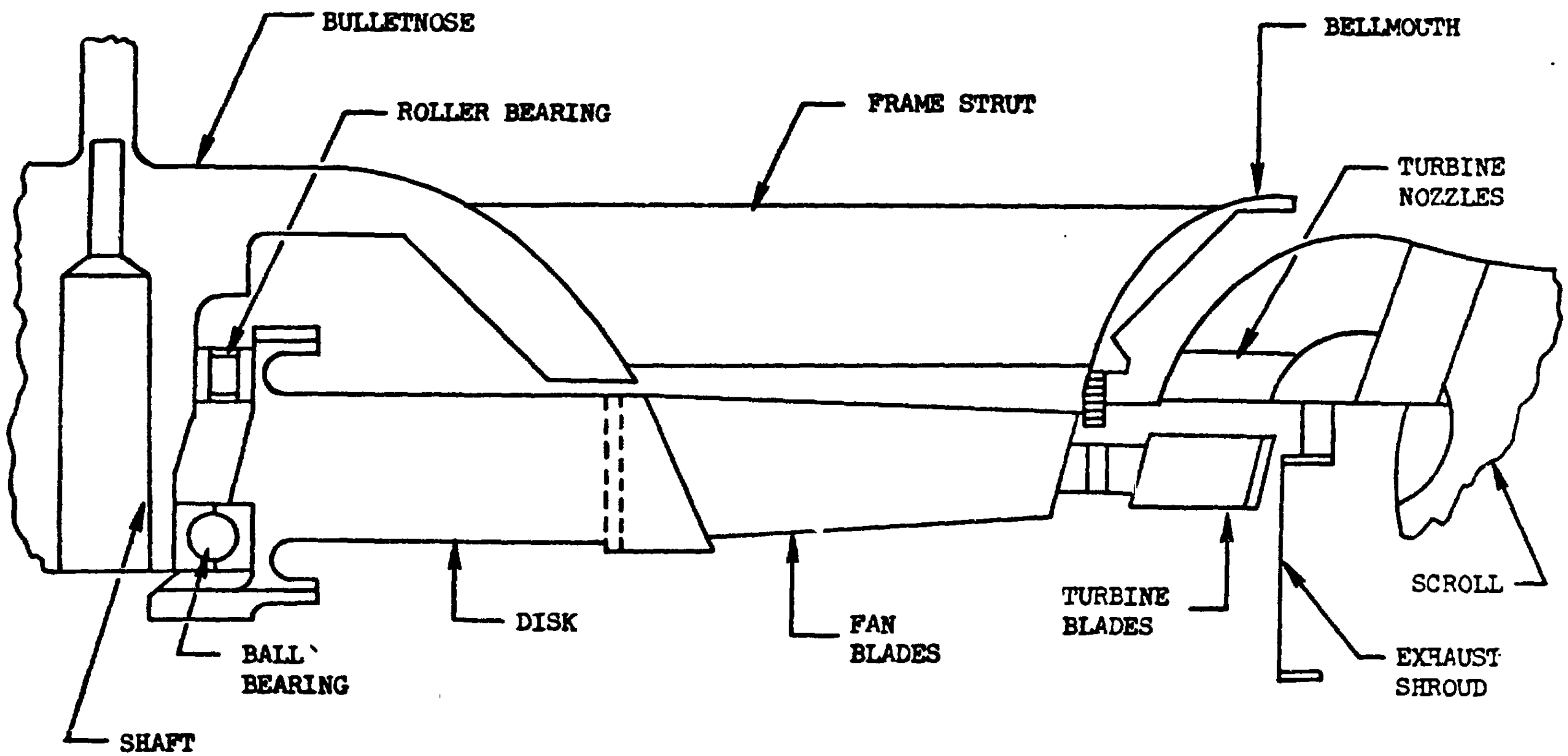
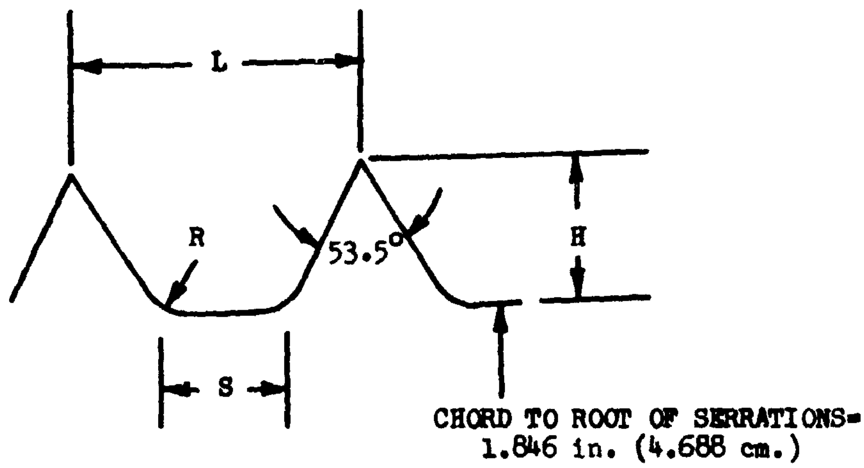


FIGURE 2 CROSS SECTION OF THE LF336/E STATORLESS FAN



H = .116 in. (.295 cm.)
H/C = .063
S = .076 in. (.193 cm.)
L = .193 in. (.490 cm.)
R = .061 in. (.155 cm.)
H/S = 1.5
L/H = 1.66

