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ACOUSTIC ENVIRONMENTS OF THE F-111A AIRCRAFT DURING GROUND RUNUP

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FOREWORD

The measurement program and analyses reported herein was performed by the Biodynamics and Bionics Division, Biomedical Laboratory of the Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio. The program was conducted by Mr. John N. Cole and Justus F. Rose, Jr., Major, USAF, Biodynamic Environment Branch, under Project 7231, "Biomechanics of Aerospace Operations," and Task 723104, "Biodynamic Environment of Aerospace Flight Operations." Acknowledgement is made of the assistance of Messrs. R. E. England and H. K. Hille. The research was initiated August 1967 and completed January 1968.

This technical report has been reviewed and is approved.

WAYNE H. McCANDLESS
Technical Director
Biomedical Laboratory
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ABSTRACT

Sound pressure level measurements were made on an F-111A aircraft at 250-foot radial distance with three different engine power configurations at Wright-Patterson AFB, Ohio. In addition, sound level measurements were made at four maintenance positions where personnel would typically be located during normal ground operations. These data were used to compute the power spectra, directivity indices, equal sound pressure level contours, equal perceived noise level contours, and equal speech interference level contours. These results are presented in graphical form and can be used to determine the acoustic environments at distances from 125 to 6000 feet from the aircraft during ground operation.

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SECTION I

INTRODUCTION

This report presents the results of measurements and analyses made of the acoustic noise levels produced by the F-111A aircraft (TF30-P-1 engines) during ground run-up operations. These results describe the sound pressure level (SPL) spectra produced at locations where engine maintenance personnel must work and at outdoor locations 250-ft radial distance from the aircraft when operated at three different power settings: one engine at military power, two engines at military power, and one engine at military power with afterburner.

Acoustic power spectra and directivity indices derived from these measured data describe the fundamental noise characteristics of this aircraft at the power settings described.

Contours of equal sound pressure level (SPL) calculated from the SPL measured at 250-ft distance using standard atmospheric attenuation data provide a convenient way to estimate octave band SPL produced at outdoor locations 125-6000 ft distance from the aircraft.

Similar contour sets that were developed in turn from the SPL contour sets provide estimates of perceived noise levels and speech interference levels. Perceived noise level (PNL) is a measure of noise that describes the relative subjective annoyance of different complex sounds. Speech interference level (SIL) is a measure of noise that describes the quality of speech communication possible in that noise environment.

These contour sets provide a simple means for determining the octave band SPL, PNL, or SIL at outdoor locations 125-6000 ft from the F-111A during ground run-up at different engine power settings. Such information is basic to evaluating the effects of such environments on structures and personnel and for establishing requirements for ear protection, communication systems, building noise reduction, etc.

SECTION II

MEASUREMENT PROGRAM

GENERAL

Sound pressure measurements were made on F-111A No. 63-9775 at Wright-Patterson Air Force Base, Ohio on 29 August 1967. The aircraft is equipped with two Pratt and Whitney TF30-P-1 engines operated at three different power configurations during the program: one engine (left) at military power, two engines at military power, and one engine (left) at military power with afterburner. The aircraft was tied down on a concrete power check stand measuring approximately 200 by 180 ft in an open field. The ground cover surrounding the stand was primarily grass, measuring approximately 4 to 5 inches in height. The only building or structure within 2000 ft of the aircraft was a corrugated metal shed located approximately 750 ft from the aircraft nose on the 0° radial; but this was not considered to have affected the measurements. The weather conditions during the measurement period were as follows: temperature 70 F, relative humidity 55%, Barometric pressure 30.18 in. Hg, and wind direction and velocity 260° at 3 knots.

MEASUREMENT LOCATIONS

Continuous measurements were made during walk arounds at 250-ft radius from the aircraft engine exhaust (fig. 1). Due to the location of the aircraft tie-down facilities at the power check stand, the aircraft was cocked 10° off the longitudinal center line of the stand and, as a result, the measurement angles actually used were 10° greater than the angles that had been surveyed prior to the measurements. The microphone was continuously pointed at the aircraft and kept at a constant height of 6 ft above the ground. Measurements were also made at head level at four locations in the near field where maintenance personnel would typically be located (fig. 2): position no. 1 - engine start and run up; position no. 2 - pulling chocks prior to taxiing; position no. 3 - engine trimming (engine access panel no. 4321 open to approximate sound pressure level during trimming operation); position no. 4 - taxi out of ramp parking spot.

INSTRUMENTATION AND DATA REDUCTION

A portable, high quality instrumentation package (PORTAPAK) developed in this laboratory was used to acquire data in the field. This system, (fig. 3) employs condenser microphones for acoustic transducers, signal conditioning equipment to provide maximum signal to noise and dynamic range, and a battery operated portable magnetic tape recorder. Specifications for this system are in brief: frequency response 20 Hz to 20 kHz (essentially flat throughout this frequency band), dynamic range with $\frac{1}{2}$-in. condenser microphone 72 to 148 dB, gain control -15 to +30dB. A battery operated pistonphone was used as a reference sound pressure level in field calibration.

Spectral analyses of the recorded data were accomplished in the laboratory using an analog data processing system employing a spectrometer and graphic level recorder with true rms detection (fig. 4).

The entire system was calibrated and small corrections were applied to the data to compensate for system response. Care was taken to insure at least a 10-dB signal to noise ratio at all times.

SECTION III

RESULTS

MEASURED DATA

Table I, II, and III summarize the octave band SPL measured at the specific locations described in figures 1 and 2. All data are fully corrected for the response characteristics of all instrumentation and are considered to be accurate within ±2 dB absolute and ±1 dB relative.

ACOUSTIC POWER SPECTRA

The Acoustic power spectra (fig. 5) of the F-111A for the three-engine power configurations were calculated directly from the SPL measured at 250 ft by integrating intensity-area products over the surface of an imaginary hemisphere of 250 ft radius. These relationships and methods are described in references 1 and 2. Results in figure 5 show that the total or overall acoustic power ranges from 1.5×10^4 watts for single engine at military power to 2.0 x 10^5 watts for single engine at military power with afterburner. Two-engine at military power produces approximately twice the total acoustic power of single engine at military power (i.e., its overall power level (OAPWL) is approximately 3 decibel power (dBp) greater).

Although no measurements were made on two-engines at military power with afterburner, the OAPWL for this can be approximated by adding 3 dBp to the levels calculated for the single engine at military power with afterburner. SPL for two engines at military power with afterburner will similarly increase by approximately 3 dB.

The dips in the power spectra around 250 Hz are caused by the fact that the SPL at 250 ft (from which these power levels (PWL) were derived) were low in this frequency region because of effects caused by ground reflection and ground impedance (ref. 3). Corrections for these effects typically involve adding 0-5 dBp to the octave band PWL over the frequency range of the 250-, 500-, and 1000-Hz bands depending upon the types of terrain and ground cover and heights of source and receiver. No attempts were made to accurately determine these corrections experimentally or theoretically for this study.

DIRECTIVITY INDICES

The directivity indices (DI) given in figure 6 were calculated from the SPL measured at 250 ft and the derived PWL of figure 5 using standard procedures (ref. 2). These DI describe in simple terms the directional radiation characteristics of the sources as functions of frequency, angle from the aircraft nose, and engine power setting. For any given frequency band the DI for one engine at military power and two engines at military power are quite similar. Maximum noise is radiated around 150-160° in the lower frequencies; the sources become less directive with increasing frequency. In the case of military power with afterburner operation, the angle of maximum radiation shifts to somewhat smaller θ values.

The directivity index, like the acoustic power spectrum, is a basic descriptor of a noise source and as such is useful to the acoustical engineer in estimating sound pressure level environments produced by that source under particular situations. For this reason, PWL and DI information are included in this report. The bioenvironmental engineer and many other readers will probably find, however, that the SPL, PNL, and SIL presented in subsequent subsections will be more directly useful.

SPL SPECTRA AT MAINTENANCE POSITIONS

The SPL measured in the near field where maintenance personnel would typically be located are given in table IV and plotted in spectral form in figure 7. Energy is broadly distributed above 125 Hz with relatively high energy content in the upper frequency bands and overall SPL ranging from 118 to 128 dB. These environmental levels can be compared with existing criteria regarding hazardous noise exposure to determine protection requirements, maximum exposure time, etc (ref. 4 and 5).

SOUND PRESSURE LEVEL CONTOURS - FAR FIELD

The SPL measured at 250-ft radii were extrapolated over a range of about 125 to 6000 ft from the aircraft by applying standard values of atmospheric attenuation due to classical and molecular absorption (ref. 6). These attenuation values were modified according to reference 7 to take into account excess attenuation and other factors observed during actual field measurement programs studying ground to ground propagation of aircraft noise. These attenuation values apply to downwind propagation and hence might be conservative for cases of upwind propagation (i.e., would give estimates of SPL higher than those that might actually occur). The specific attenuation values applied to produce the F-111A equal SPL contours will provide good estimates of SPL (±5 dB) out to about 1 mile for a temperature range of 68 to 95 F and relative humidity of 46-100% if no large scale refractive effects exist such as focusing or the formation of shadow zones. For temperature and humidity conditions quite different from those considered herein (e.g., very dry or cold conditions) consult references 6 and 7 to obtain atmospheric attenuation values corresponding to those particular meteorological conditions. These values can be applied to the data of table I, II, and III to obtain estimated SPL for distances other than 250 ft.

The equal SPL contours, figures 8, 9, and 10, describe far-field noise environments of the F-111A as a function of frequency, angle from nose of aircraft, engine power setting, and distance from aircraft. From these contour sets the SPL spectrum at an outdoor location may be readily estimated, subject to the limitations prescribed.

PERCEIVED NOISE LEVEL CONTOURS - FAR FIELD

Perceived noise level (PNL) expressed in units of PNdB is a measure of noise that has gained wide acceptance as a measure of the relative annoyance or noiseness of different sounds. PNL is a quantity calculated from the SPL spectrum of a sound (ref. 8 and 9).

The PNL contours of figure 11 were derived by applying these methods to the SPL, (i.e., distance information obtained in preparing the equal SPL contours).

These PNL contours do not include any correction for discrete frequency components since no significant pure tone components were discernible in the recorded data when analyzed with 1/3-octave band resolution.

SPEECH INTERFERENCE LEVEL CONTOURS - FAR FIELD

The speech interference level (SIL) of a noise is defined as the arithmetic average of the SPL in the 600 to 1200 Hz, 1200 to 2400 Hz, and 2400 to 4800 Hz octave bands. SIL were calculated for the F-111A taking into account the difference between the older, conventional frequency bands (600 to 1200 Hz, etc) and the presently preferred frequency bands used in this study.

These contours of equal SIL, figure 12, provide a ready means to estimate the outdoor SIL produced by the F-111A operations at distances of 125 to 6000 ft from the aircraft during ground run-up.

Existing SIL criteria, (ref. 10) can be applied to determine the degree of speech communication possible in such environments.