FIGURE 3. SUMMARY OF SERRATION GEOMETRY

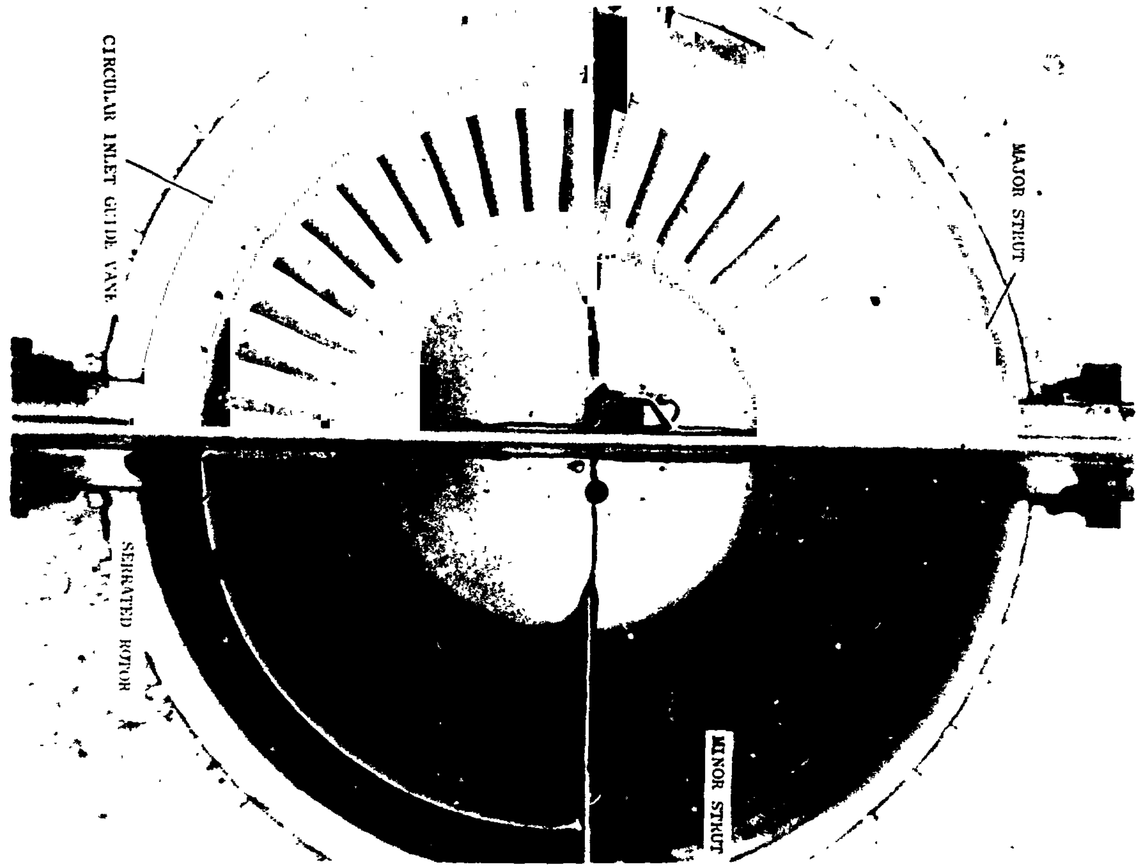


FIGURE 4 PHOTOGRAPH OF THE CIRCULAR IGV INSTALLED ON THE LF336/E

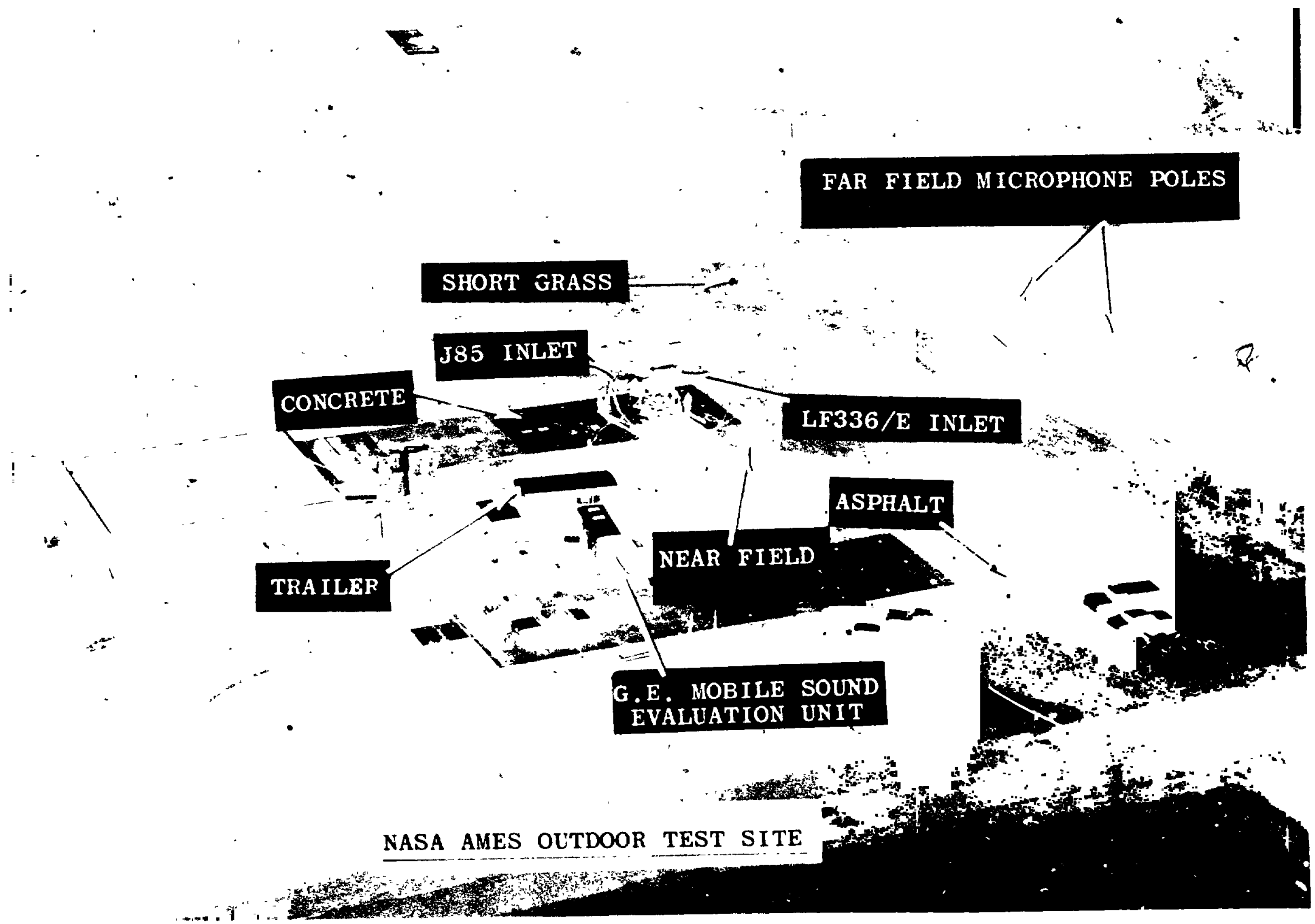


FIGURE 5 AERIAL PHOTOGRAPH OF NASA AMES OUTDOOR TEST SITE

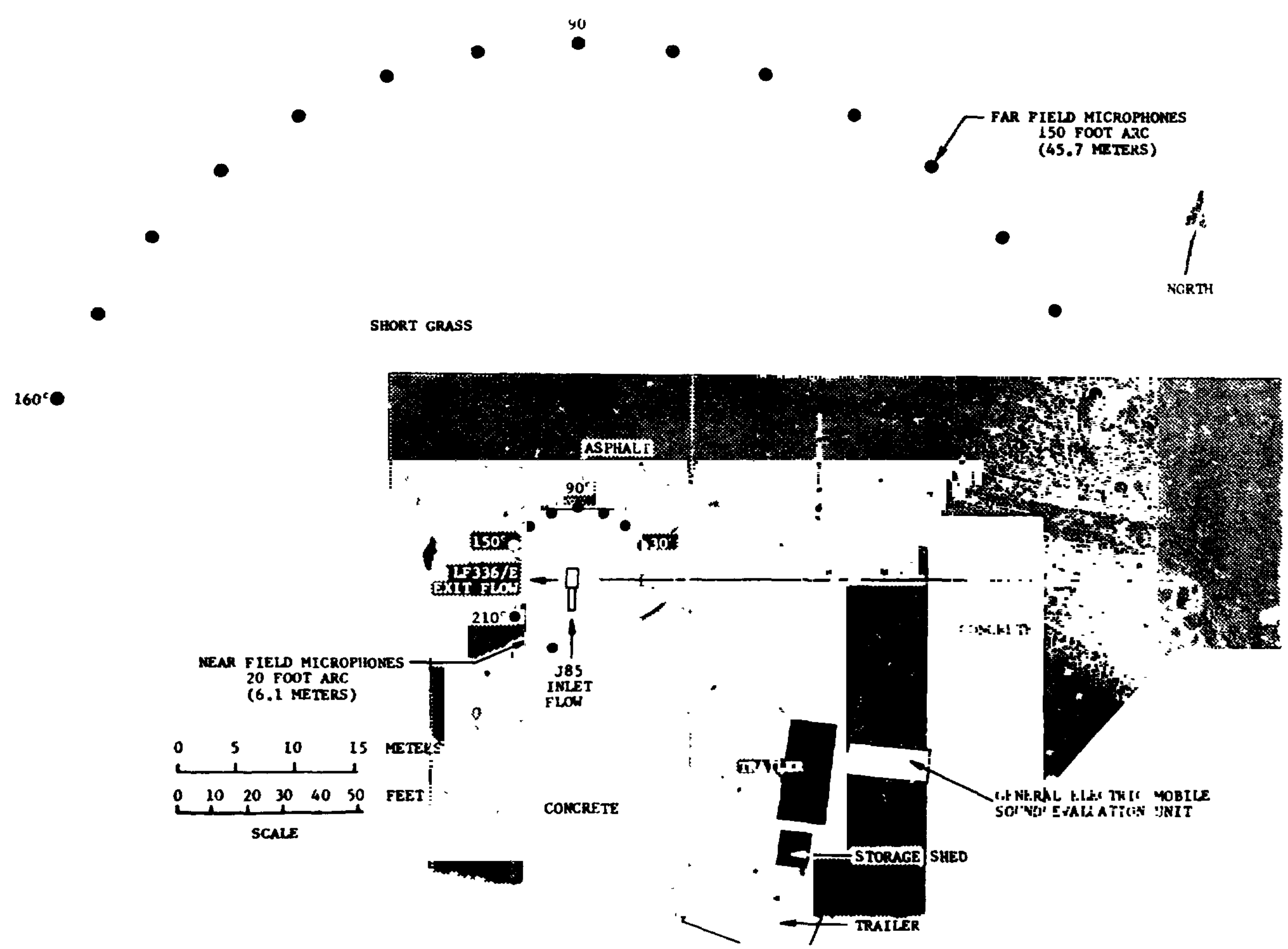


FIGURE 6 MICROPHONE ORIENTATION FOR THE UNSERRATED LF336/E ACOUSTIC TESTS

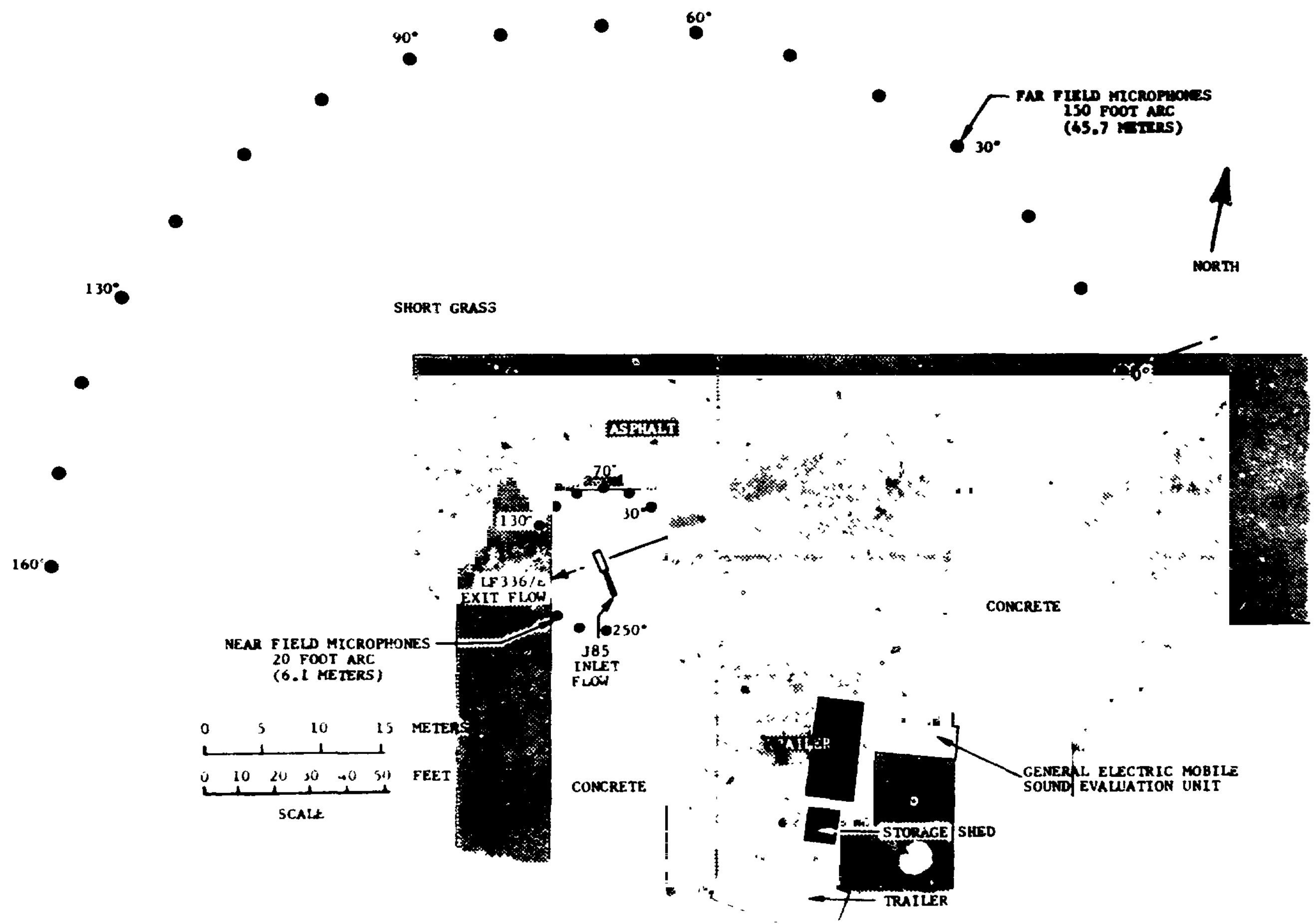


FIGURE 7 MICROPHONE ORIENTATION FOR THE SERRATED LF336/E ACOUSTIC TESTS

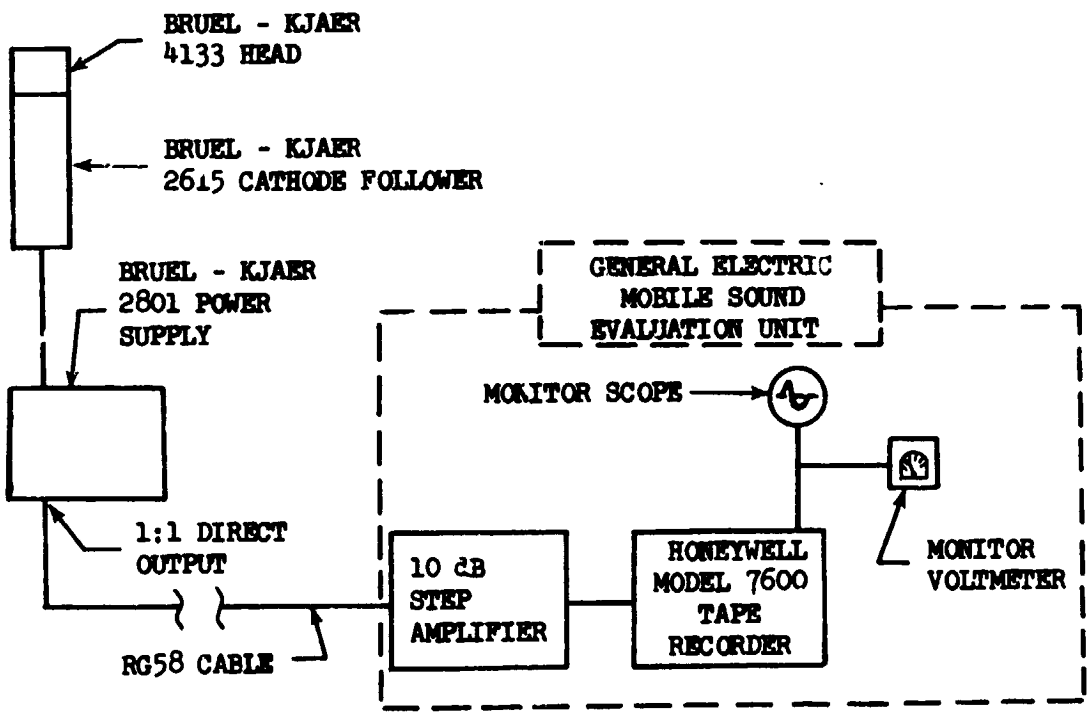


FIGURE 8 ACOUSTIC DATA ACQUISITION AT NASA AMES OUTDOOR SITE

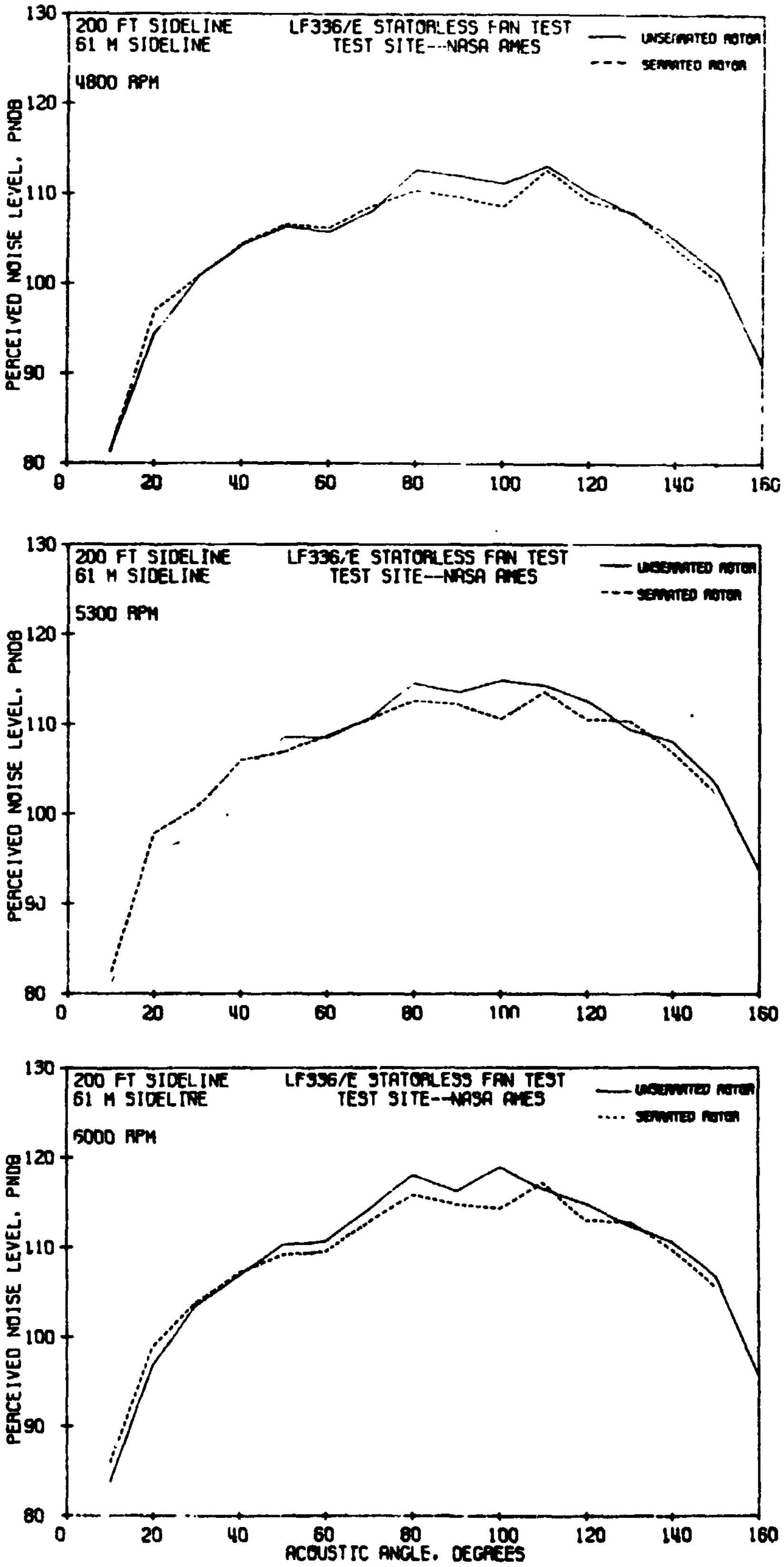


FIGURE 9 SERRATED AND UNSERRATED LF336/E PNL DIRECTIVITY PATTERNS

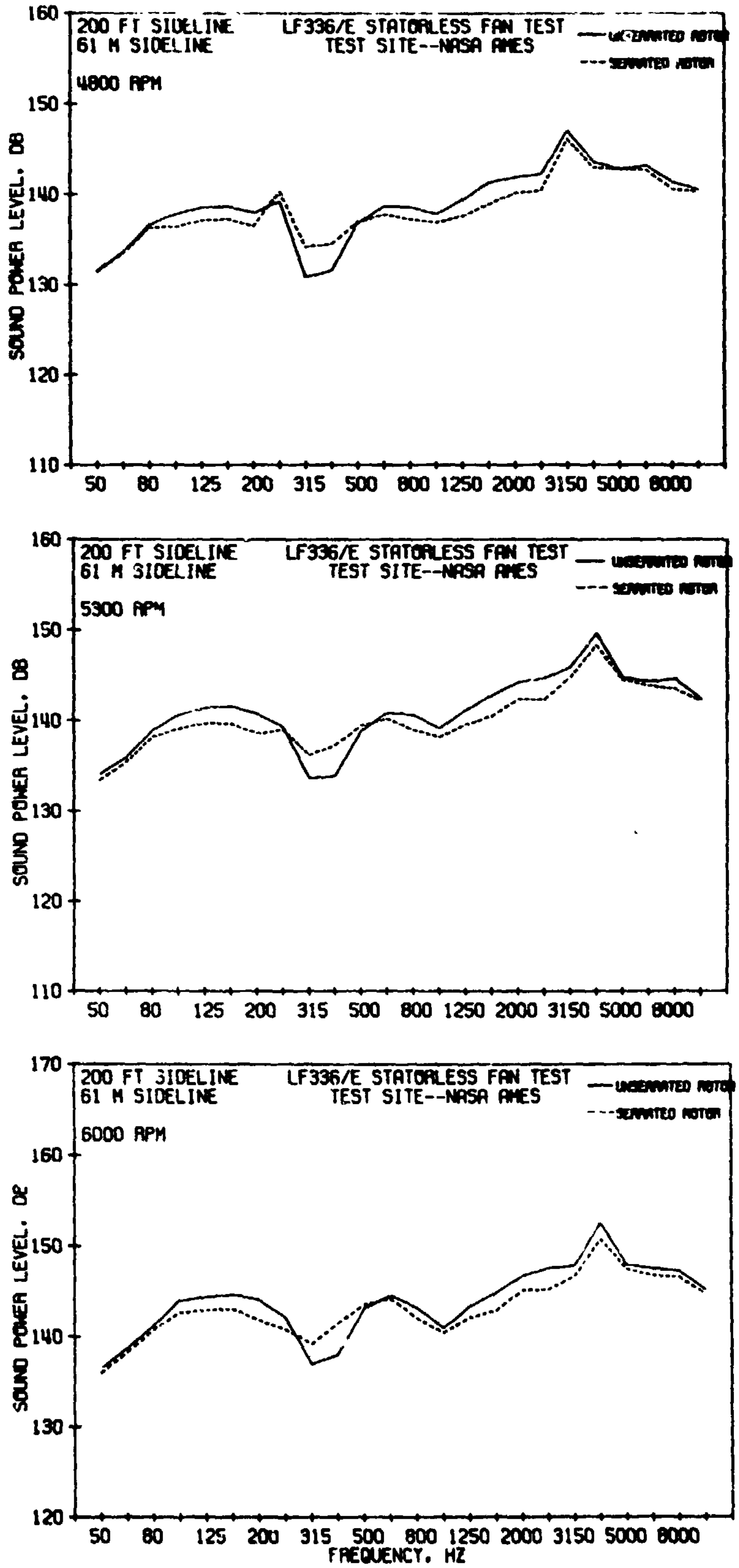


FIGURE 10 SERRATED AND UNSERRATED LF336/E PWL SPECTRA

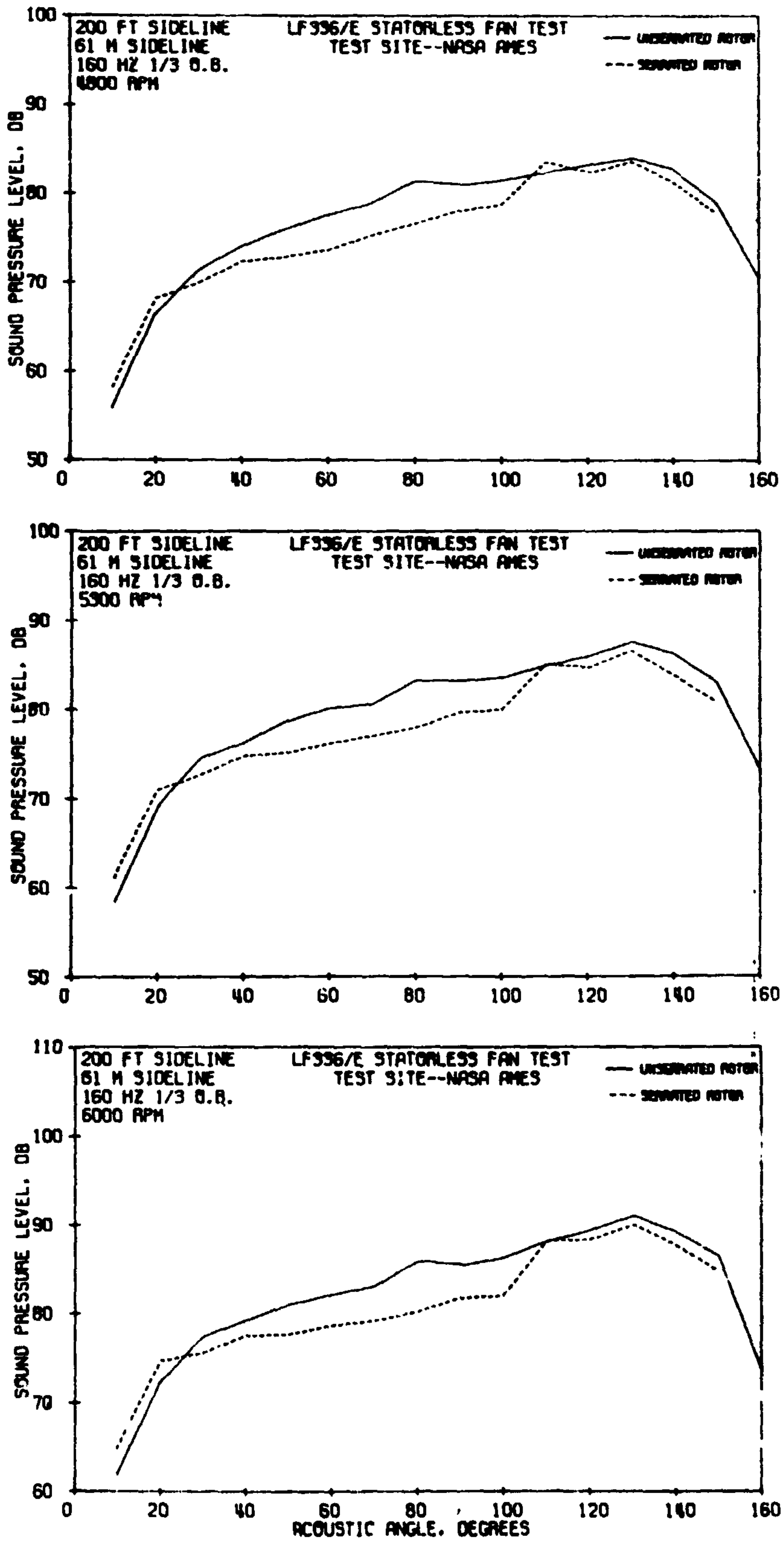


FIGURE 1. SERRATED AND UNSERRATED LF336/E 160 Hz 1/3 OCTAVE BAND SPL DIRECTIVITY PATTERNS

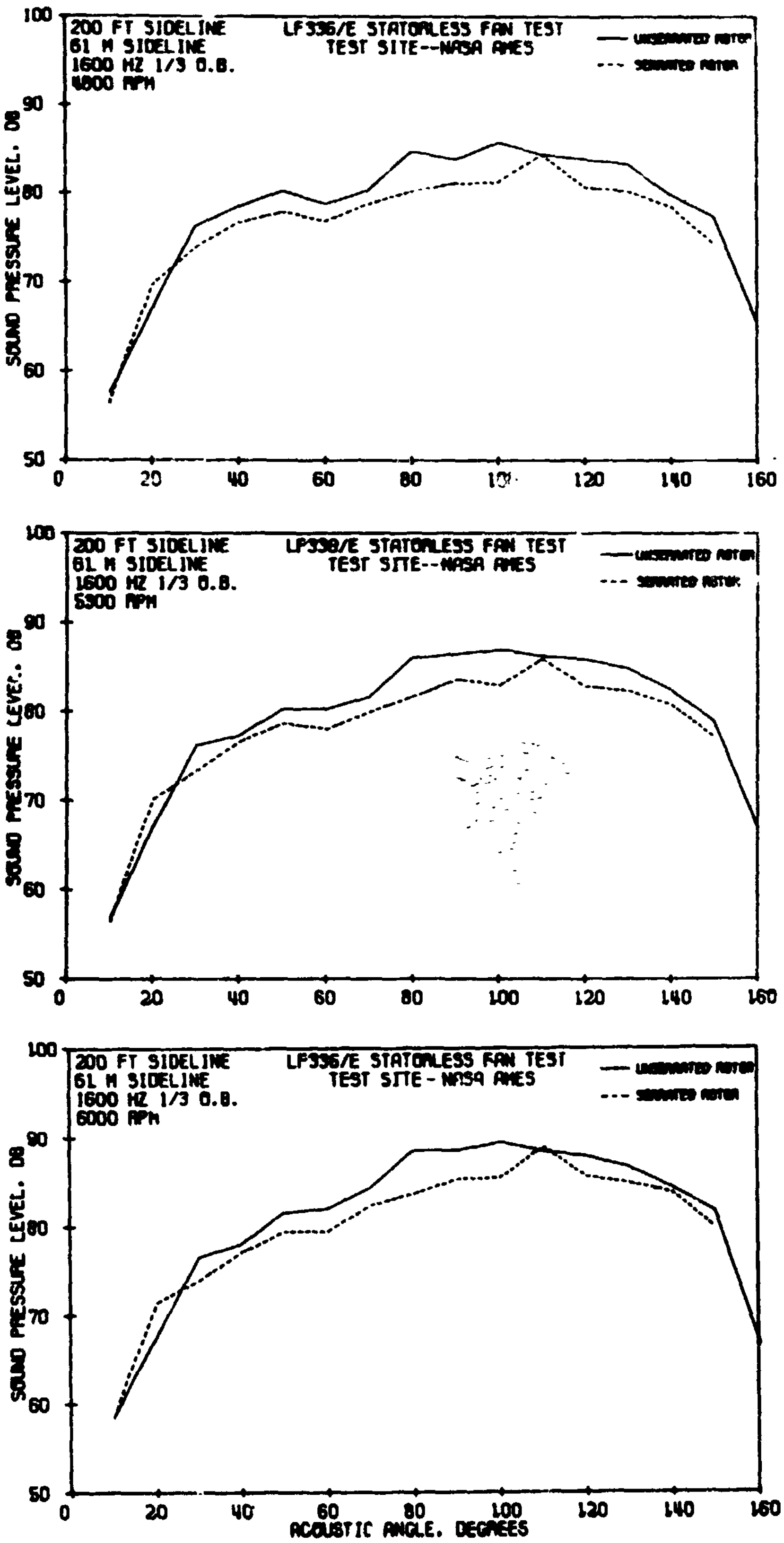