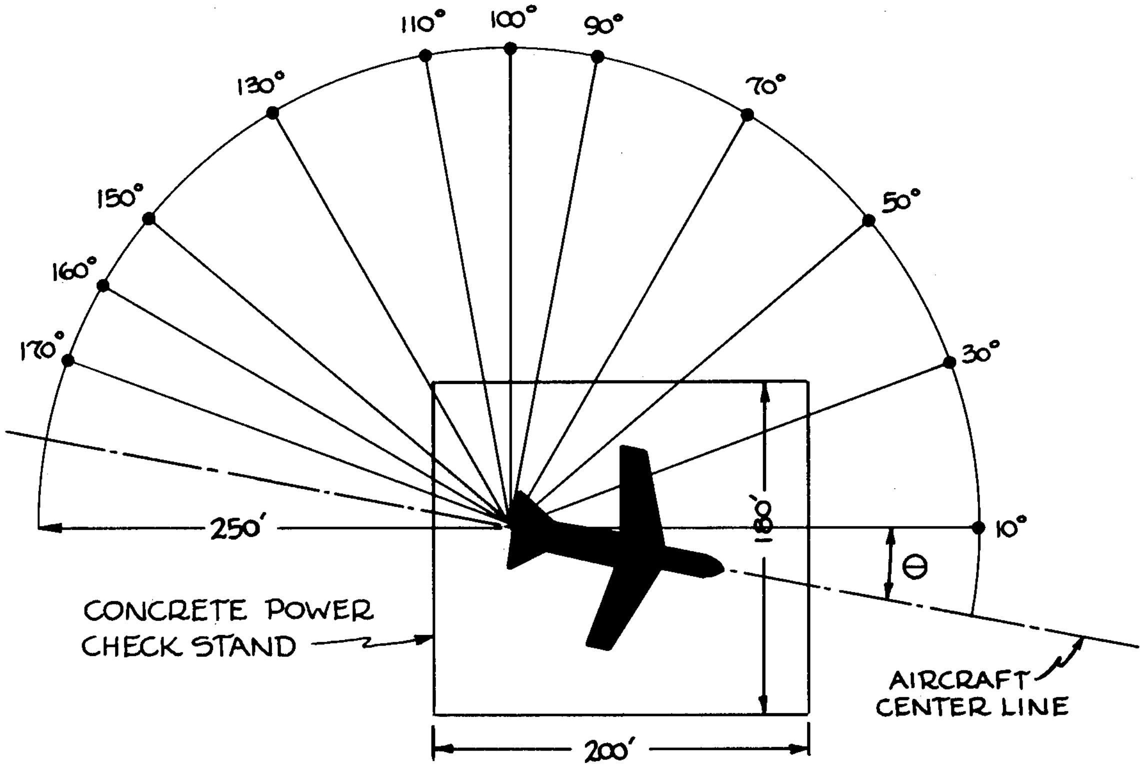

Figure 1. Far Field Measurement Locations

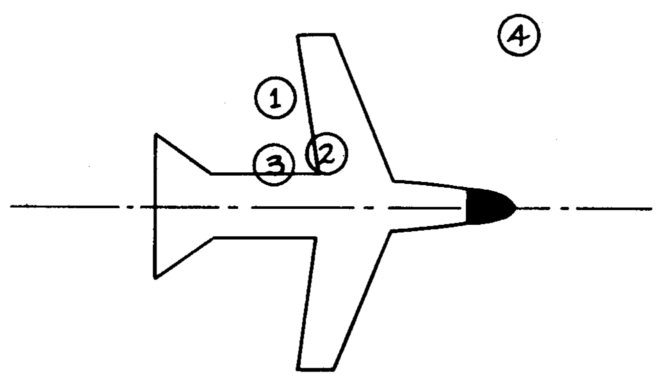

Figure 2. Maintenance Positions Measurement Locations

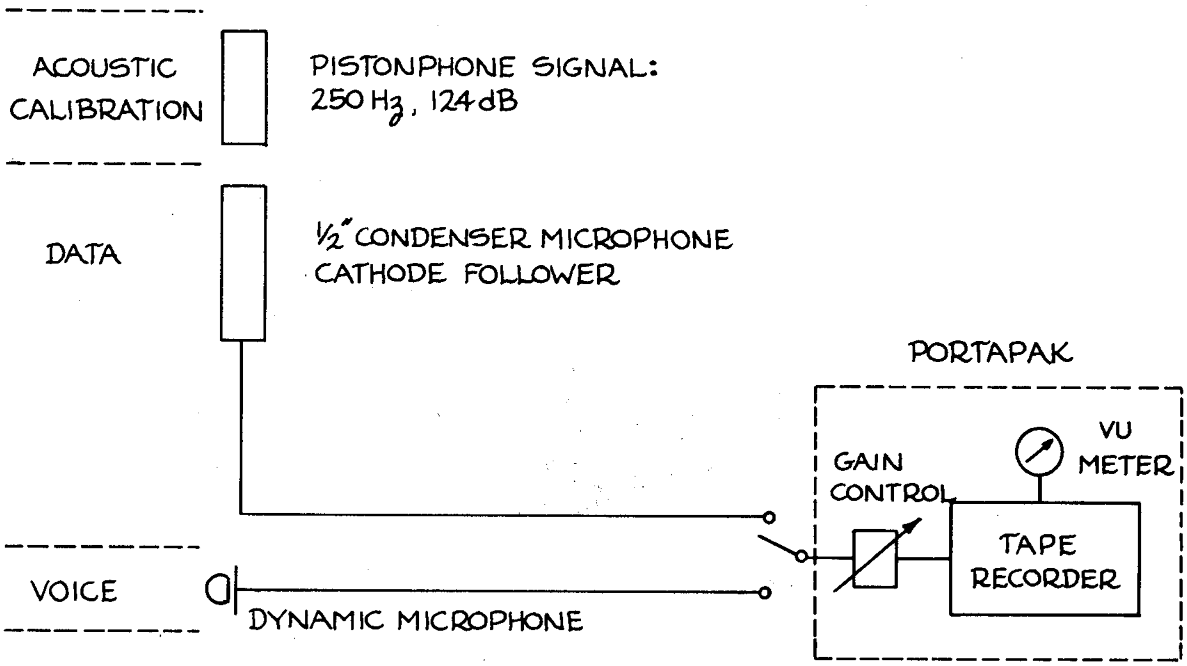

Figure 3. Portable Data Acquisition System

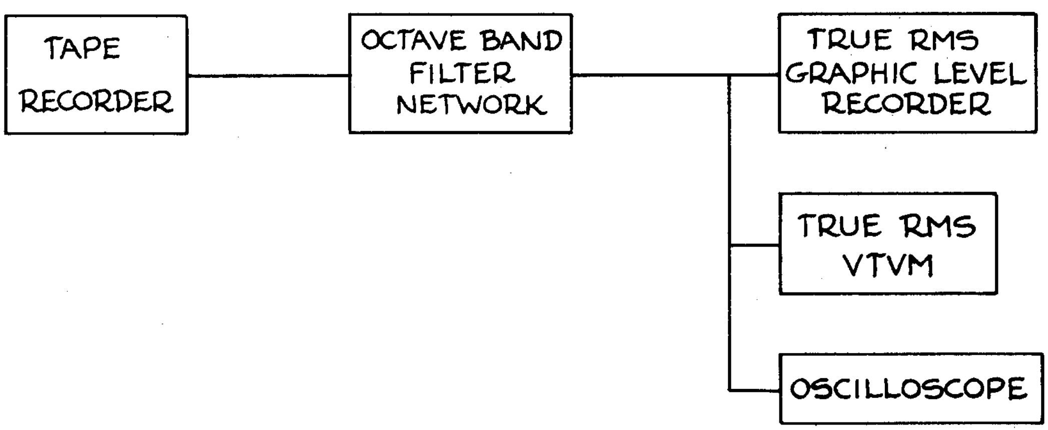

Figure 4. Analysis System

TABLE I. F-111A SOUND PRESSURE LEVELS MEASURED AT 250 FEET ONE ENGINE AT MILITARY POWER SETTING

OCTAVE BAND SOUND PRESSURE LEVELS IN dB re 0.0002 $dynes/cm^2$

OCTAVE BAND CENTER FREQUENCY Hz	ANGLE θ FROM AIRCRAFT NOSE IN DEGREES										
	10°	30°	50°	70°	90°	100°	110°	130°	150°	160°	170°
31.5	86	86	87	90	92	93	94	101	108	109	107
63	87	93	97	98	100	100	102	110	119	120	114
125	94	100	99	99	102	104	105	113	121	122	112
250	101	100	96	99	101	100	101	109	113	114	109
500	96	98	99	101	102	104	106	112	114	113	101
1K	97	98	98	102	104	107	108	113	112	109	104
2K	96	96	97	98	100	103	105	107	103	100	98
4K	96	97	97	97	98	100	102	103	98	95	94
8K	95	97	96	95	96	95	97	97	95	92	92
16K	91	93	92	89	91	88	89	89	88	86	86

TABLE II. F-111A SOUND PRESSURE LEVELS MEASURED AT 250 FEET TWO ENGINES AT MILITARY POWER SETTING

OCTAVE BAND SOUND PRESSURE LEVELS IN dB re 0.0002 $dynes/cm^2$

OCTAVE BAND CENTER FREQUENCY Hz	ANGLE θ FROM AIRCRAFT NOSE IN DEGREES										
	10°	30°	50°	70°	90°	100°	110°	130°	150°	160°	170°
31.5	88	88	91	92	95	94	97	103	111	113	110
63	94	95	100	101	102	103	107	113	122	121	113
125	98	101	102	102	104	106	109	117	123	123	116
250	103	102	98	102	103	101	104	110	114	117	111
500	98	100	100	102	104	105	108	115	116	114	105
1K	98	99	99	104	105	108	110	114	113	111	105
2K	98	97	98	100	103	104	107	109	105	102	98
4K	96	98	98	98	100	102	103	104	100	98	93
8K	97	98	98	96	97	98	98	98	97	93	91
16K	91	93	92	88	90	90	89	89	88	85	84

TABLE III. F-111A SOUND PRESSURE LEVELS MEASURED AT 250 FEET ONE ENGINE WITH AFTERBURNER

OCTAVE BAND SOUND PRESSURE LEVELS IN dB re 0.0002 dynes/cm^2

OCTAVE BAND CENTER FREQUENCY Hz	ANGLE θ FROM AIRCRAFT NOSE IN DEGREES										
	10°	30°	50°	70°	90°	100°	110°	130°	150°	160°	170°
31.5	98	98	100	102	106	106	108	117	122	121	115
63	103	103	108	109	111	112	117	126	129	124	116
125	101	107	107	108	111	111	116	127	130	124	114
250	103	104	99	103	105	106	113	123	118	115	101
500	100	103	105	109	113	114	119	128	114	109	95
1K	99	104	106	110	114	116	120	123	113	107	95
2K	99	101	104	107	112	113	117	117	105	100	94
4K	97	100	103	105	109	110	113	111	100	97	91
8K	96	98	99	99	103	104	106	104	95	92	86
16K	91	93	93	90	94	96	97	97	88	85	82

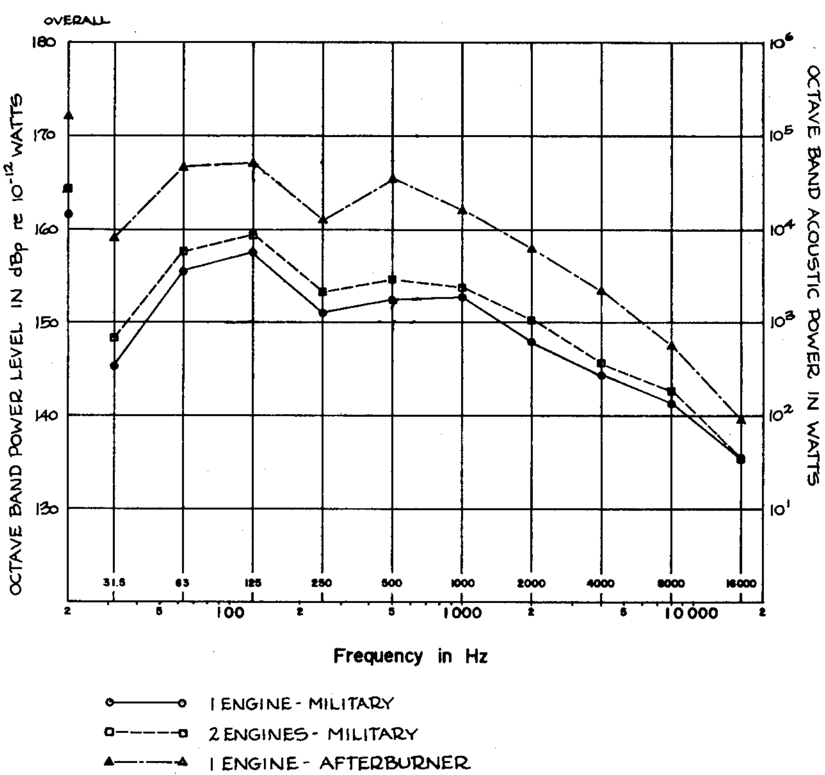

Figure 5. F-111A Acoustic Power Spectra

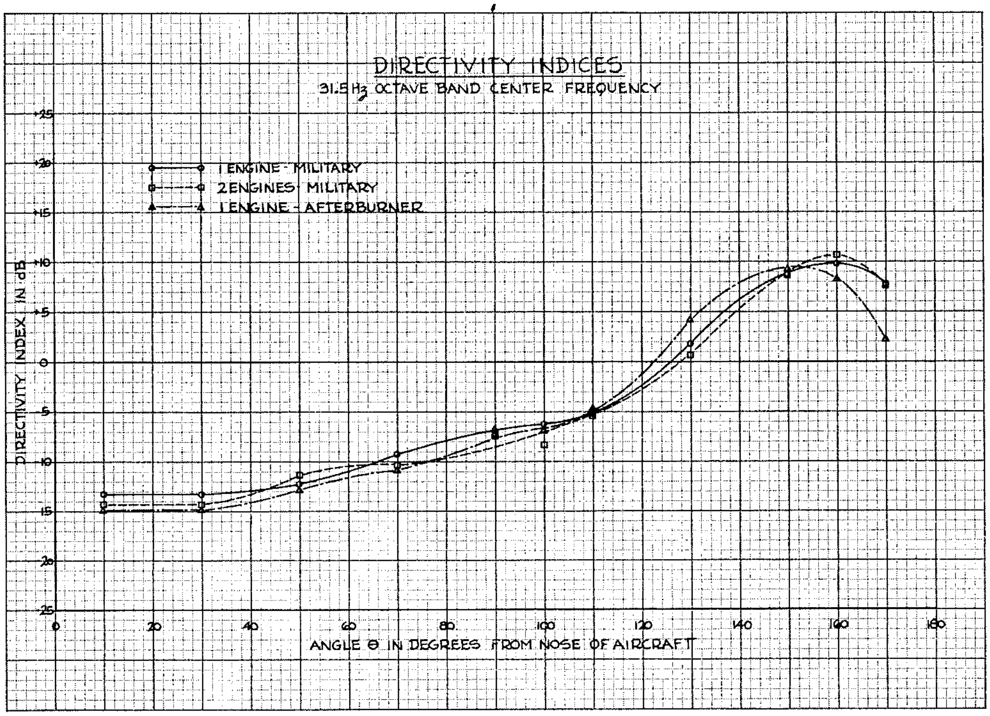

Figure 6a. F-111A Directivity Indices - 31.5 Hz Octave Band Center Frequency

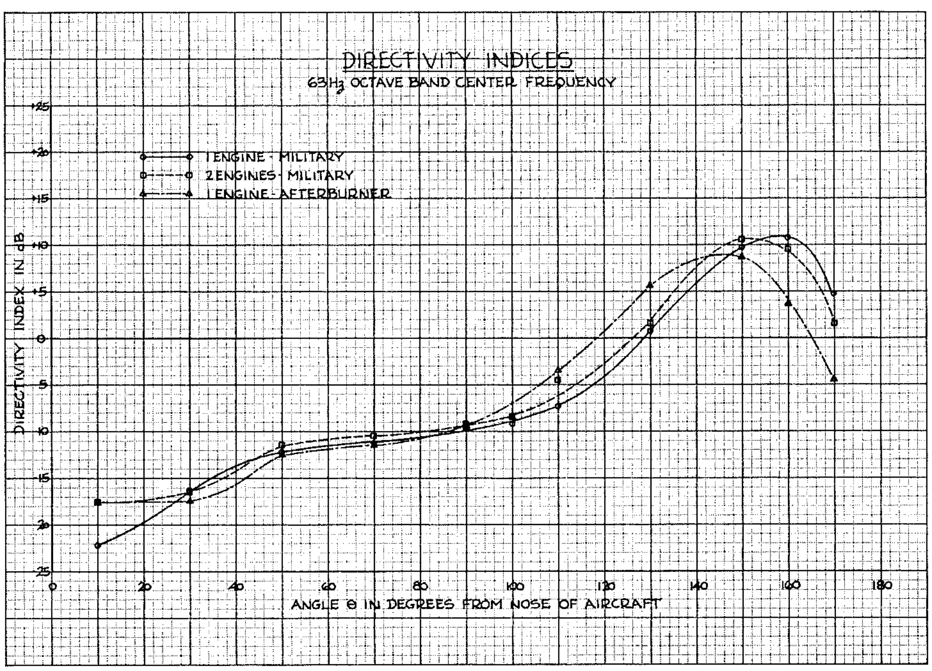

Figure 6b. F-111A Directivity Indices - 63 Hz Octave Band Center Frequency

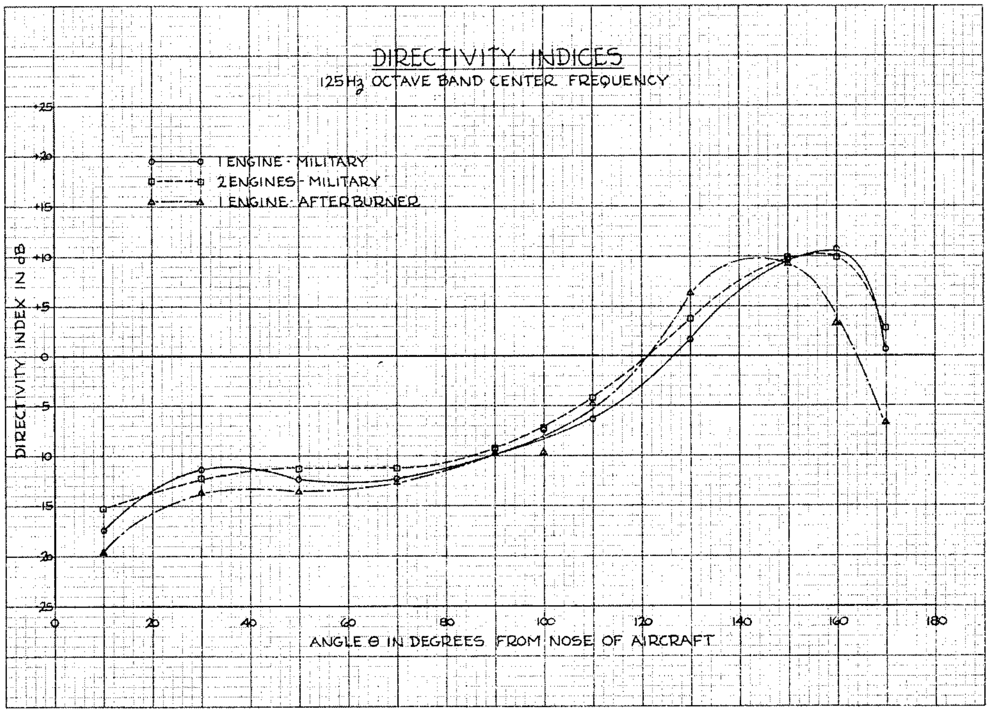

Figure 6c. F-111A Directivity Indices - 125 Hz Octave Band Center Frequency

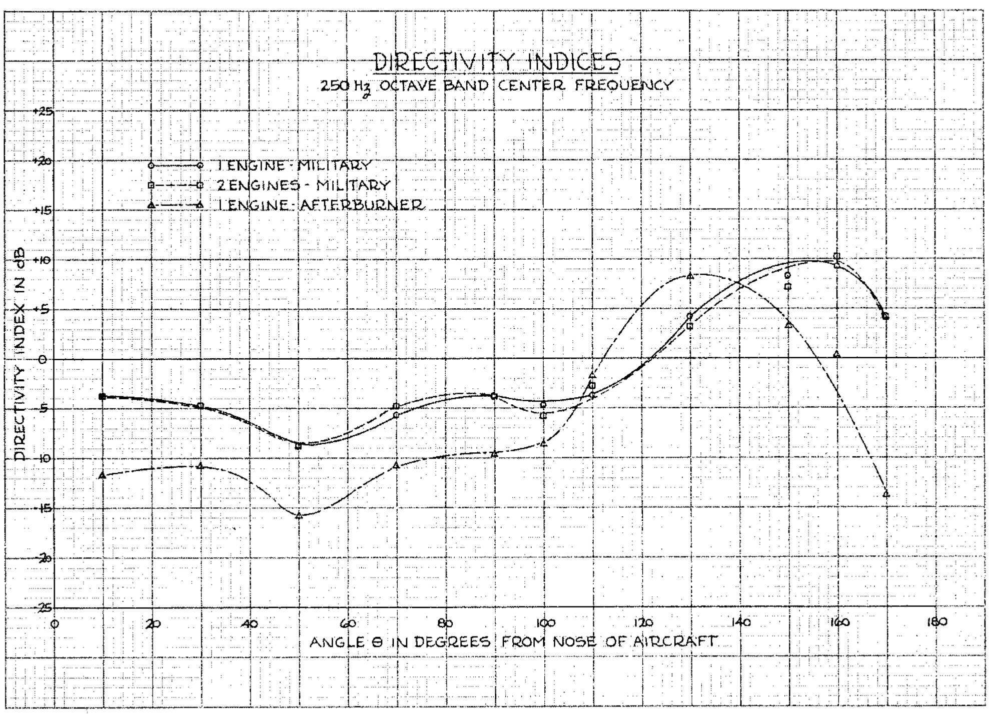

Figure 6d. F-111A Directivity Indices - 250 Hz Octave Band Center Frequency

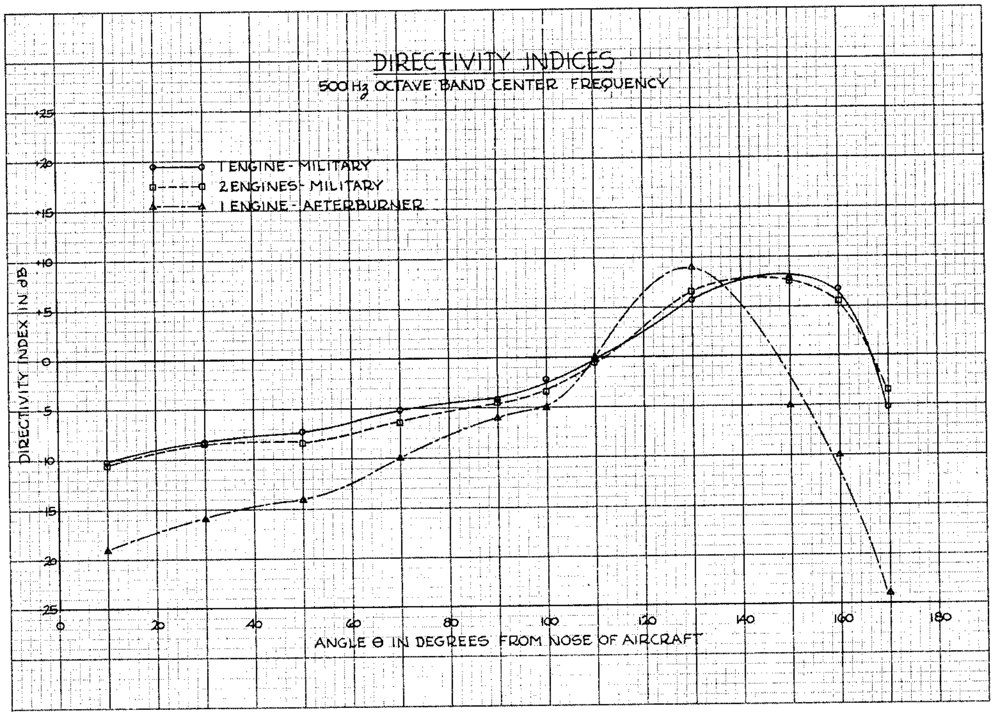

Figure 6e. F-111A Directivity Indices - 500 Hz
Octave Band Center Frequency

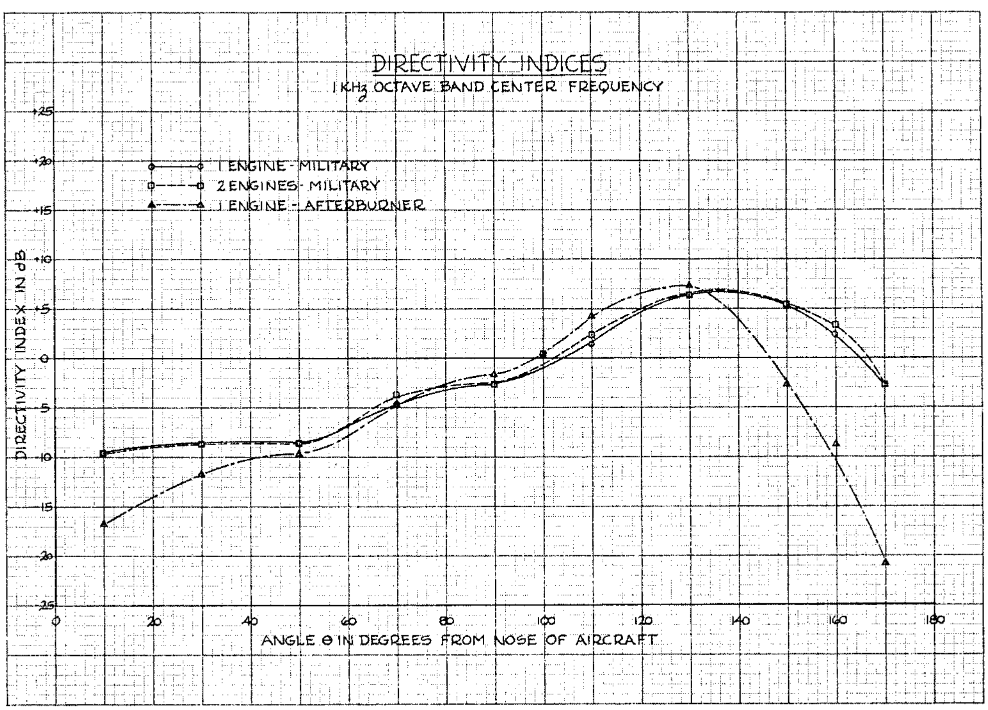

Figure 6f. F-111A Directivity Indices - 1kHz
Octave Band Center Frequency

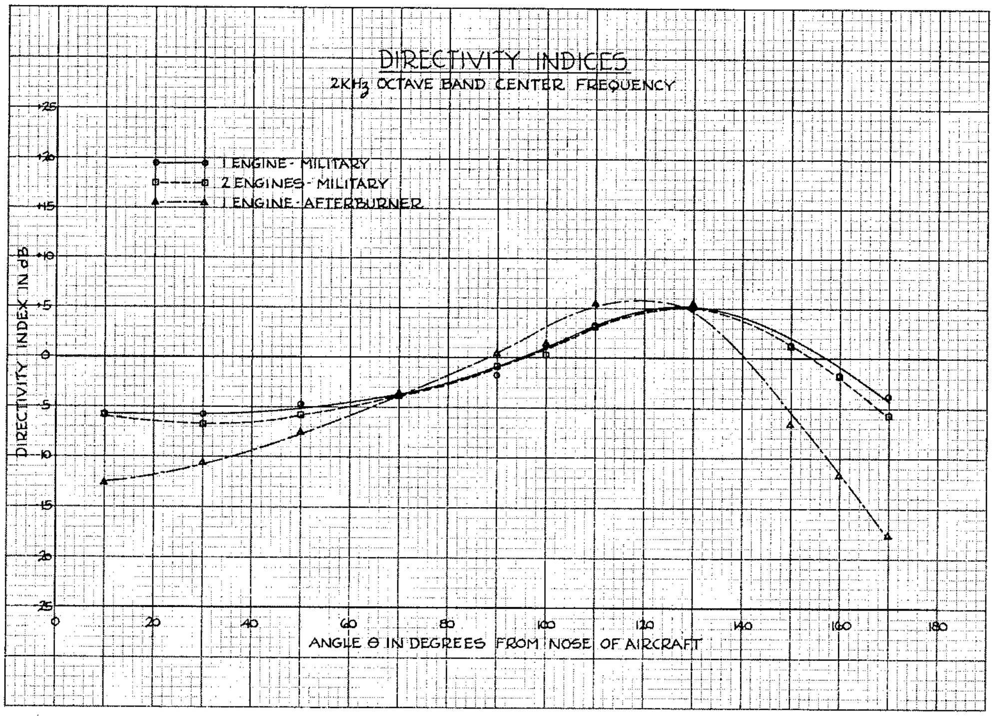

Figure 6g. F-111A Directivity Indices - 2kHz
Octave Band Center Frequency

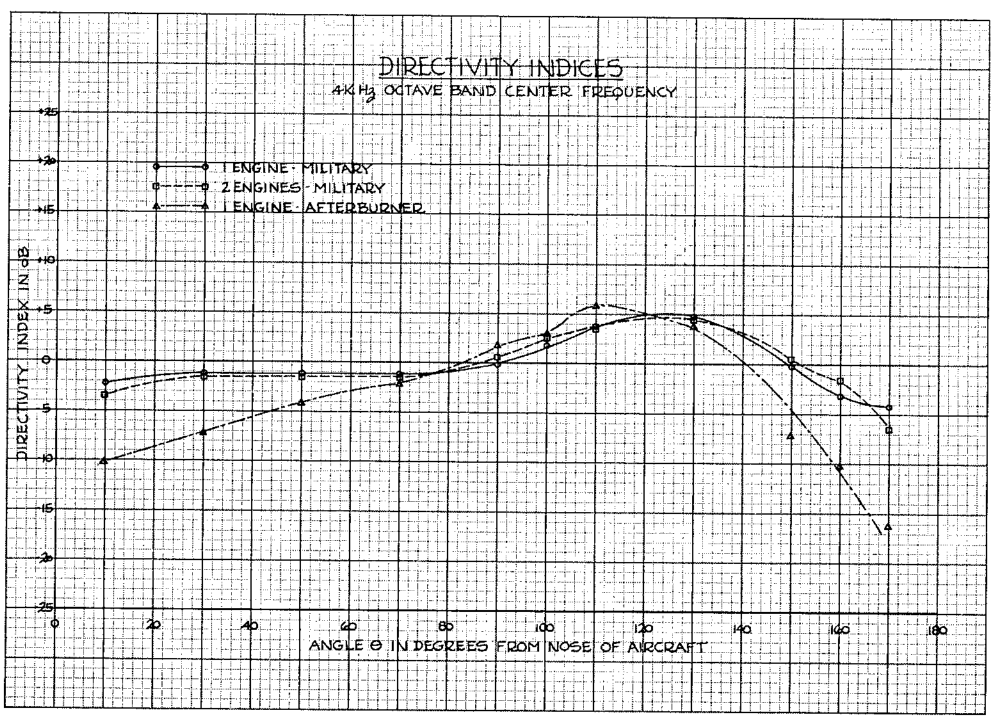

Figure 6h. F-111A Directivity Indices - 4kHz
Octave Band Center Frequency

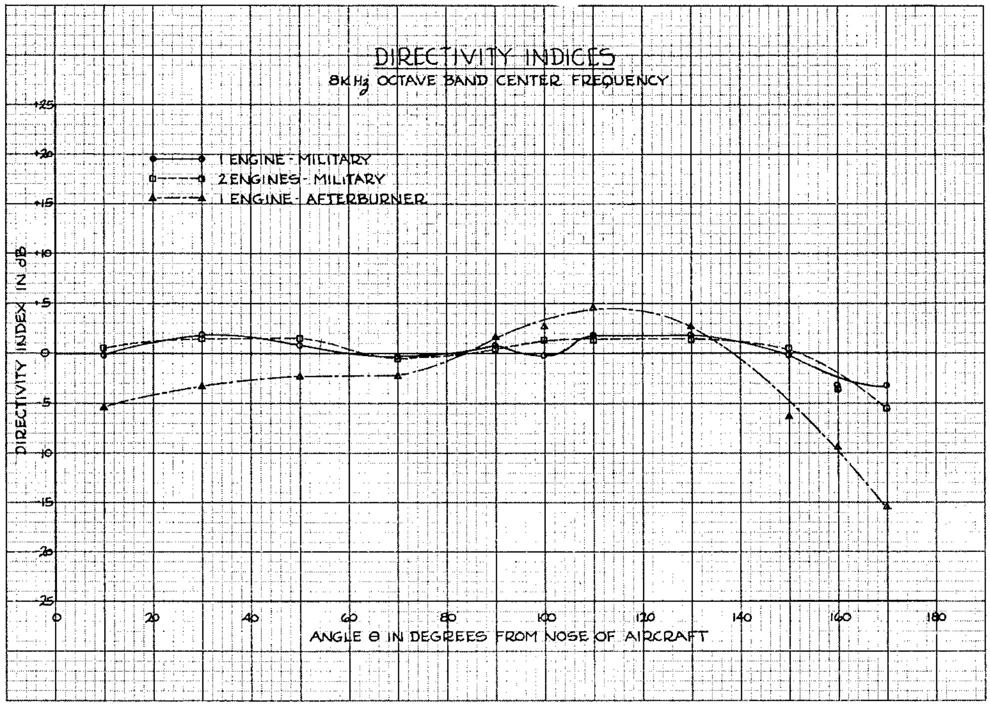