FIGURE 12 SERRATED AND UNSERRATED LF336/E 1600 Hz 1/3 OCTAVE BAND SPL DIRECTIVITY PATTERNS

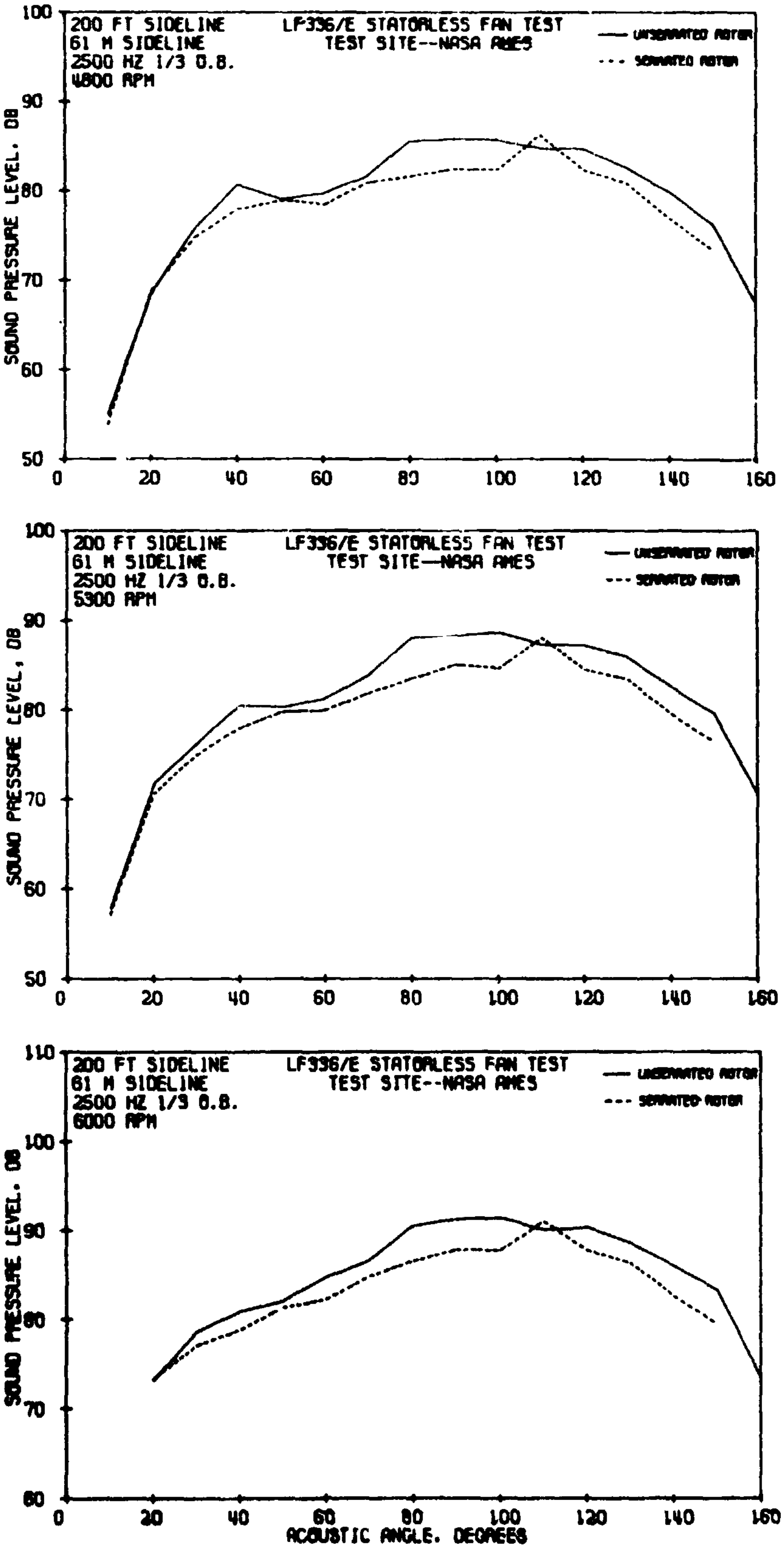
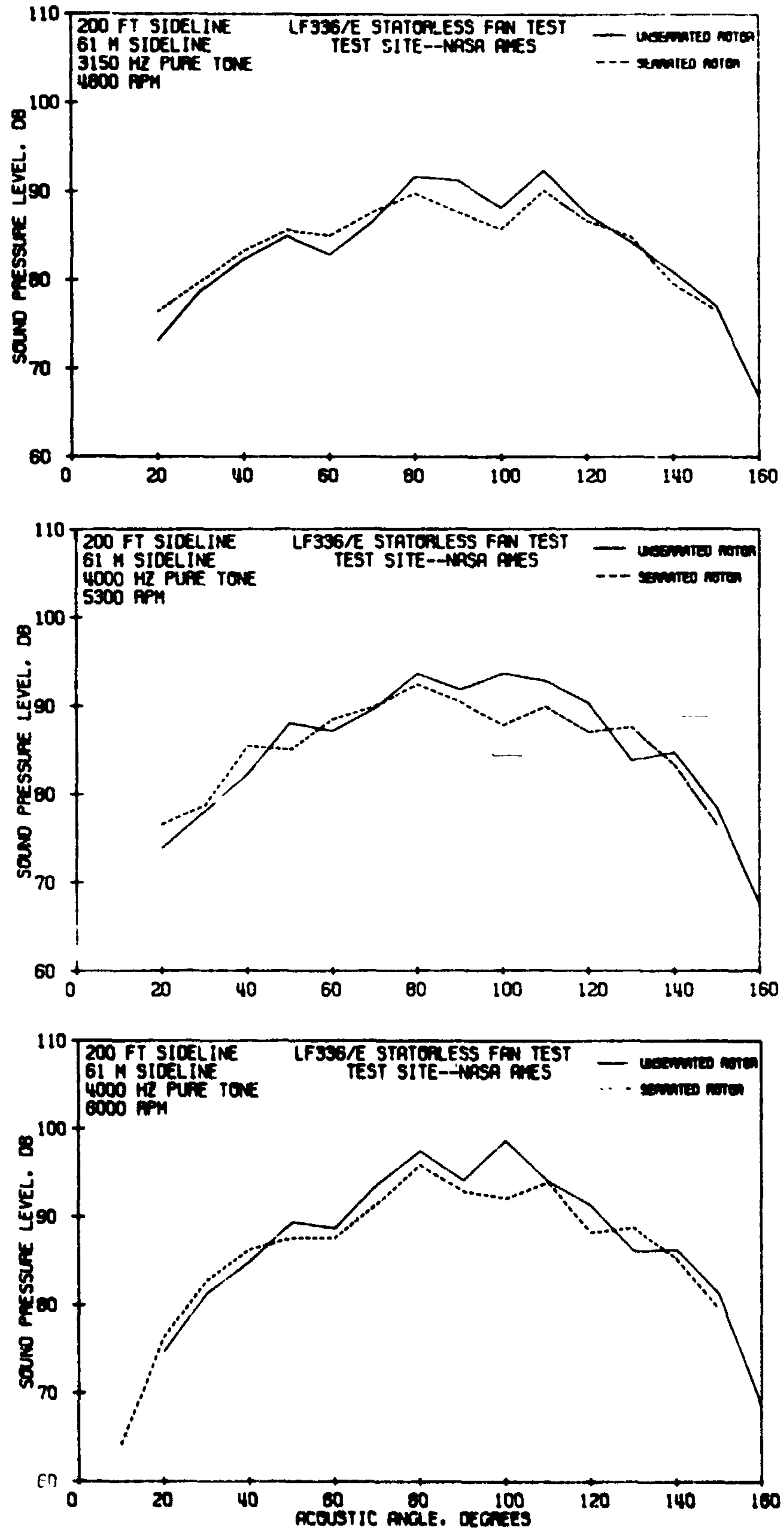


FIGURE 13 SERRATED AND UNSERRATED LF336/E 2500 Hz 1/3 OCTAVE BAND SPL SIRECTIVITY PATTERNS



FIGU' 14 SERRATED AND UNSERRATED LF336/E BPF 1/3 OCTAVE BAND SPL DIRECTIVITY PATTERNS

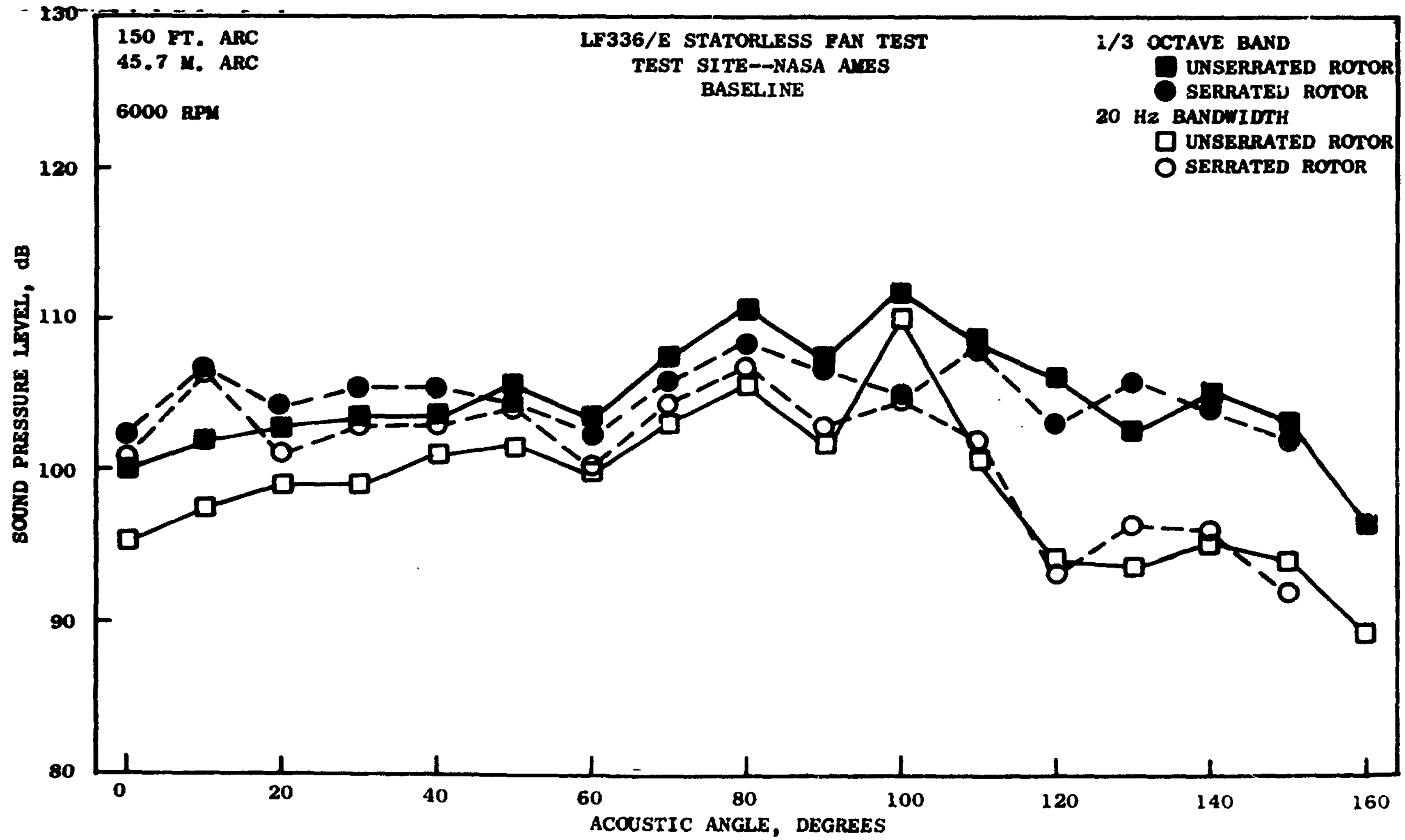


FIGURE 15 SERRATED AND UNSERRATED LF336/E BPF (1/3 OCTAVE BAND AND 20 Hz NARROWBAND) SPL DIRECTIVITY PATTERNS ON A 150 FOOT (45.7 m) ARC