Figure 6i. F-111A Directivity Indices - 8kHz Octave Band Center Frequency

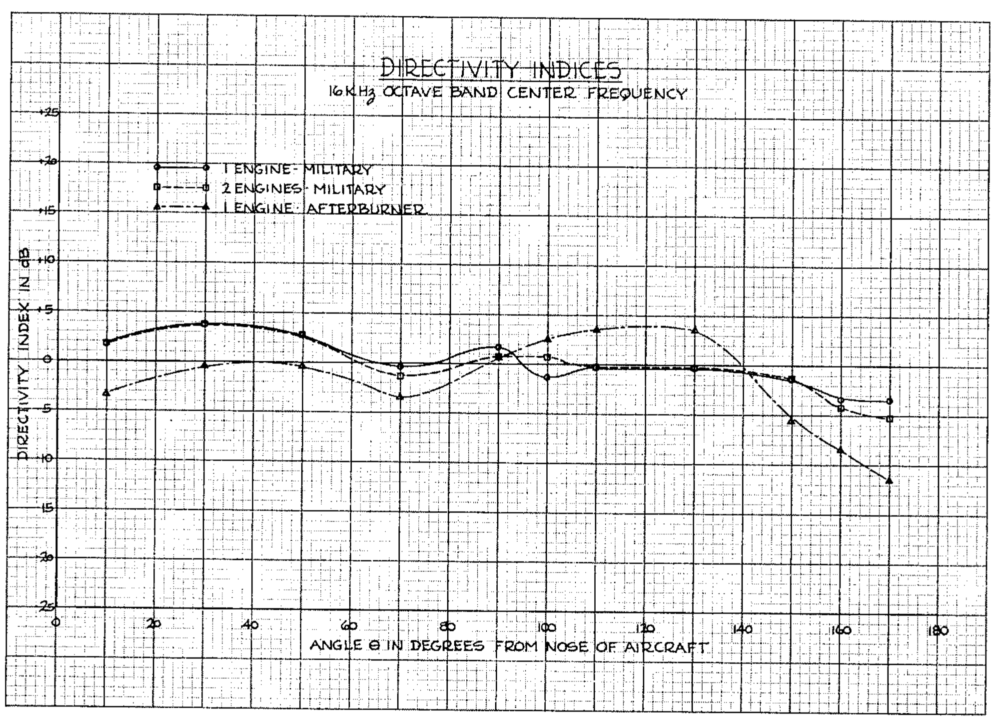

Figure 6j. F-111A Directivity Indices - 16kHz Octave Band Center Frequency

TABLE IV. F-111A MAINTENANCE POSITION MEASURED SOUND PRESSURE LEVELS - LEFT ENGINE 85% POWER, RIGHT ENGINE IDLE

OCTAVE BAND SOUND PRESSURE LEVELS IN dB re 0.0002 dynes/cm^2

OCTAVE BAND CENTER FREQUENCY Hz	*POSITION #1	*POSITION #2	*POSITION #3	*POSITION #4
31.5	97	99	99	94
63	110	111	110	101
125	116	115	116	109
250	122	117	118	112
500	117	117	118	109
1K	115	118	115	107
2K	113	119	113	107
4K	112	120	121	108
8K	114	121	118	112
16K	113	121	115	112

* See Fig. 1b for position locations

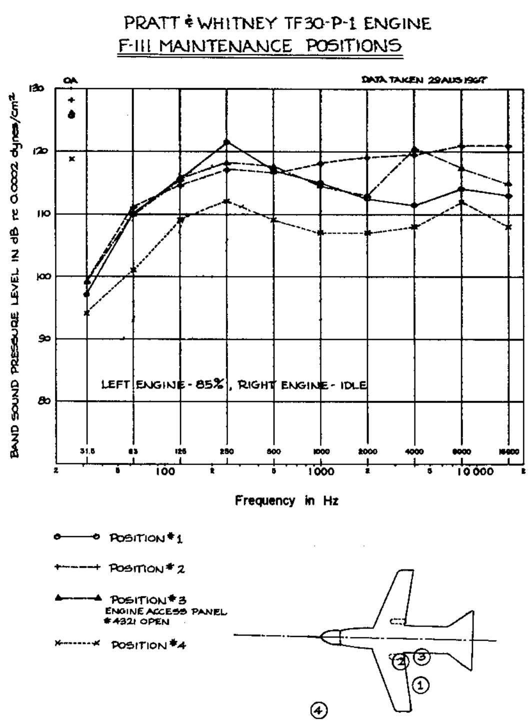

Figure 7. F-111A Maintenance Positions - Measured Sound Pressure Levels

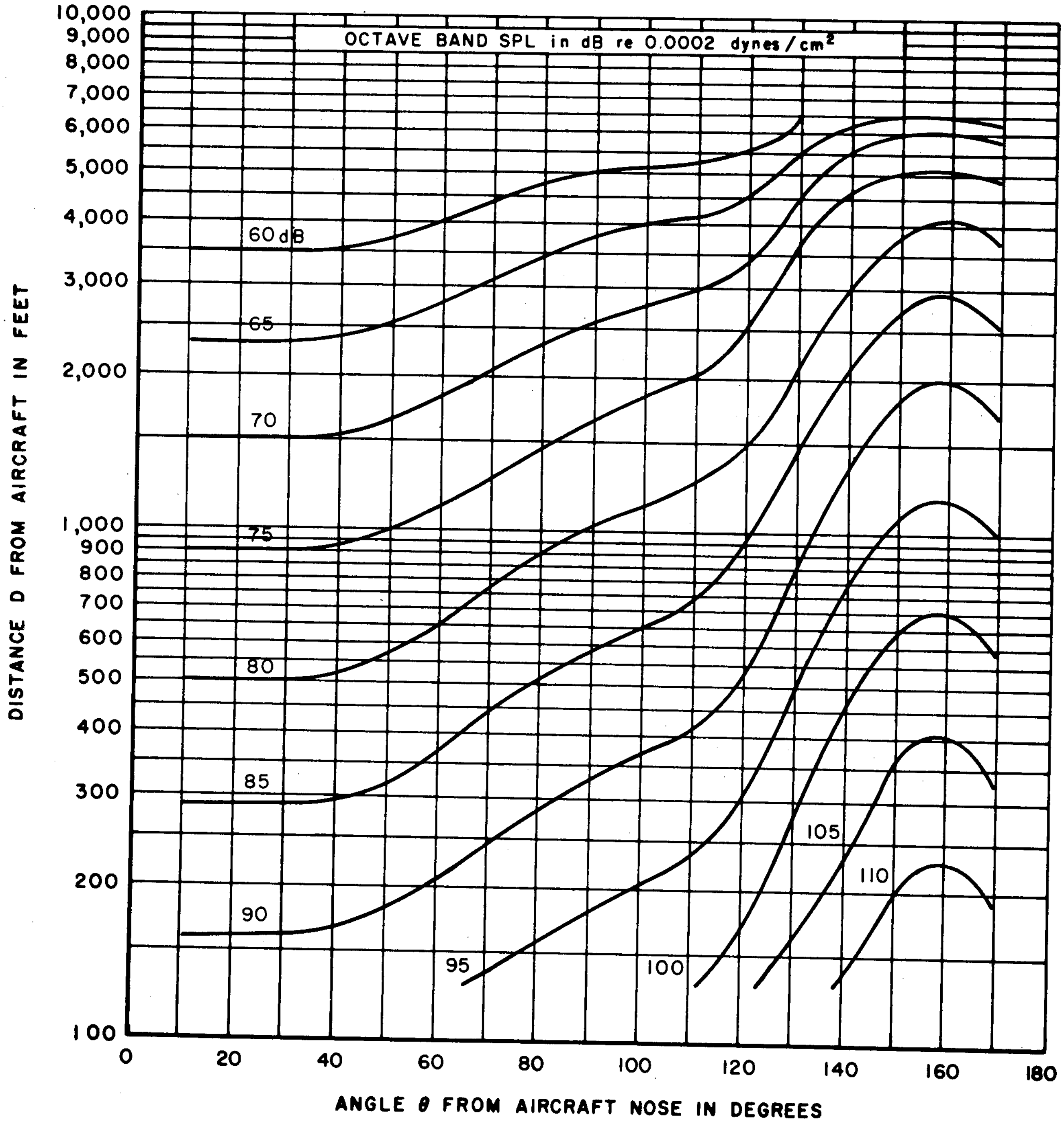

Figure 8a. F-111A Equal Sound Pressure Level Contours-Center Frequency 31.5 Hz, One Engine at Military Power

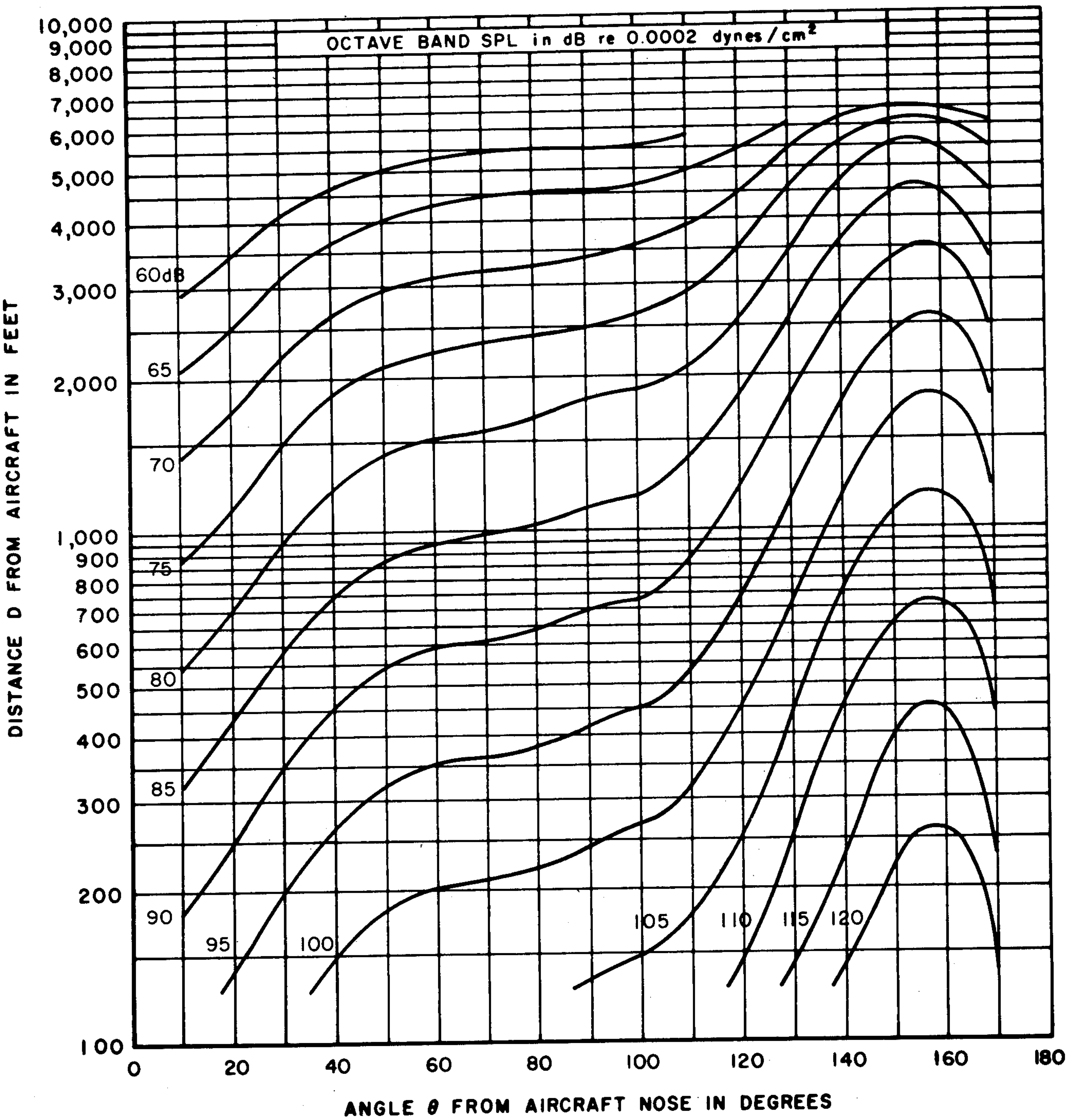

Figure 8b. F-111A Equal Sound Pressure Level Contours-Center Frequency 63 Hz, One Engine at Military Power

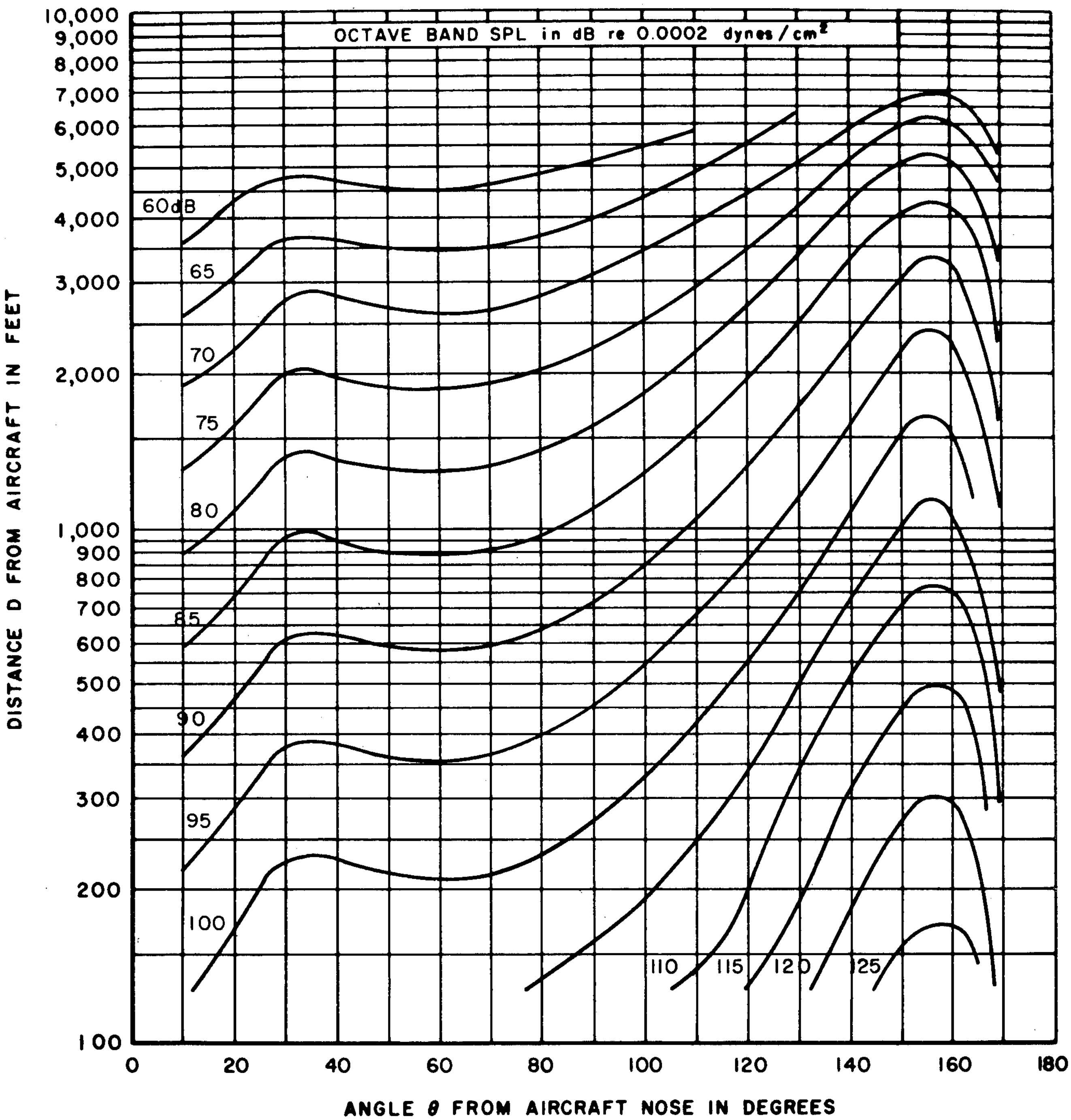

Figure 8c. F-111A Equal Sound Pressure Level Contours-Center Frequency 125 Hz, One Engine at Military Power

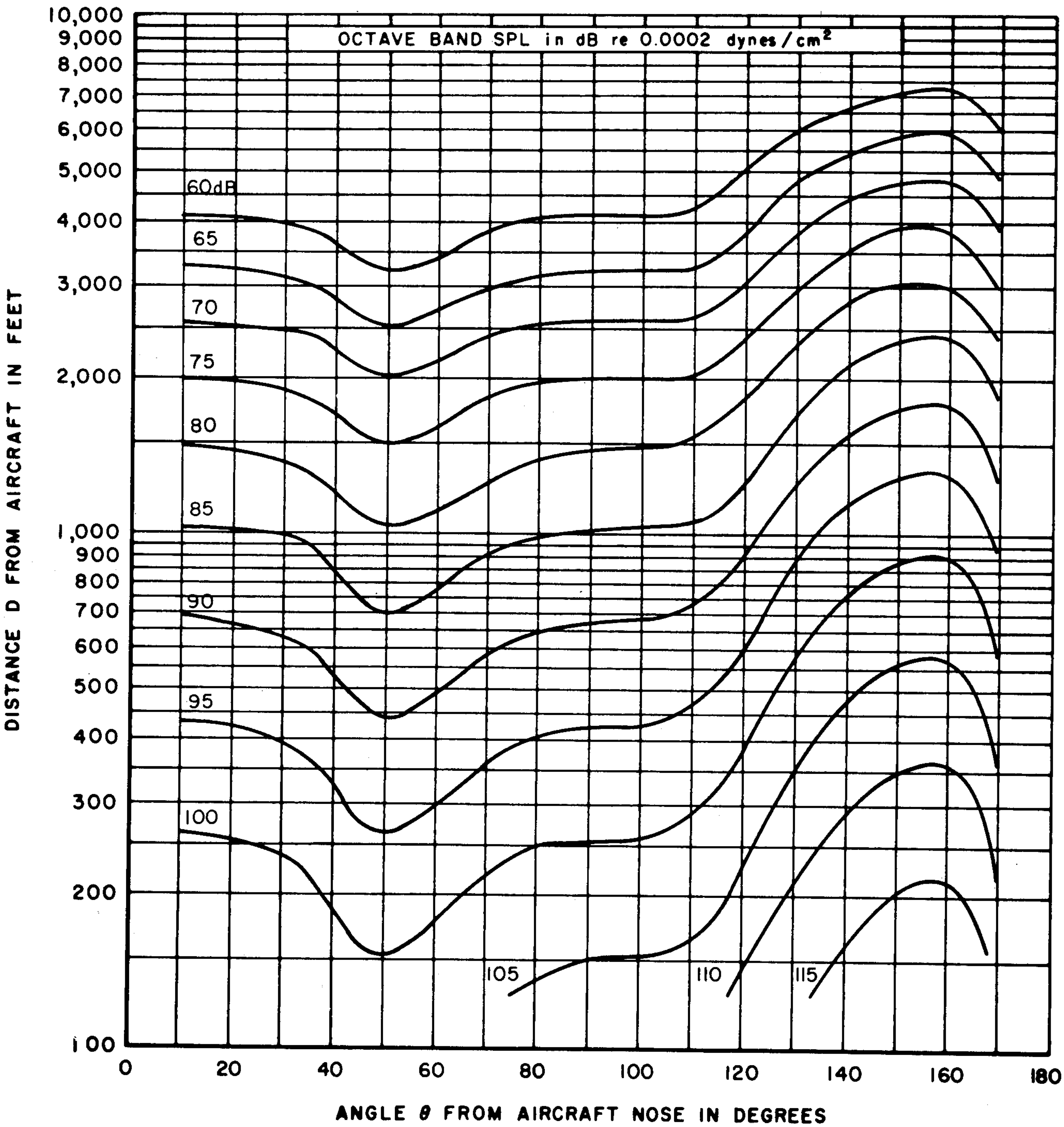

Figure 8d. F-111A Equal Sound Pressure Level Contours-Center Frequency 250 Hz, One Engine at Military Power

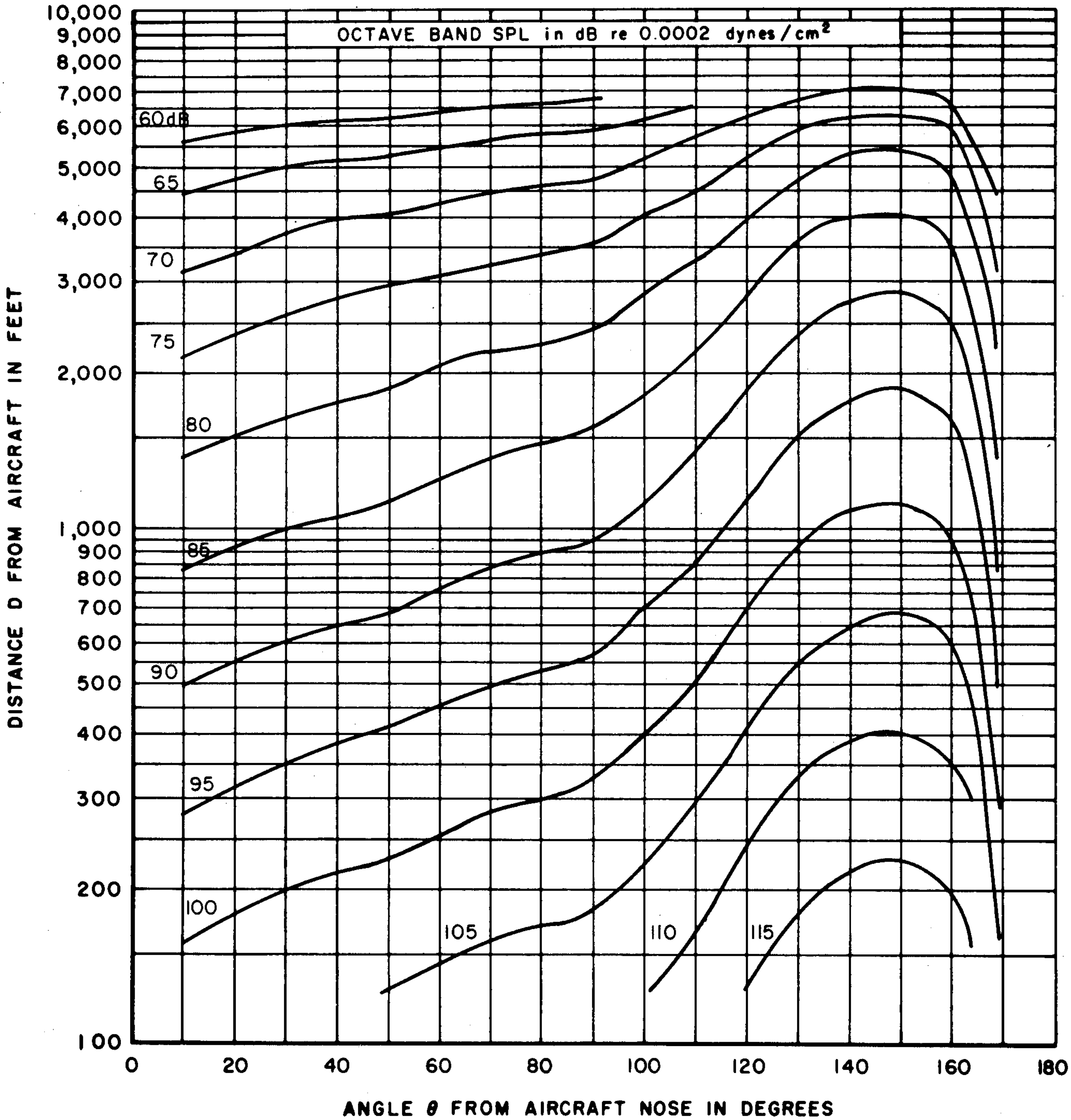

Figure 8e. F-111A Equal Sound Pressure Level Contours-Center Frequency 500 Hz, One Engine at Military Power