150 FT. ARC
45.7 M. ARC
20 Hz BANDWIDTH
6000 RPM

LF336/E STATORLESS FAN TEST
TEST SITE--NASA AMES

——— UNSERRATED ROTOR
– – – SERRATED ROTOR

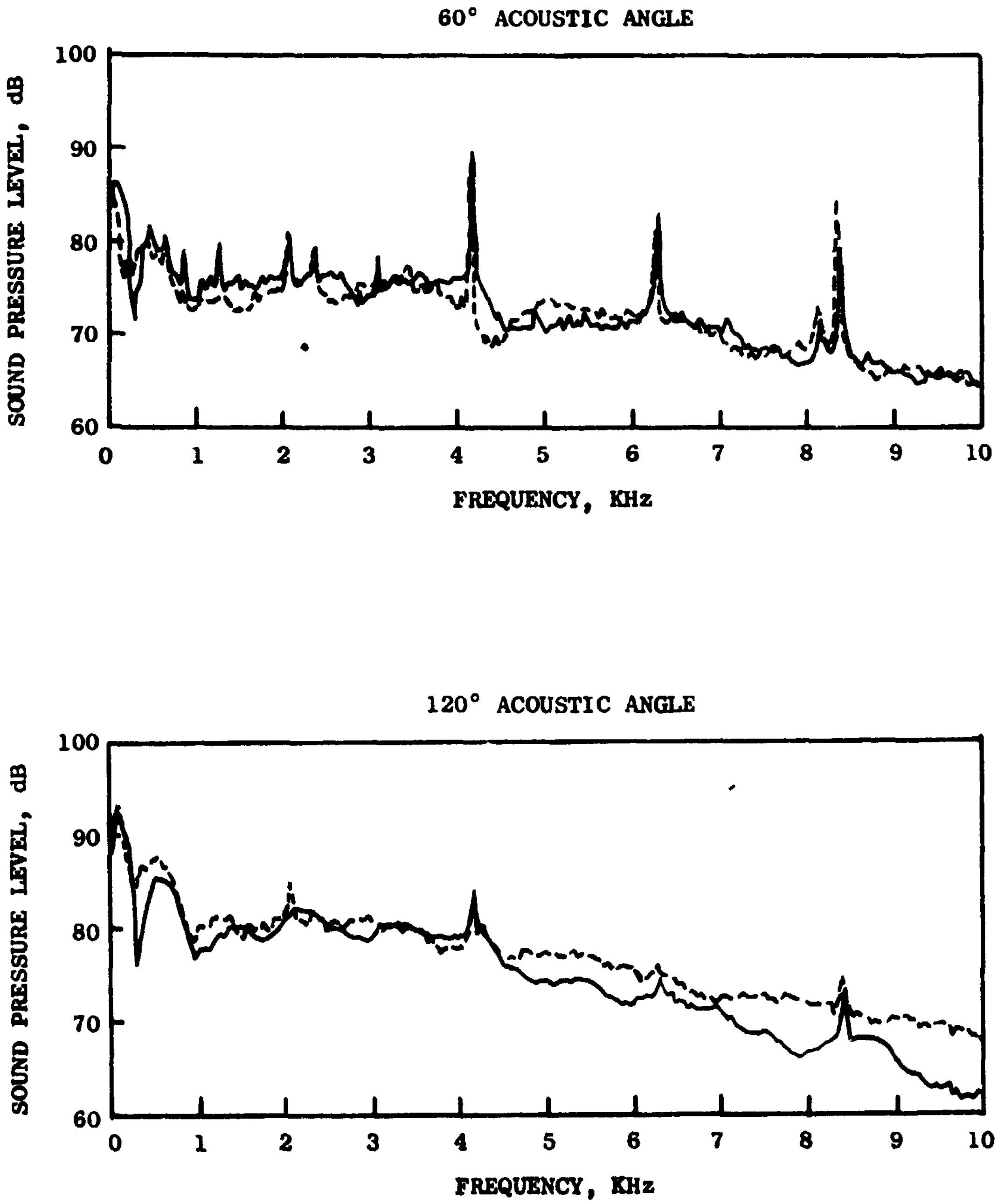


FIGURE 16 SERRATED AND UNSERRATED LF336/E 20 Hz NARROWBAND SPECTRA AT 60 DEGREES

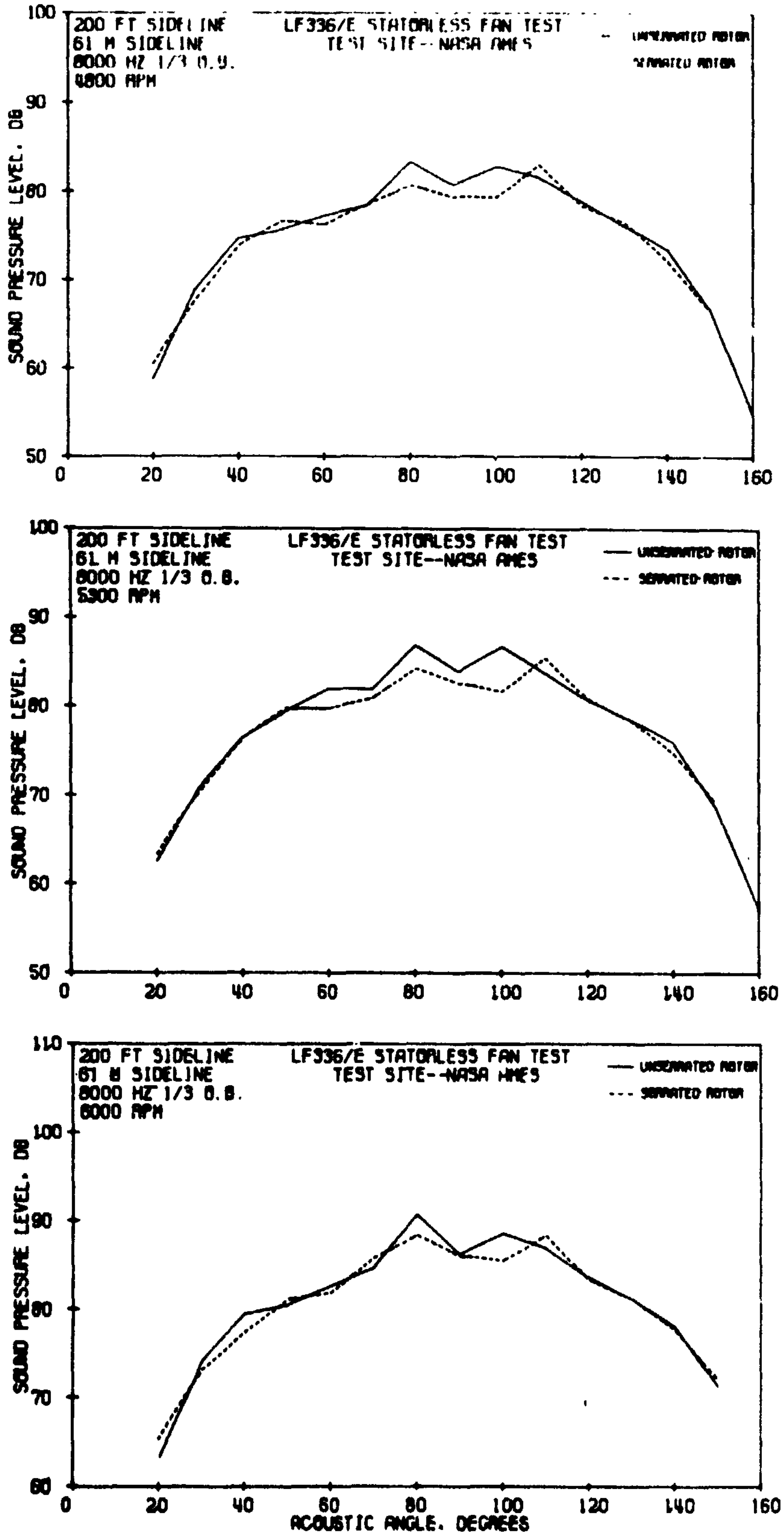
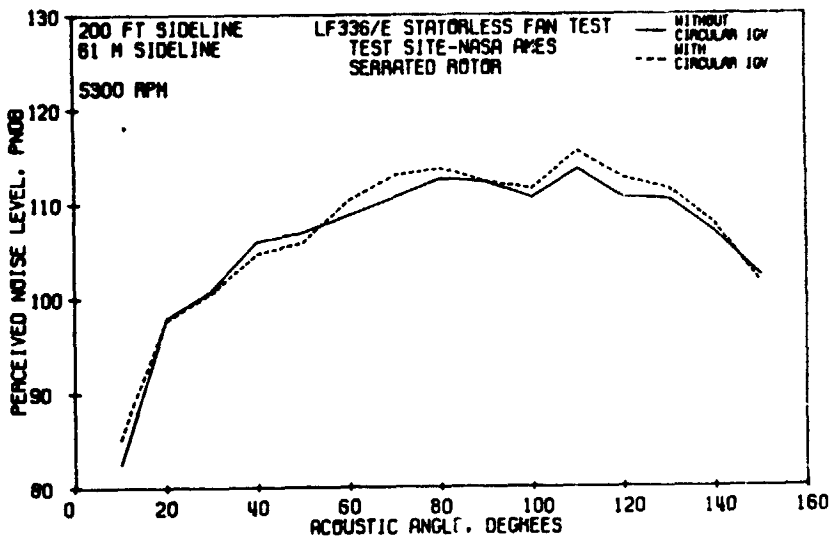


FIGURE 17 SERRATED AND UNSERRATED LF336/E 8000 Hz 1/3 OCTAVE BAND SPL DIRECTIVITY PATTERNS



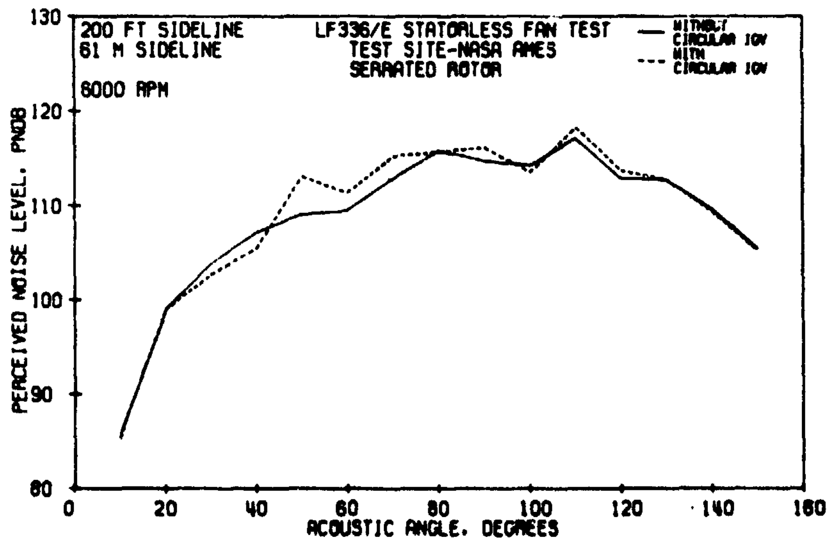


FIGURE 18 SERRATED LF336/E PNL DIRECTIVITY PATTERNS WITH AND WITHOUT A CIRCULAR IGV

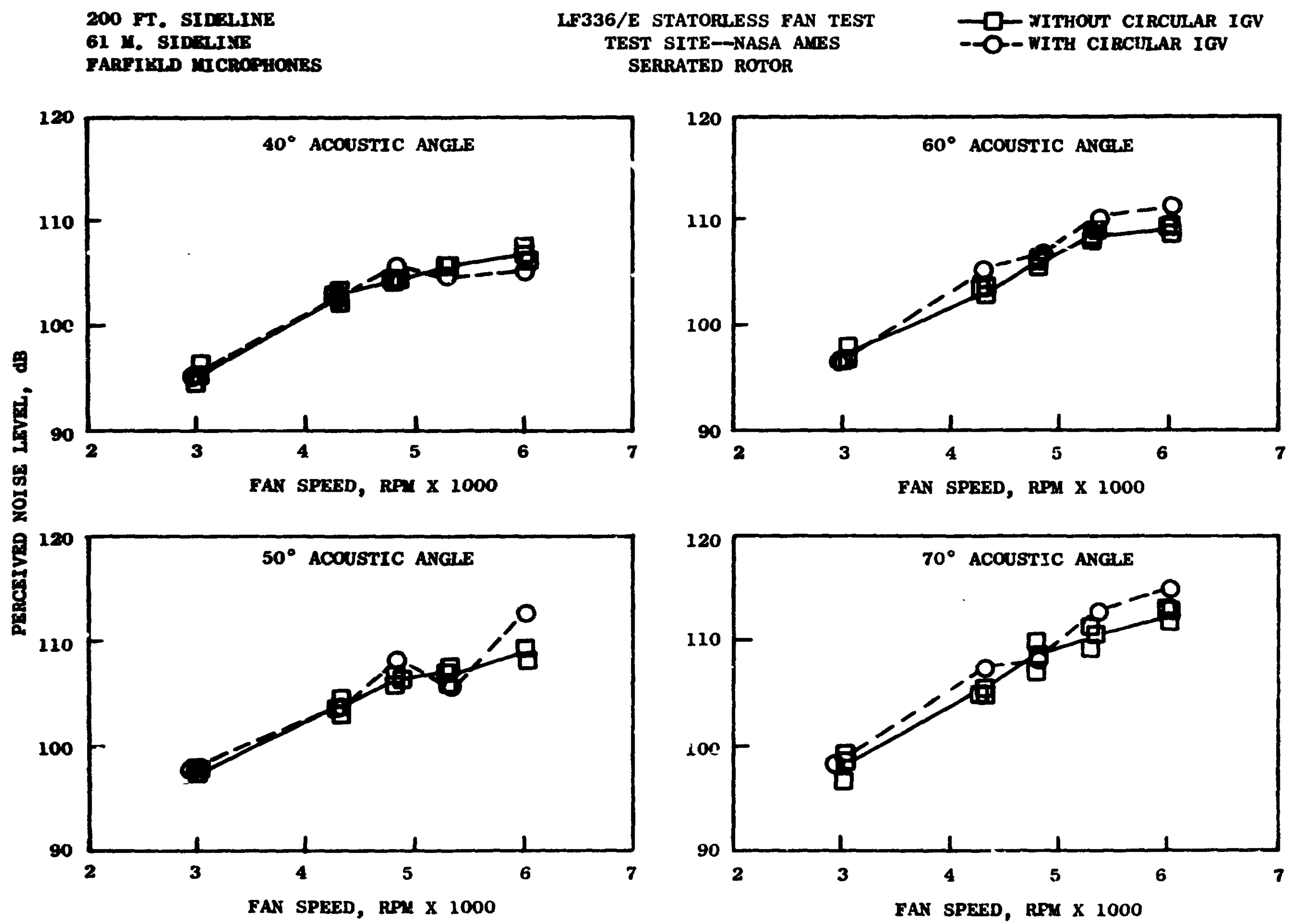
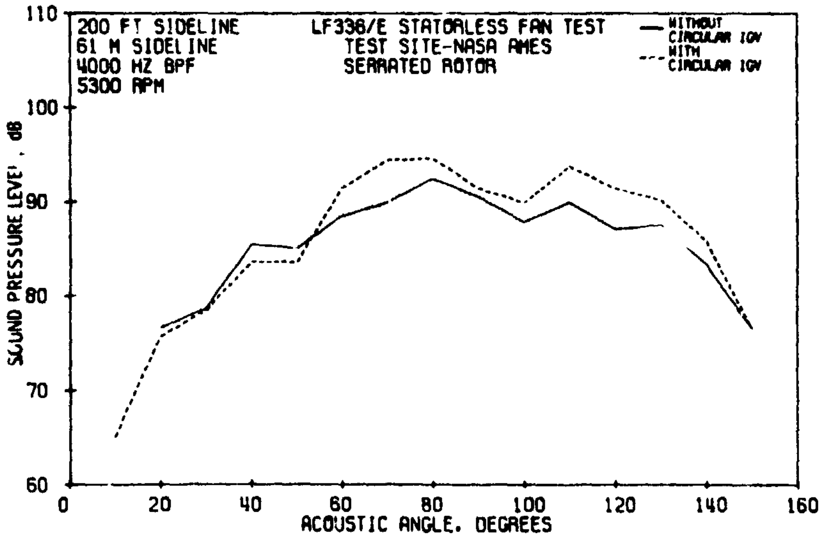