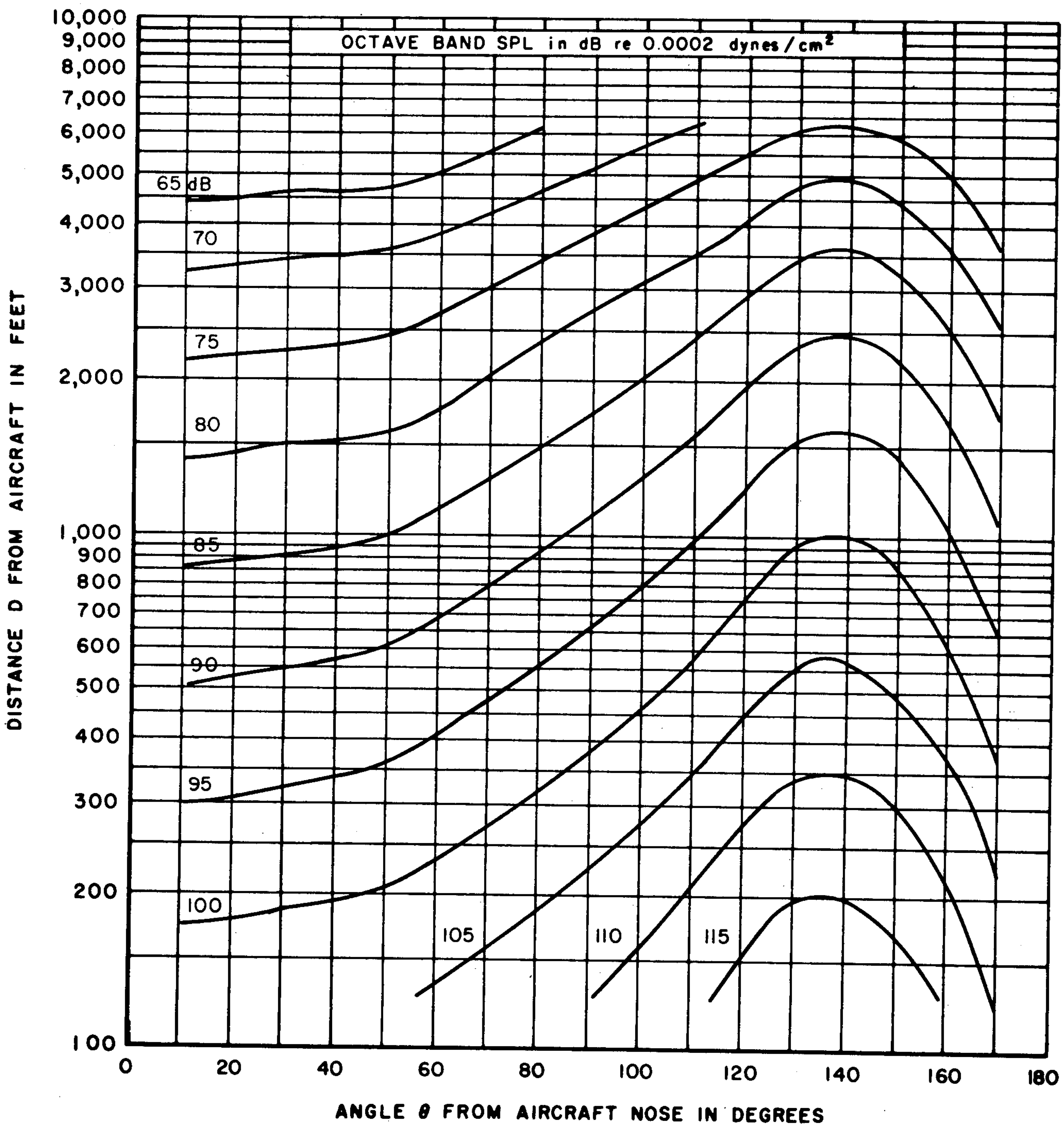

Figure 8f. F-111A Equal Sound Pressure Level Contours-Center Frequency 1 Kc, One Engine at Military Power

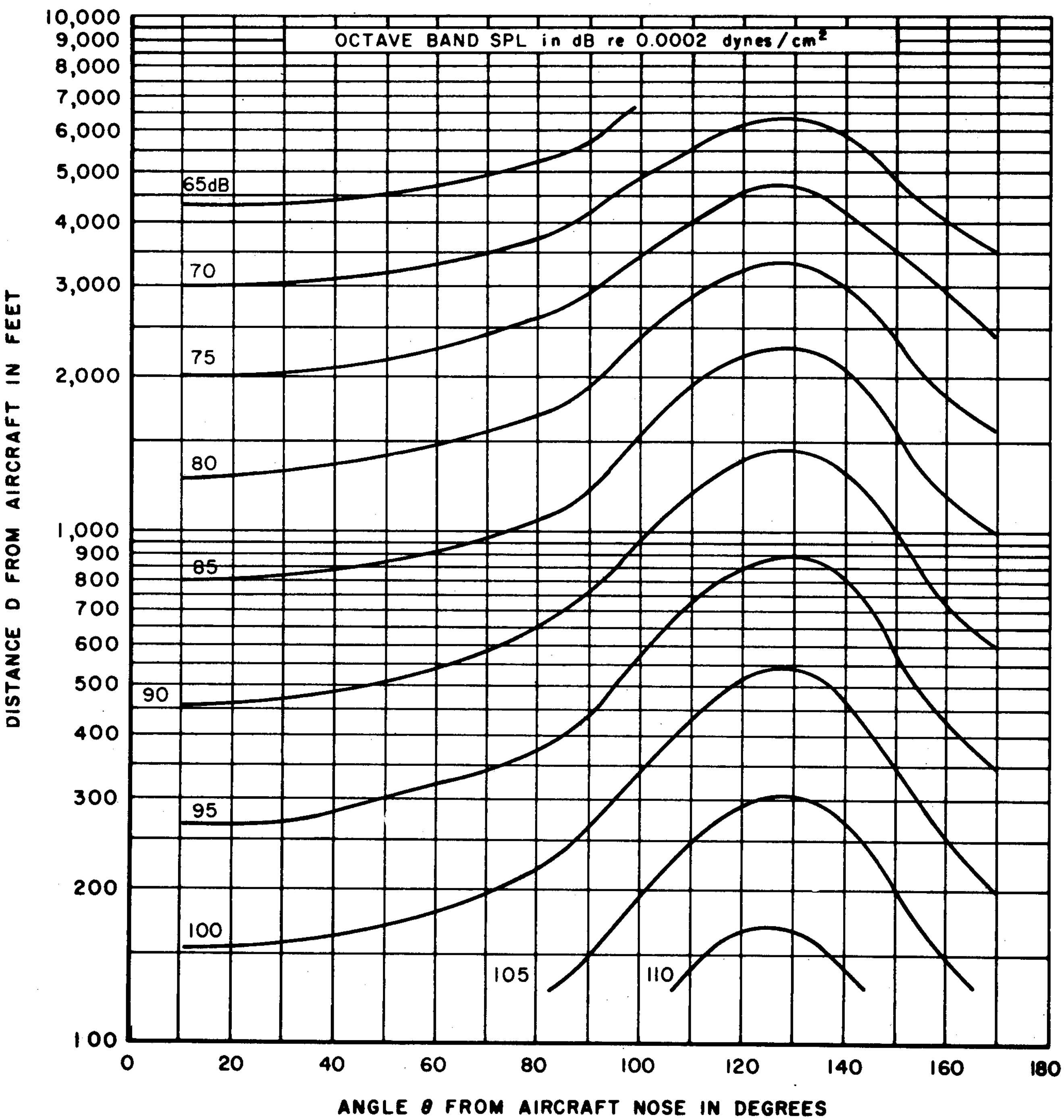

Figure 8g. F-111A Equal Sound Pressure Level Contours-Center Frequency 2Kc, One Engine at Military Power

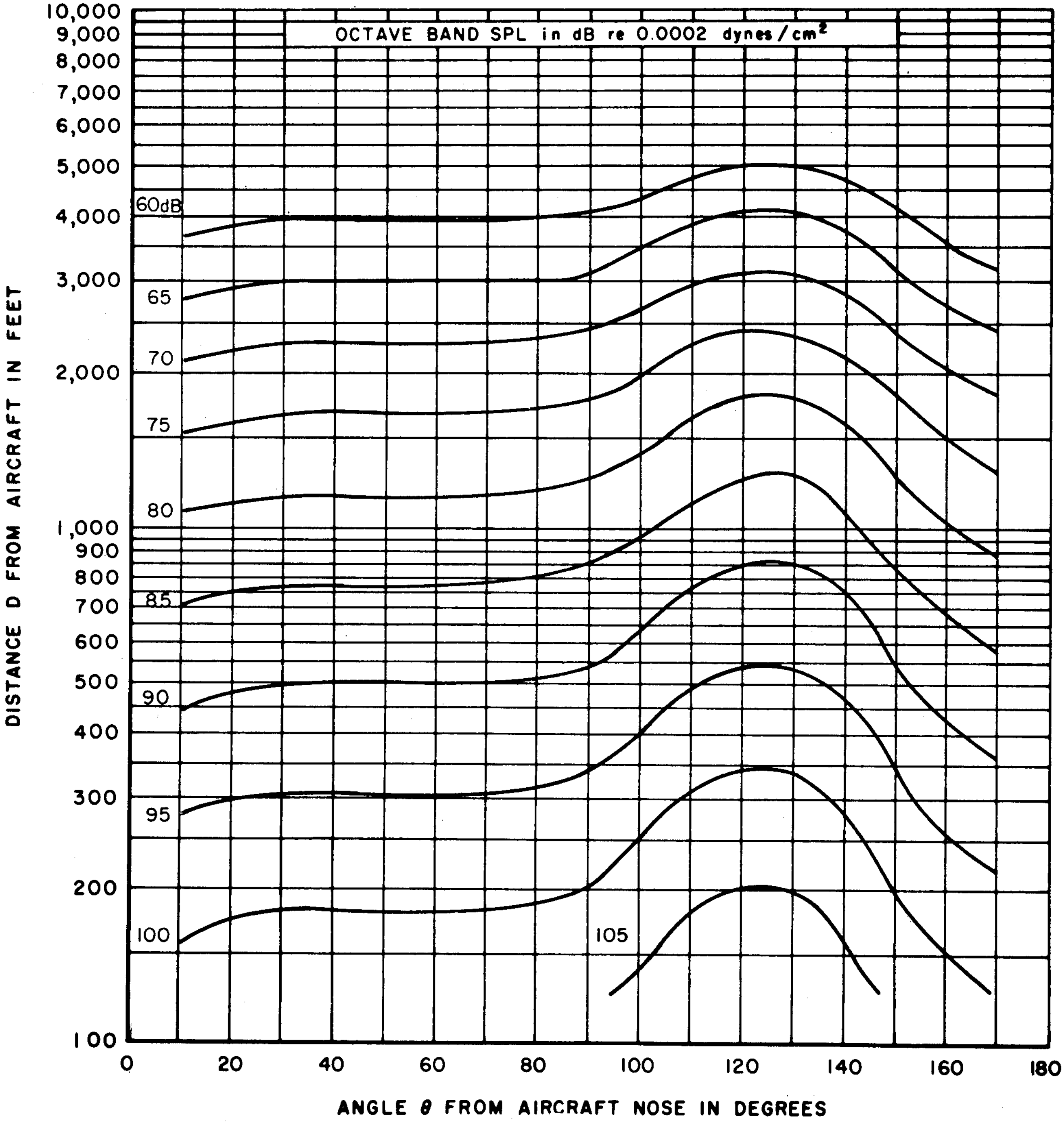

Figure 8h. F-111A Equal Sound Pressure Level Contours-Center Frequency 4 Kc, One Engine at Military Power

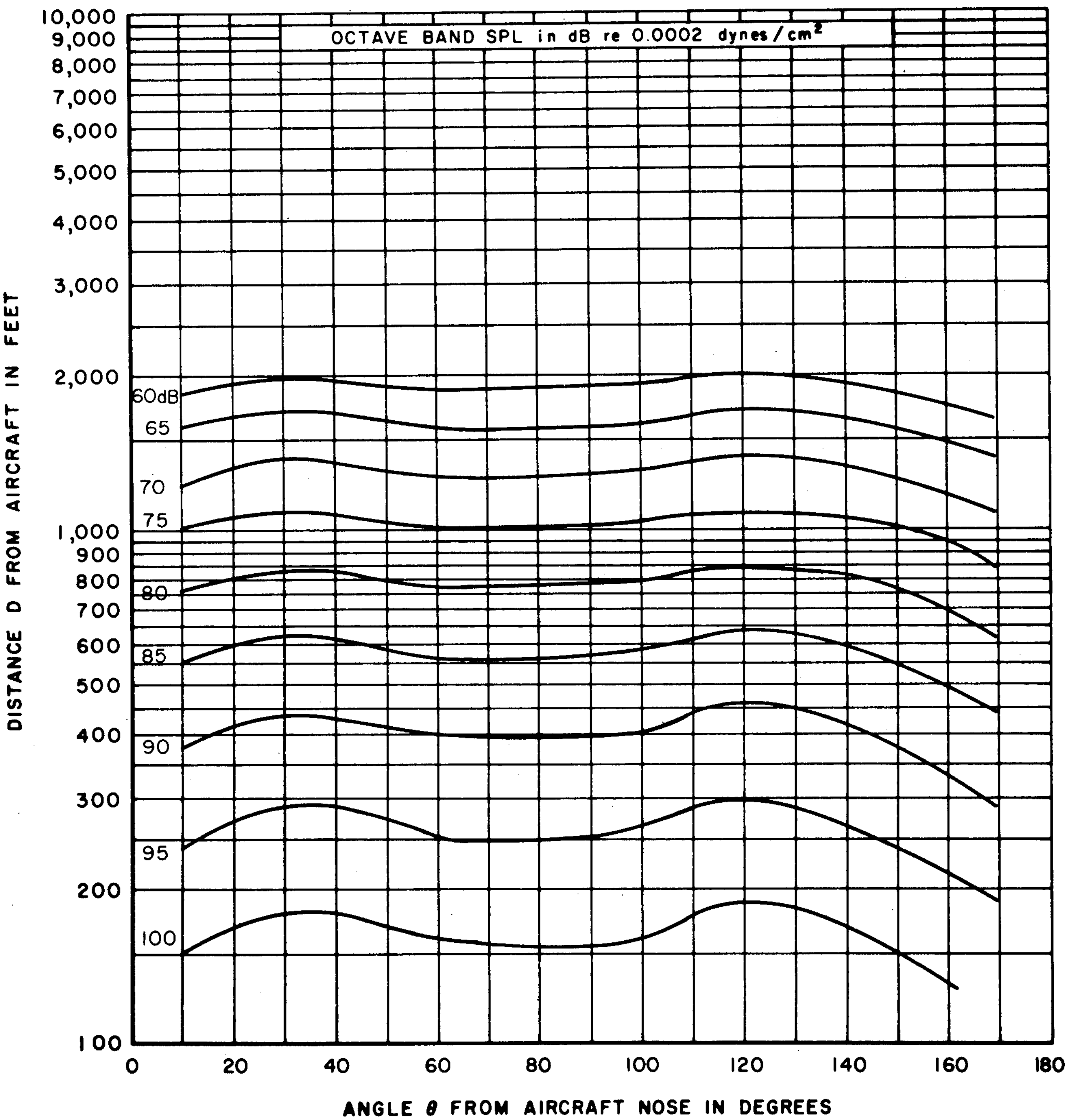

Figure 8i. F-111A Equal Sound Pressure Level Contours-Center Frequency 8 Kc, One Engine at Military Power

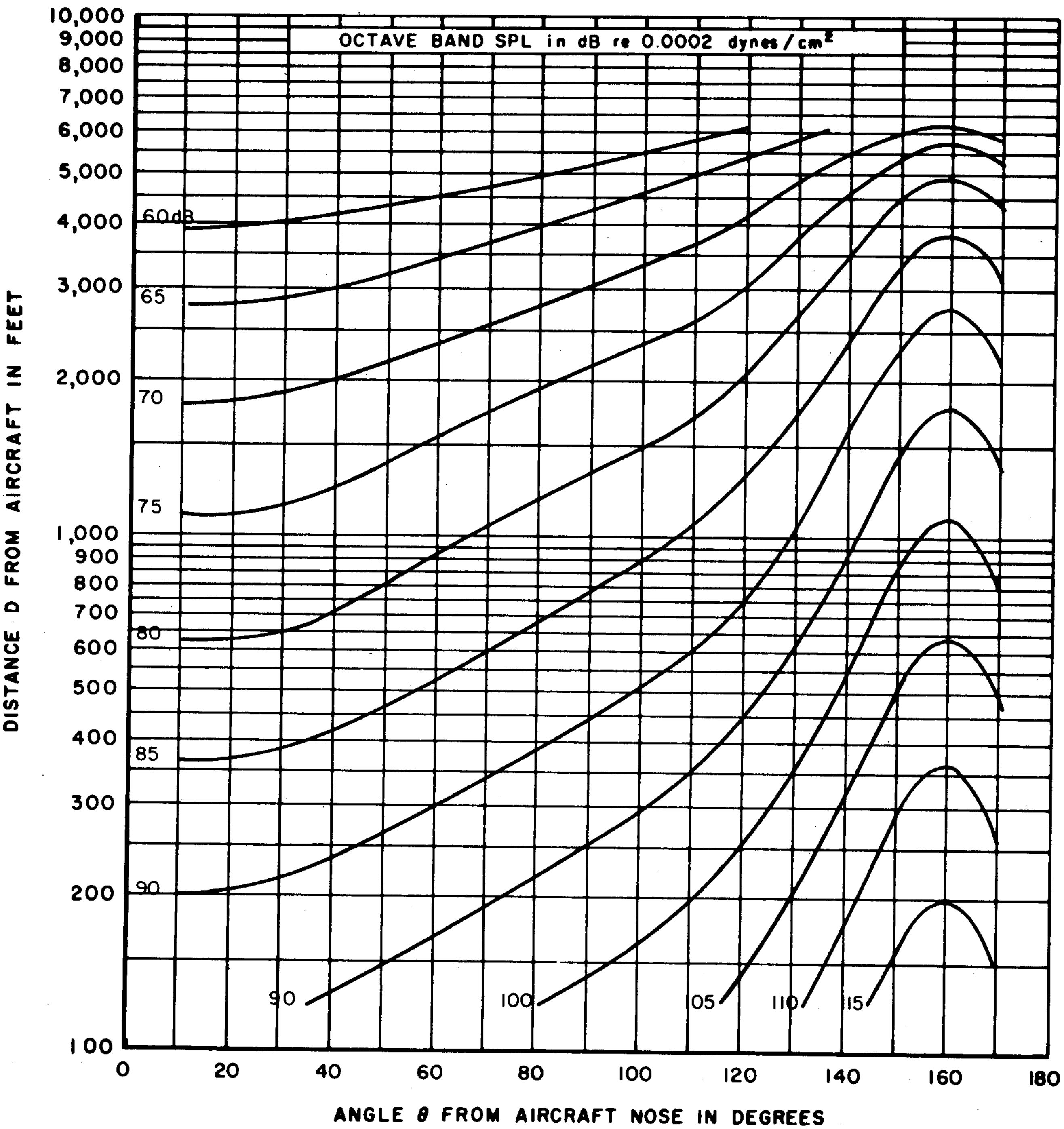

Figure 9a. F-111A Equal Sound Pressure Level Contours-Center Frequency 31.5 Hz, Two Engines at Military Power

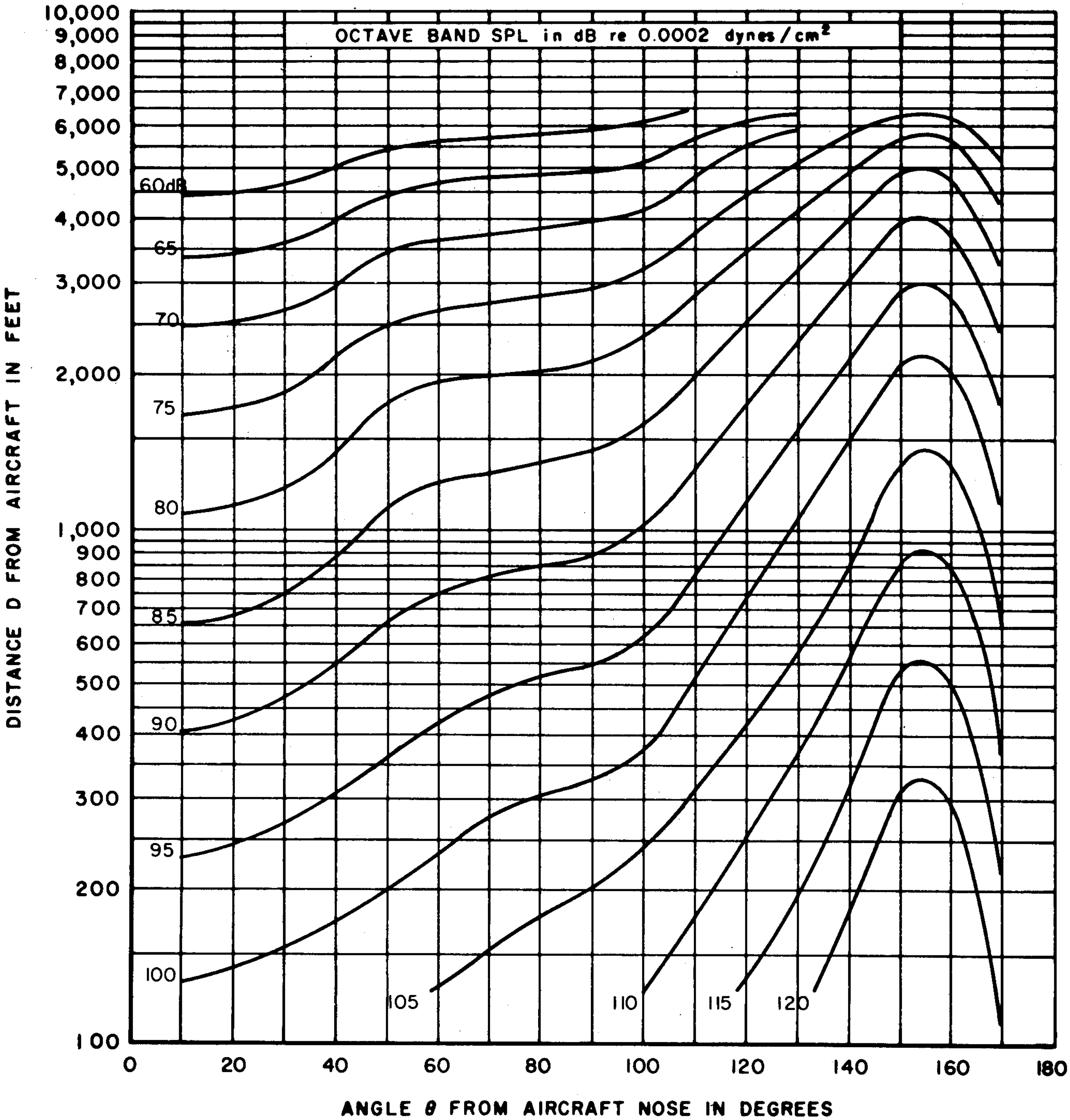

Figure 9b. F-111A Equal Sound Pressure Level Contours-Center Frequency 63.0 Hz, Two Engines at Military Power

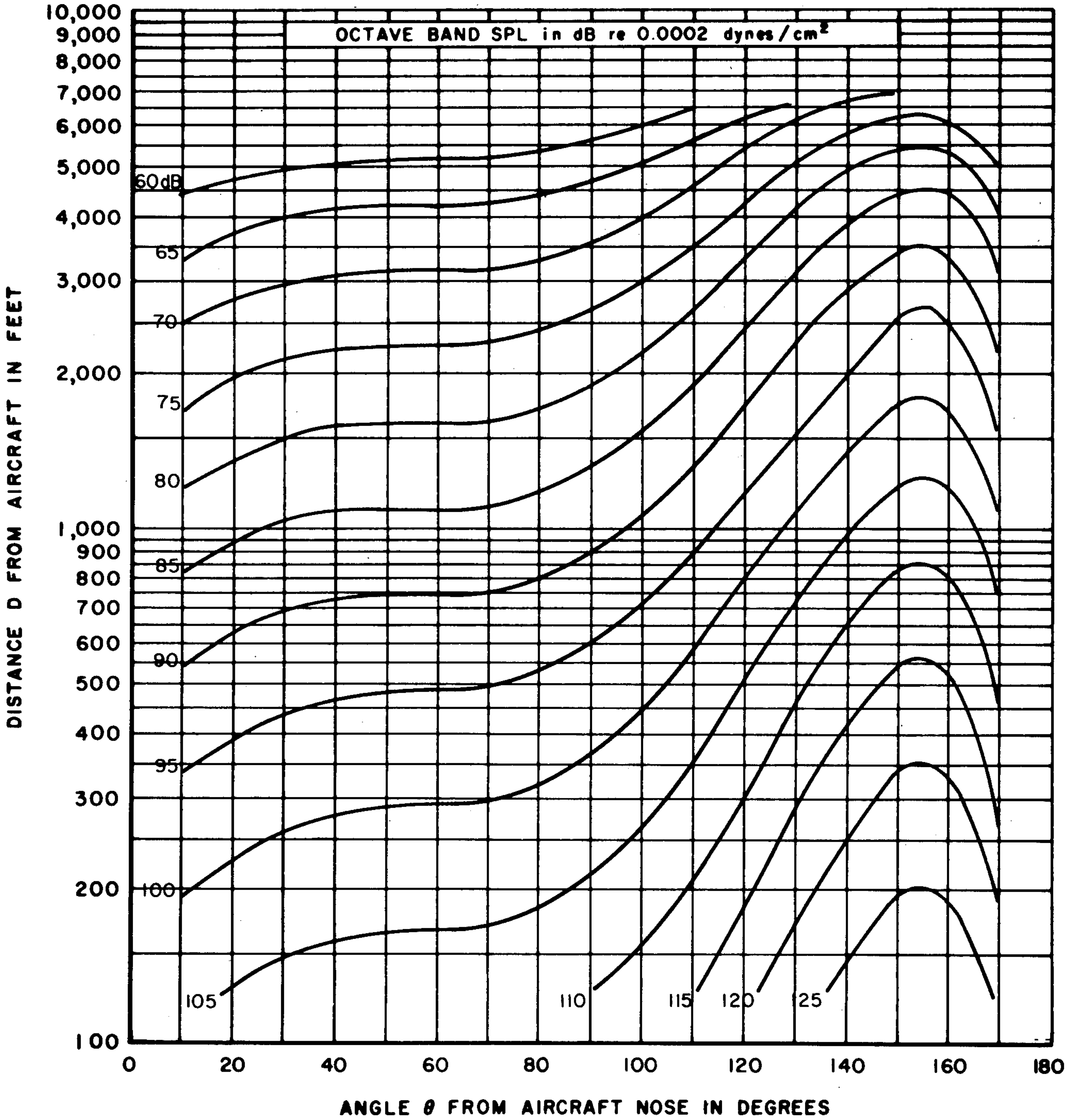

Figure 9c. F-111A Equal Sound Pressure Level Contours-Center Frequency 125 Hz, Two Engines at Military Power