FIGURE 19 SERRATED LF336/E PNL'S WITH AND WITHOUT CIRCULAR IGV AS A FUNCTION OF FAN SPEED



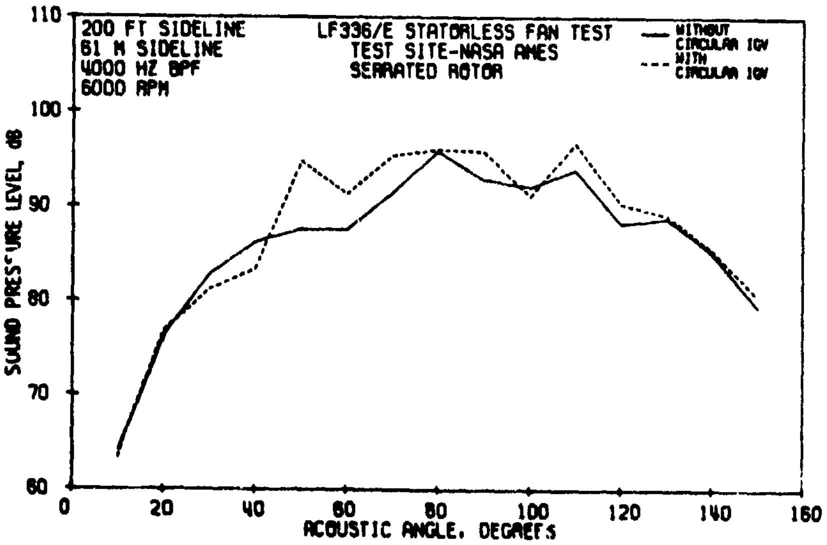


FIGURE 20 **SERRATED LF336/E BPF SPL (1/3 OCTAVE BAND) DIRECTIVITY PATTERNS WITH AND WITHOUT CIRCULAR IGV**

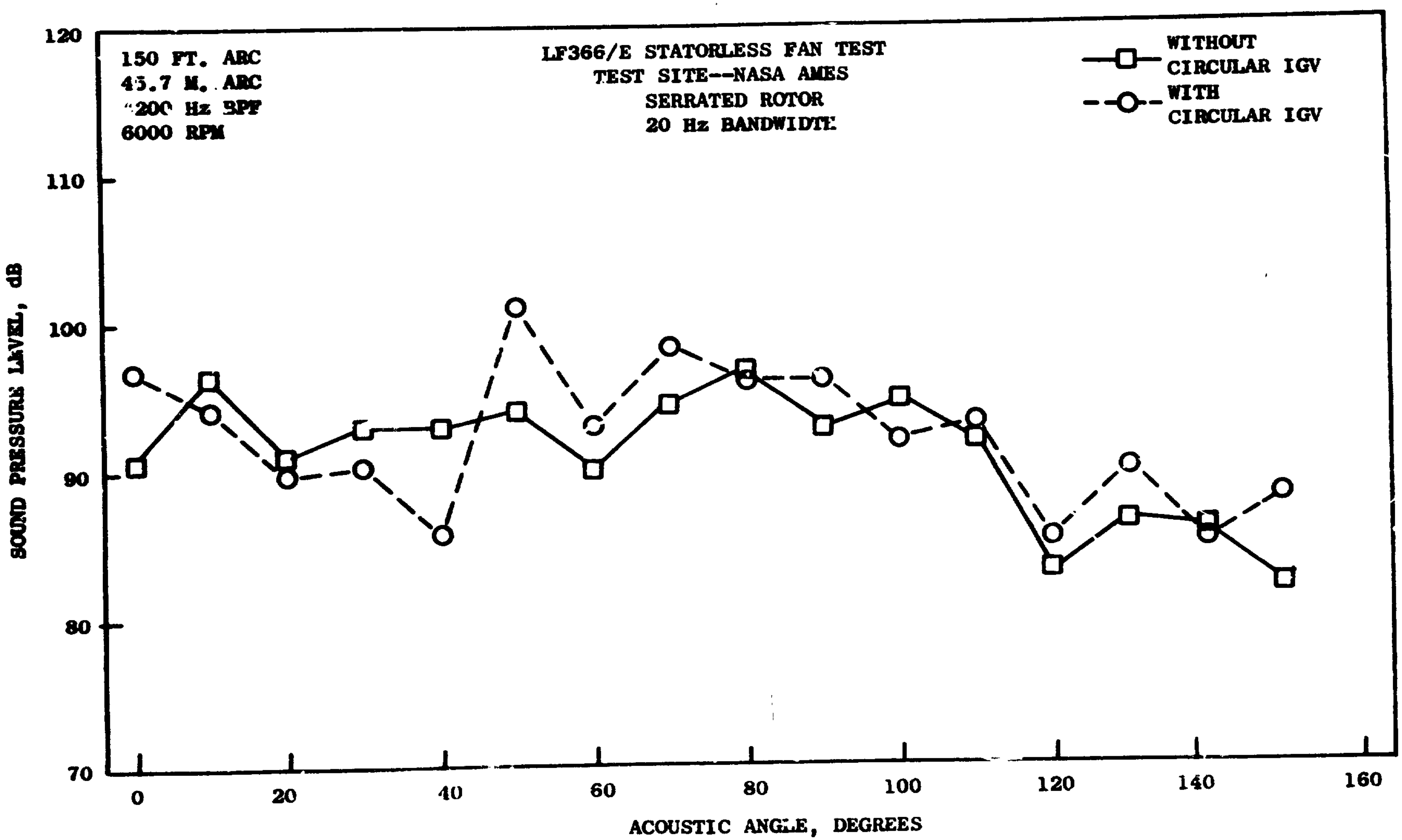


FIGURE 21 SERRATED LF336/E BPF (20 Hz NARROWBAND) DIRECTIVITY PATTERNS WITH AND WITHOUT CIRCULAR IGV

150 FT. ARC
45.7 M. ARC
20 Hz BANDWIDTH
6000 RPM

LF336/E STATORLESS FAN TEST
TEST SITE—NASA AMES
SERRATED ROTOR

——— WITHOUT CIRCULAR IGV
- - - - WITH CIRCULAR IGV

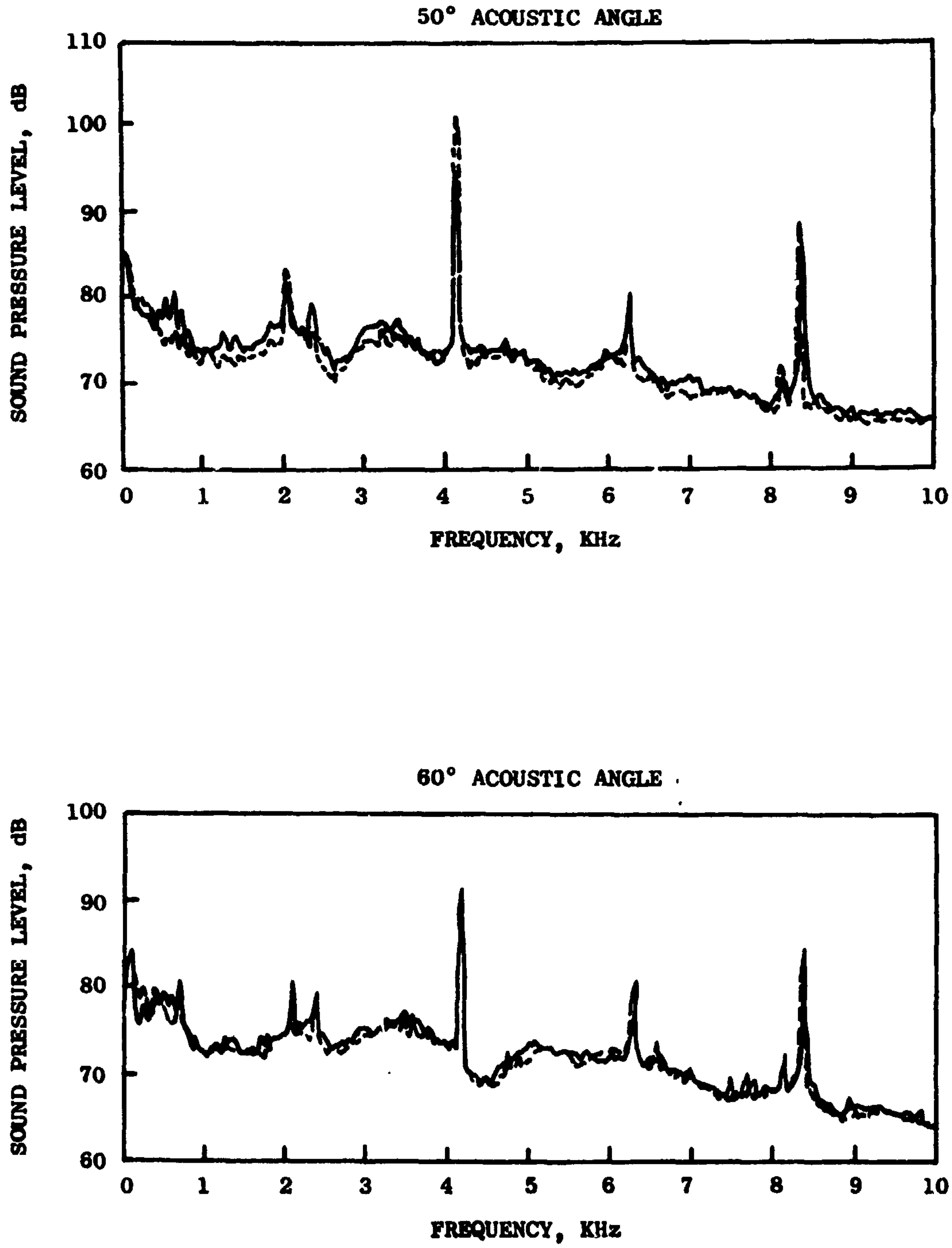


FIGURE 22 SERRATED LF336/E NARROWBAND SPECTRA AT 50 DEGREES WITH AND WITHOUT CIRCULAR IGV

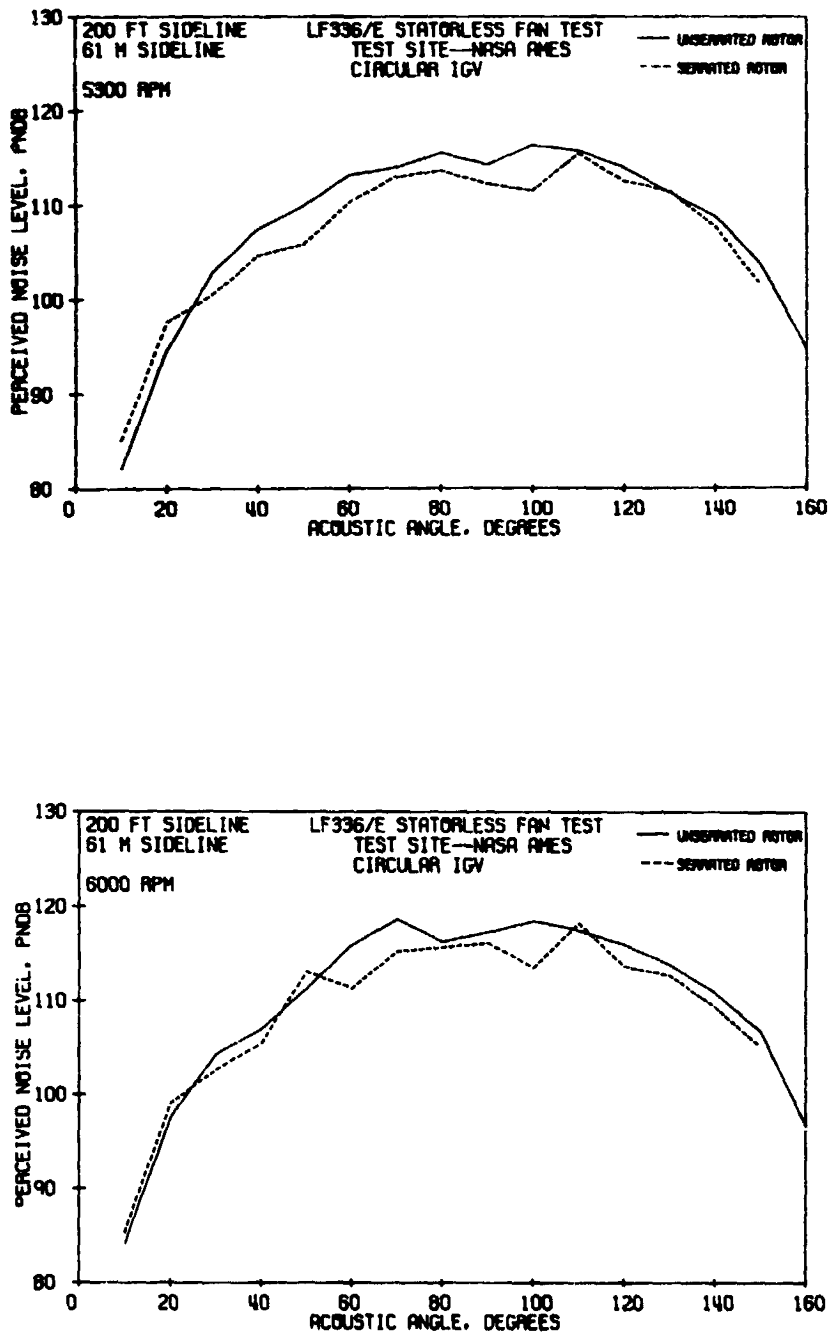


FIGURE 23 SERRATED AND UNSERRATED LF336/E PNL DIRECTIVITY PATTERNS WITH CIRCULAR IGV

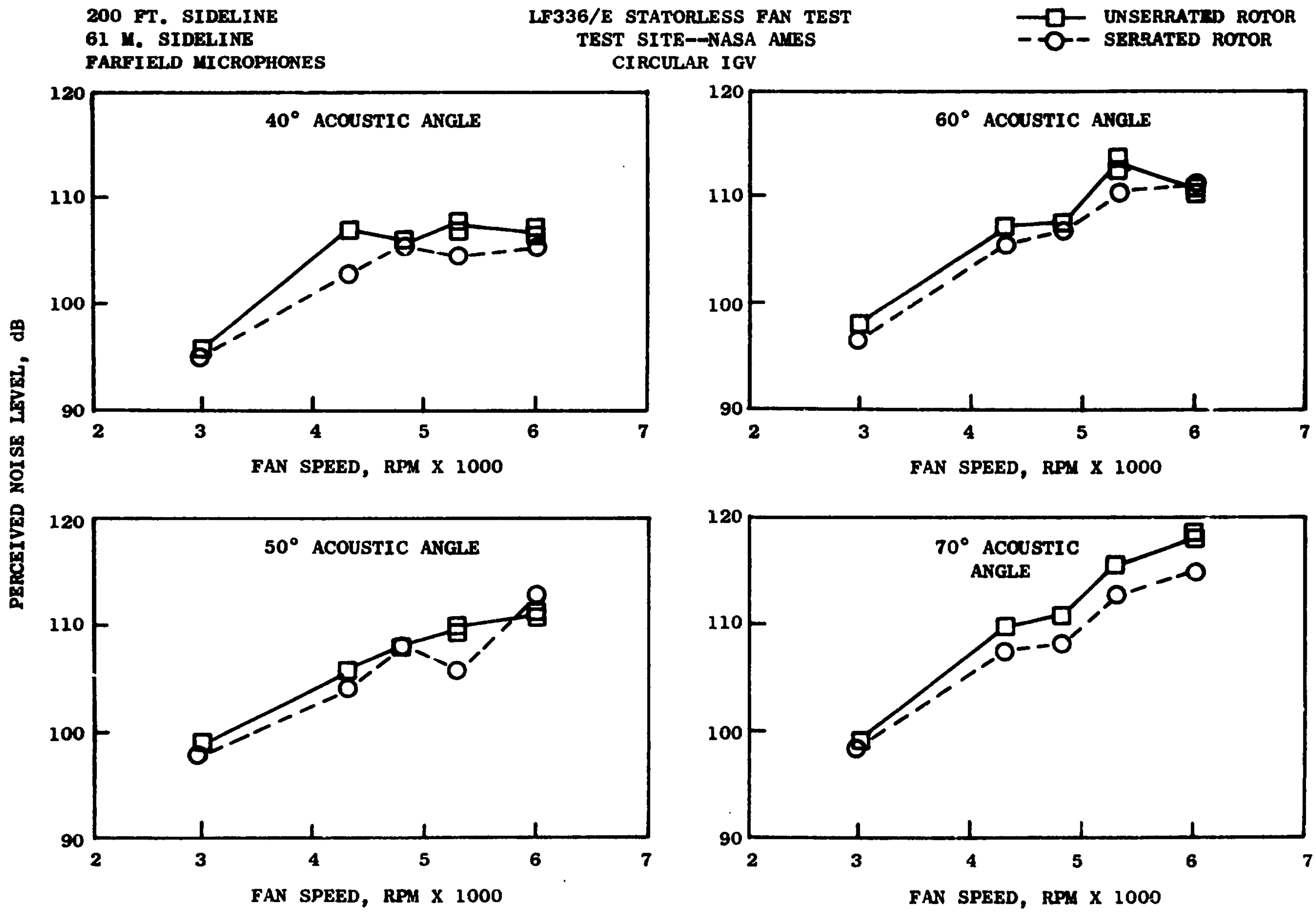


FIGURE 24 SERRATED AND UNSERRATED LF336/E PNL'S WITH CIRCULAR IGV'S COMPARED AS A FUNCTION OF FAN SPEED

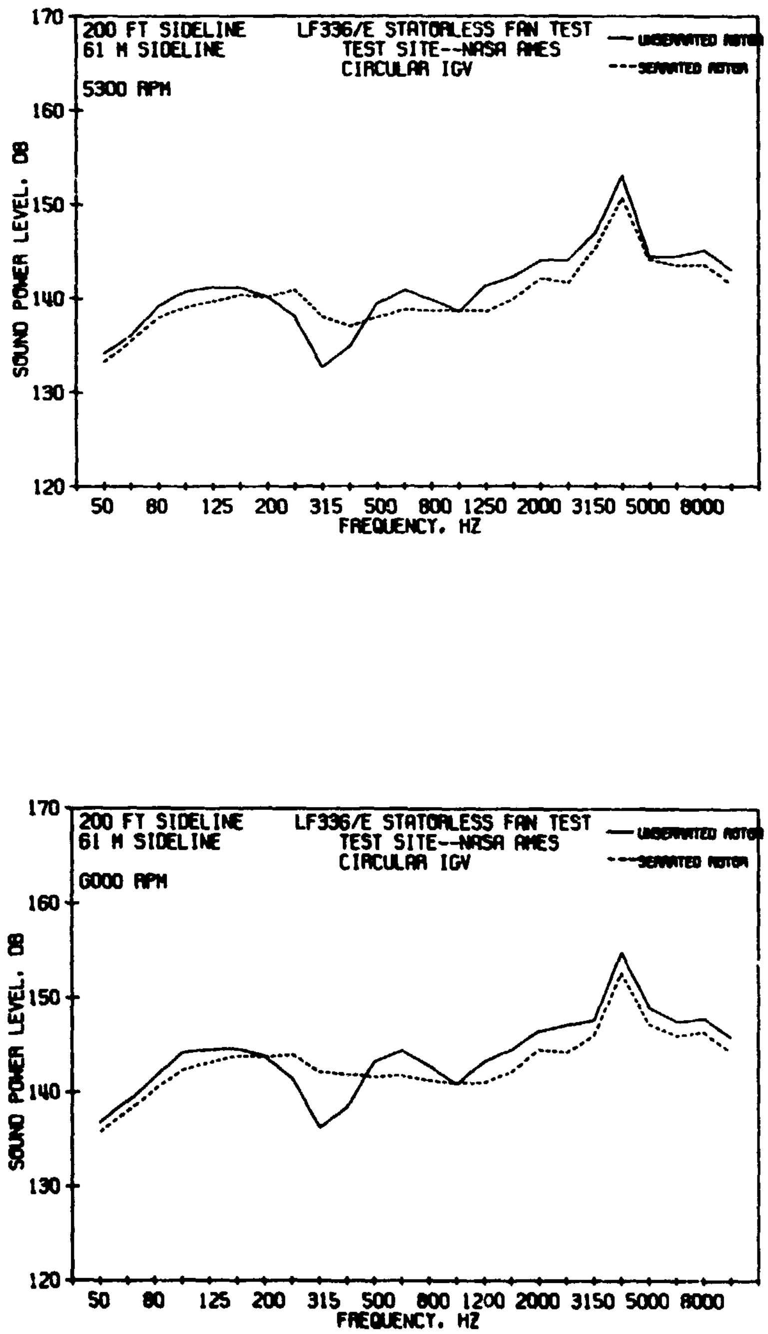
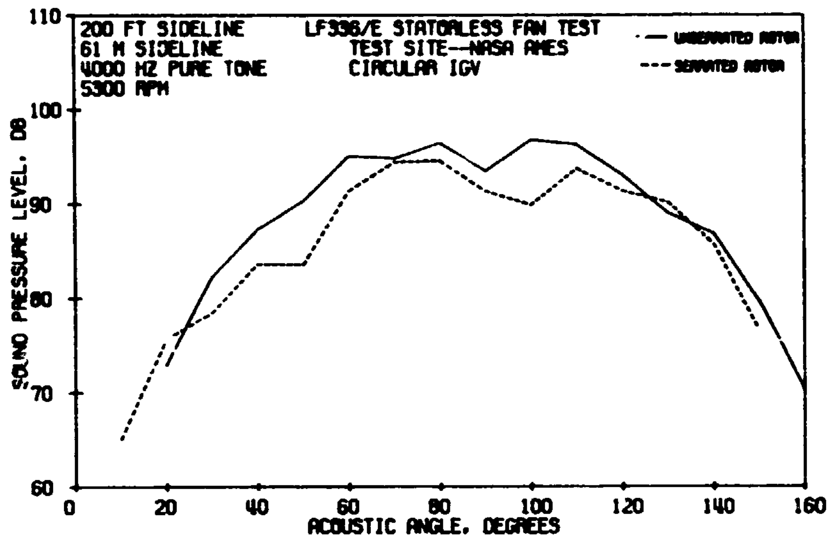


FIGURE 25 SERRATED AND UNSERRATED LF336/E PWL SPECTRA WITH CIRCULAR IGV



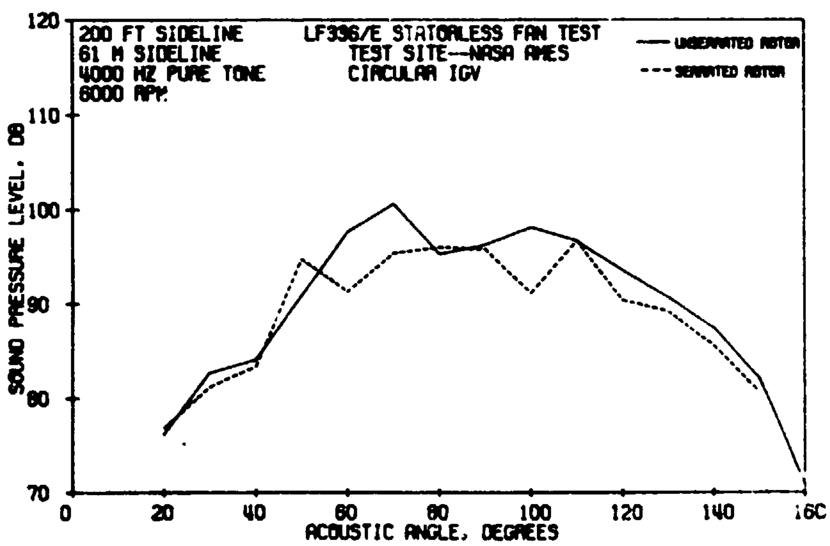


FIGURE 26 SERRATED AND UNSERRATED LF336/E BPF 1/3 OCTAVE BAND SPL DIRECTIVITY PATTERNS WITH CIRCULAR IGV

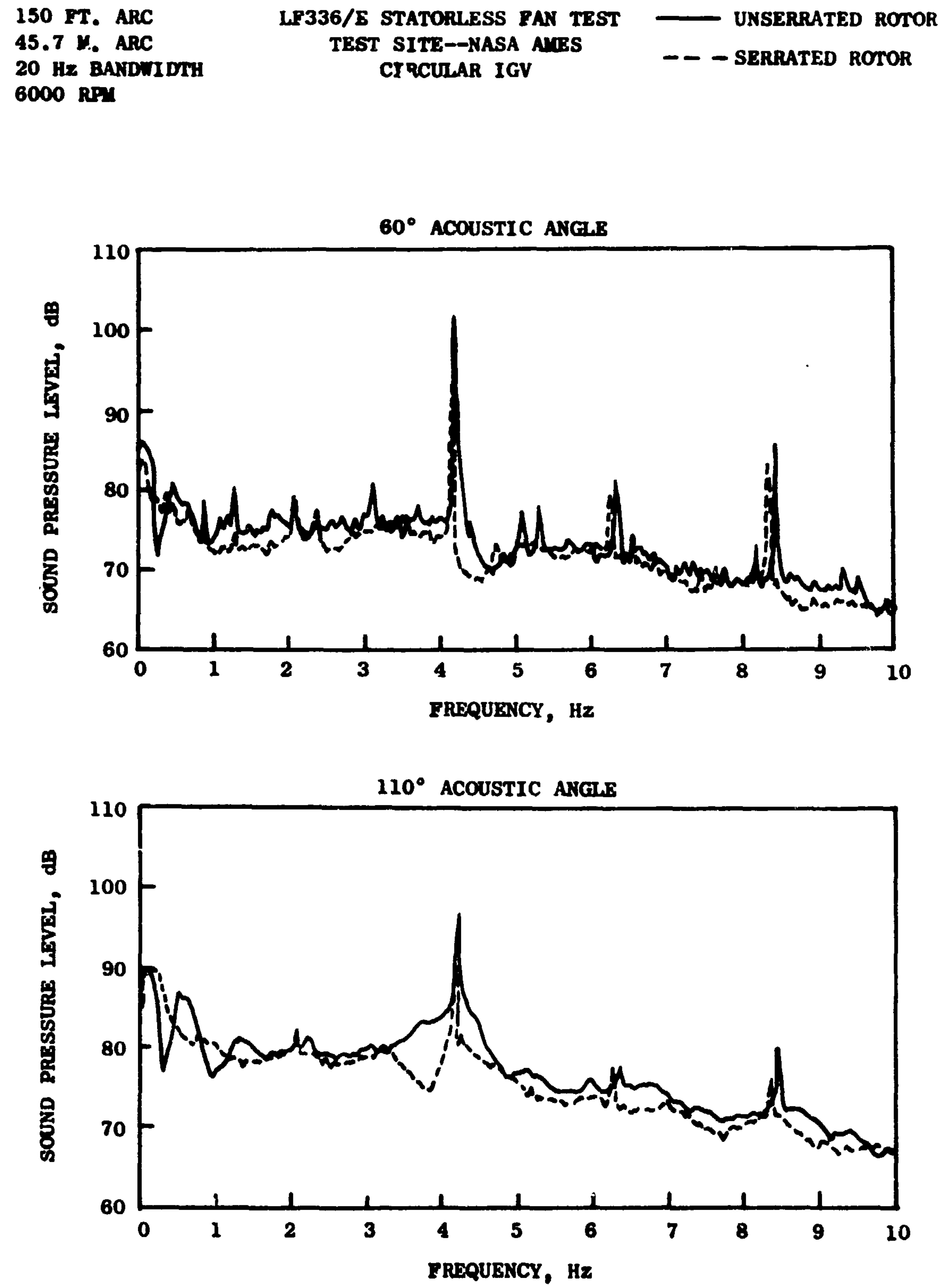
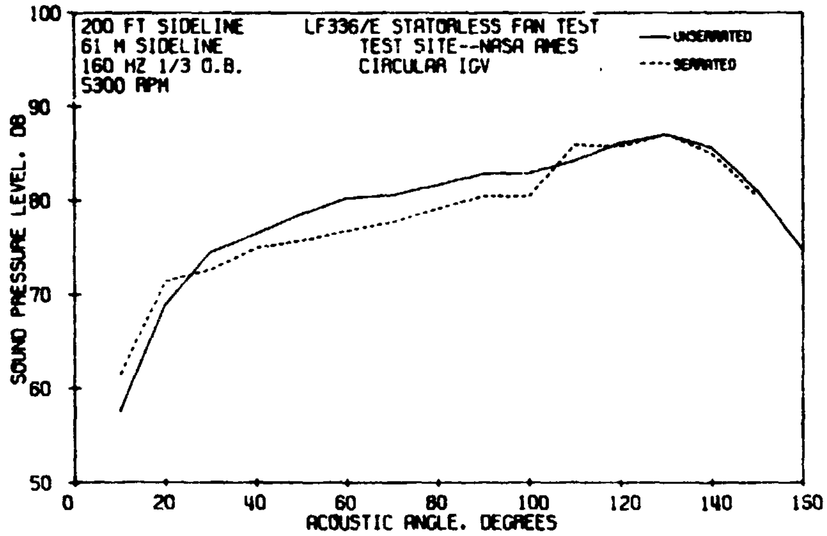


FIGURE 27 SERRATED AND UNSERRATED LF336/E NARROWBAND SPECTRA WITH CIRCULAR IGV



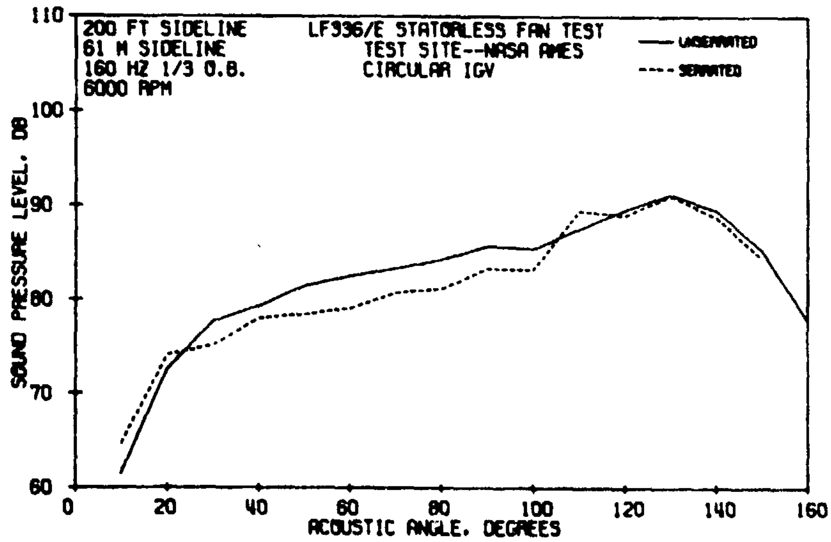
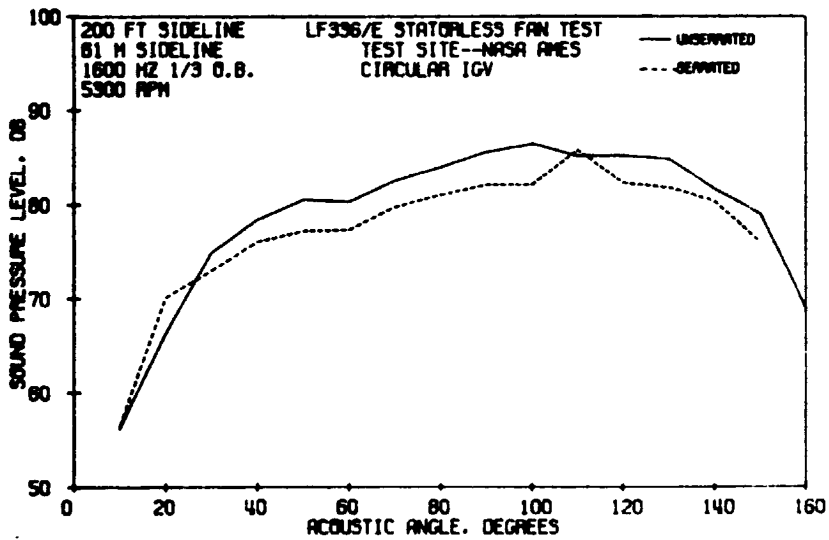


FIGURE 28 SERRATED AND UNSERRATED LF336/E WITH CIRCULAR IGV 160 Hz 1/3 OCTAVE BAND SPL DIRECTIVITY PATTERNS



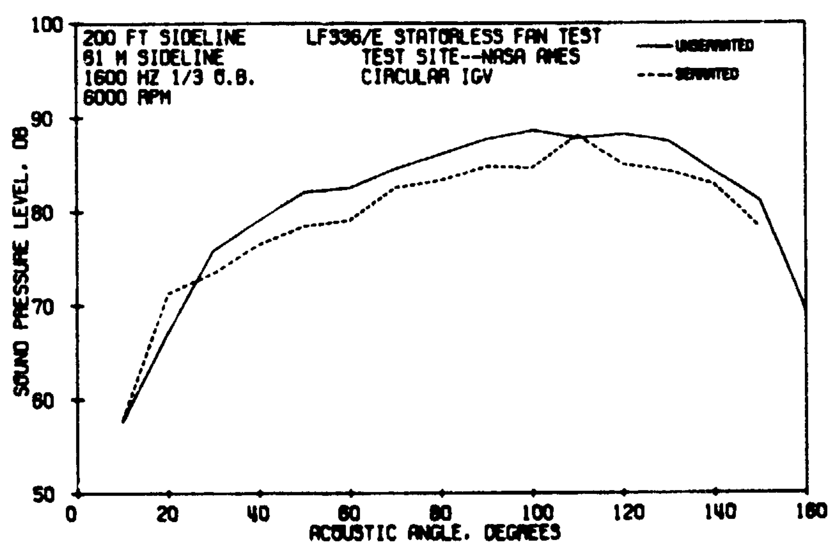
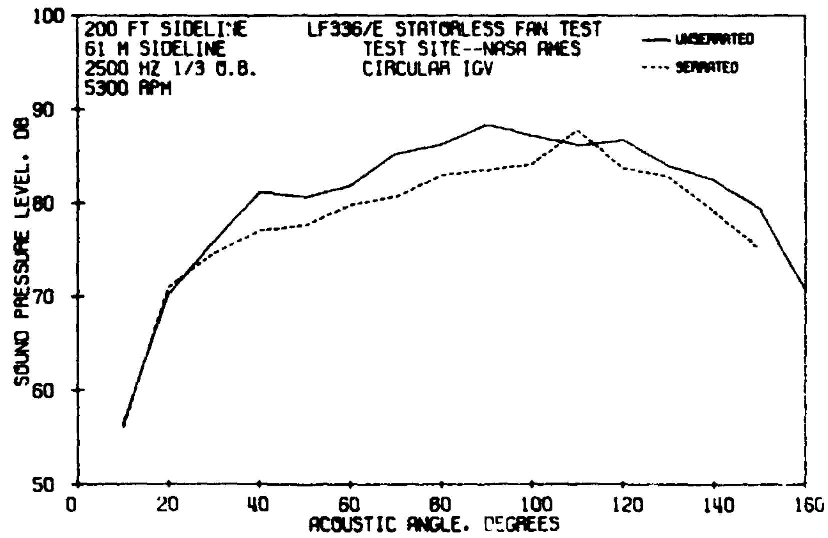


FIGURE 29 SERRATED AND UNSERRATED LF336/E WITH CIRCULAR IGV 1600 Hz 1/3 OCTAVE BAND SPL DIRECTIVITY PATTERNS



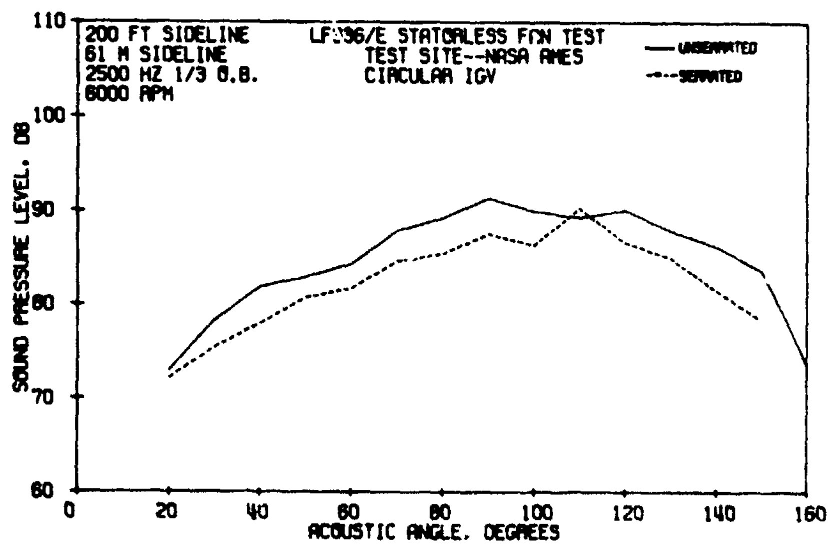
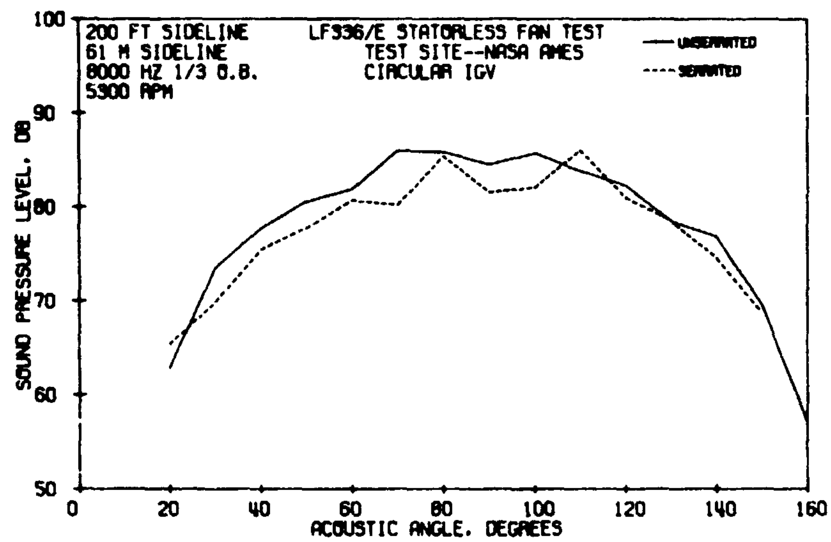


FIGURE 30 **SERRATED AND UNSERRATED LF336/E WITH CIRCULAR IG' 2500 Hz 1/3 OCTAVE BAND SPL DIRECTIVITY PATTERNS**



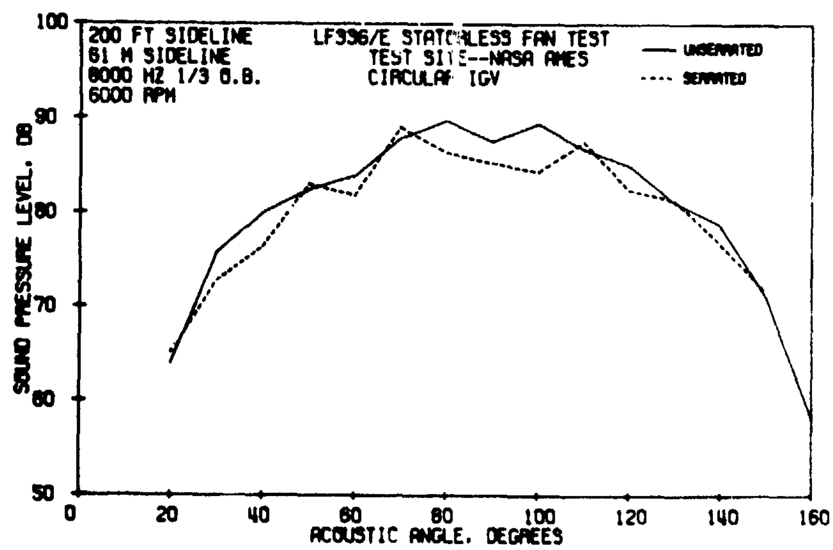


FIGURE 31 SERRATED AND UNSERRATED LF336/E WITH CIRCULAR IGV 8000 Hz 1/3 OCTAVE BAND SPL DIRECTIVITY PATTERNS