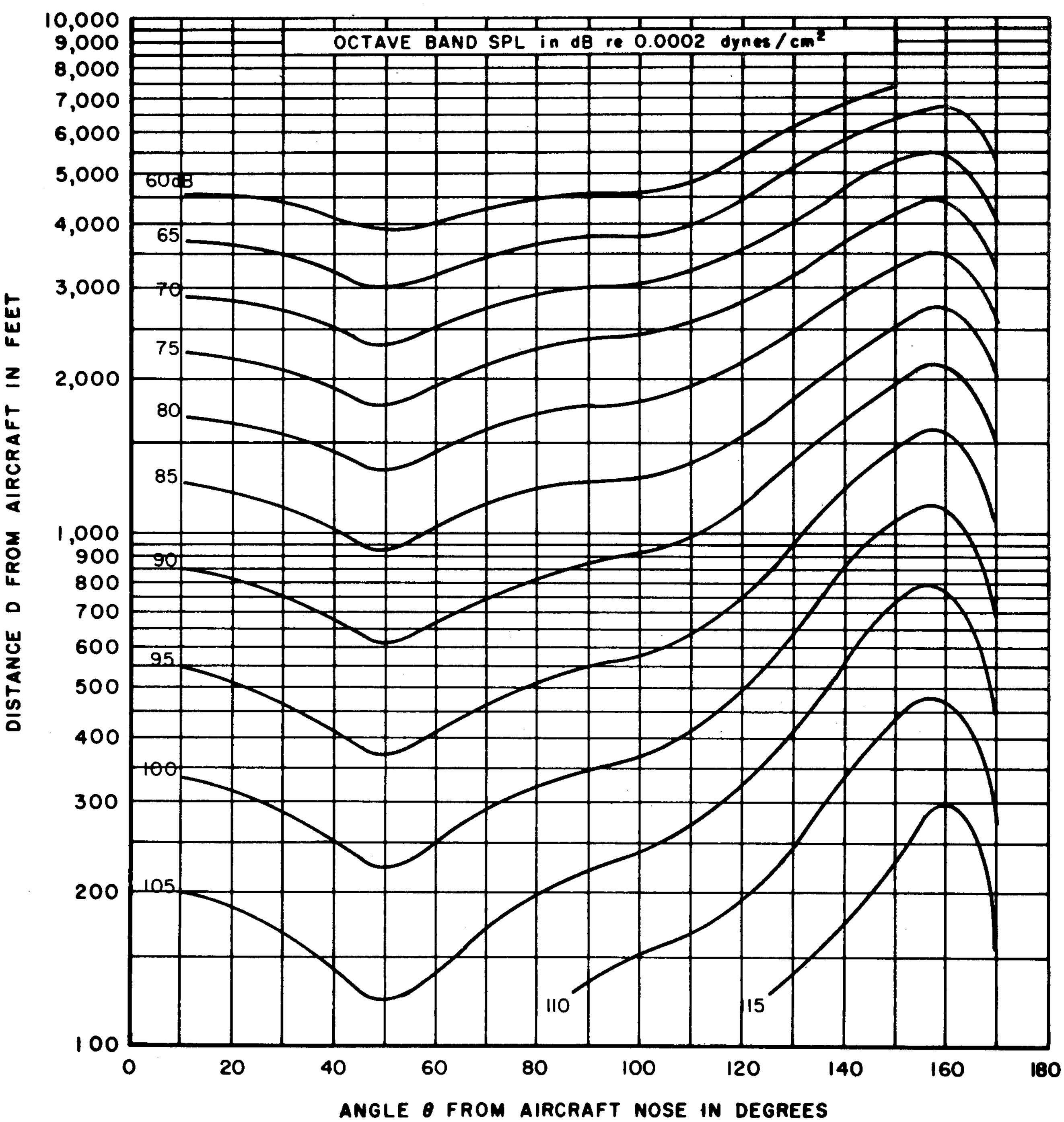

Figure 9d. F-111A Equal Sound Pressure Level Contours-Center Frequency 250 Hz, Two Engines at Military Power

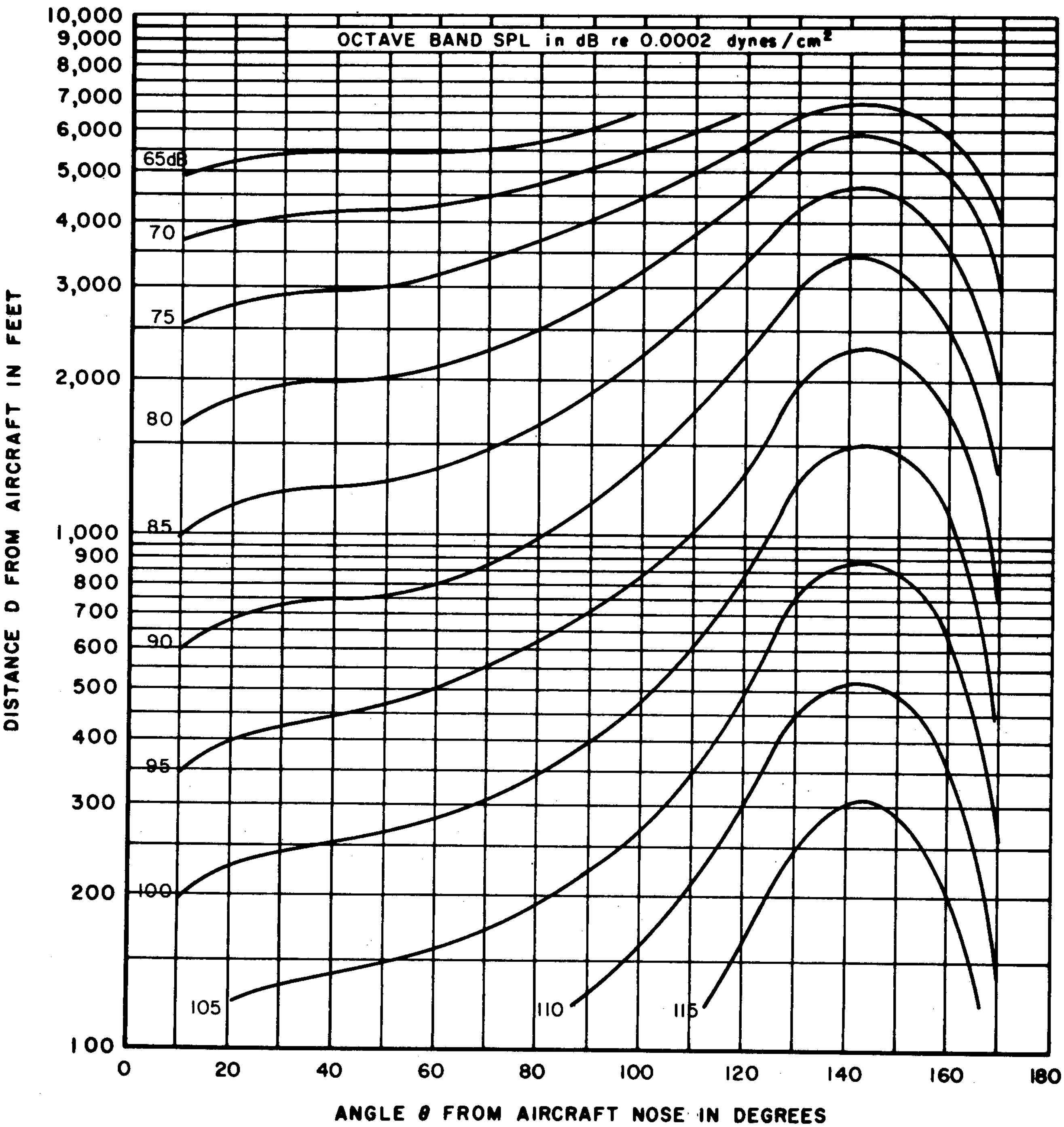

Figure 9e. F-111A Equal Sound Pressure Level Contours-Center Frequency 500 Hz, Two Engines at Military Power

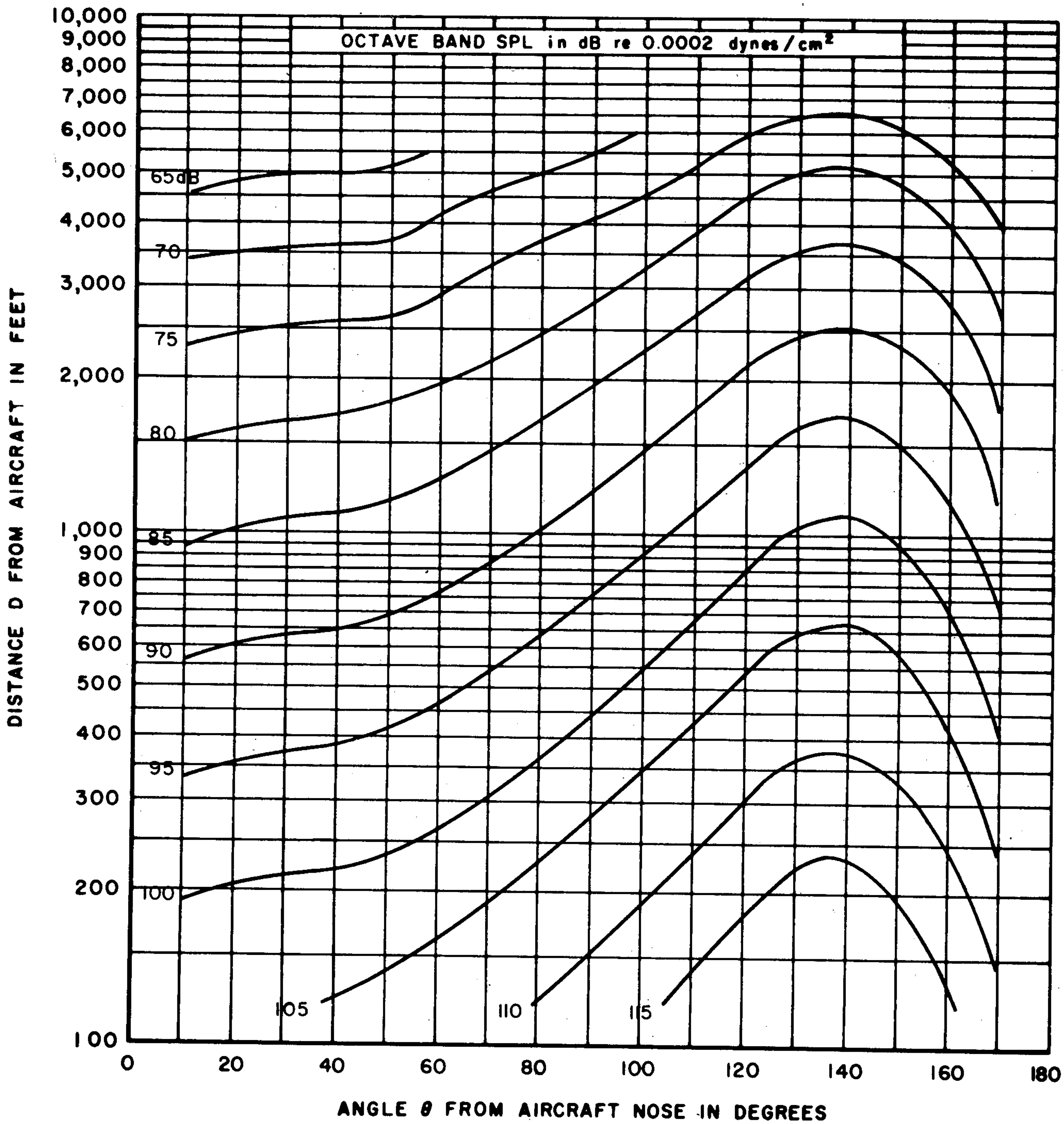

Figure 9f. F-111A Equal Sound Pressure Level Controus-Center Frequency 1 Kc, Two Engines at Military Power

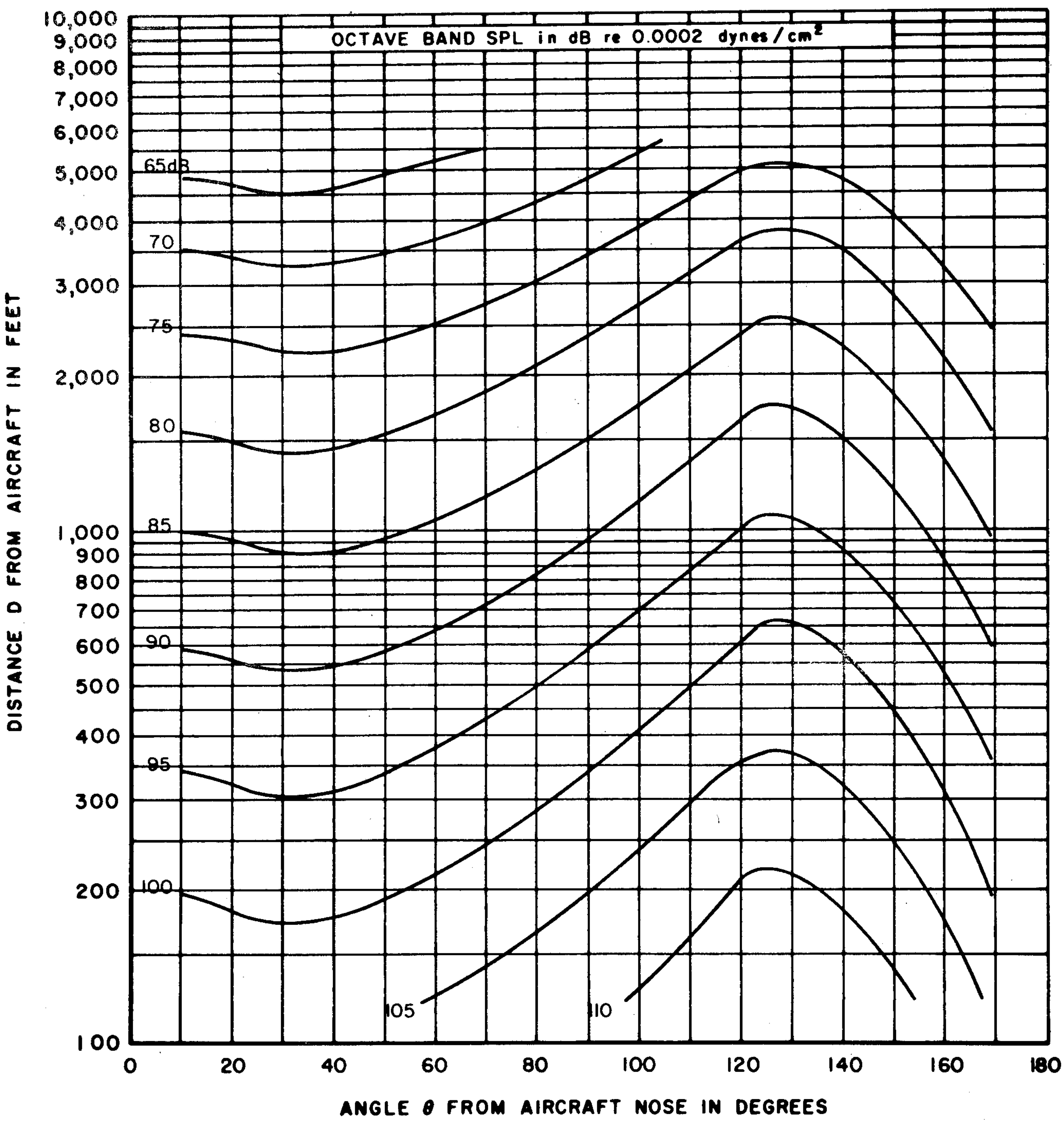

Figure 9g. F-111A Equal Sound Pressure Level Contours-Center Frequency 2 Kc, Two Engines at Military Power

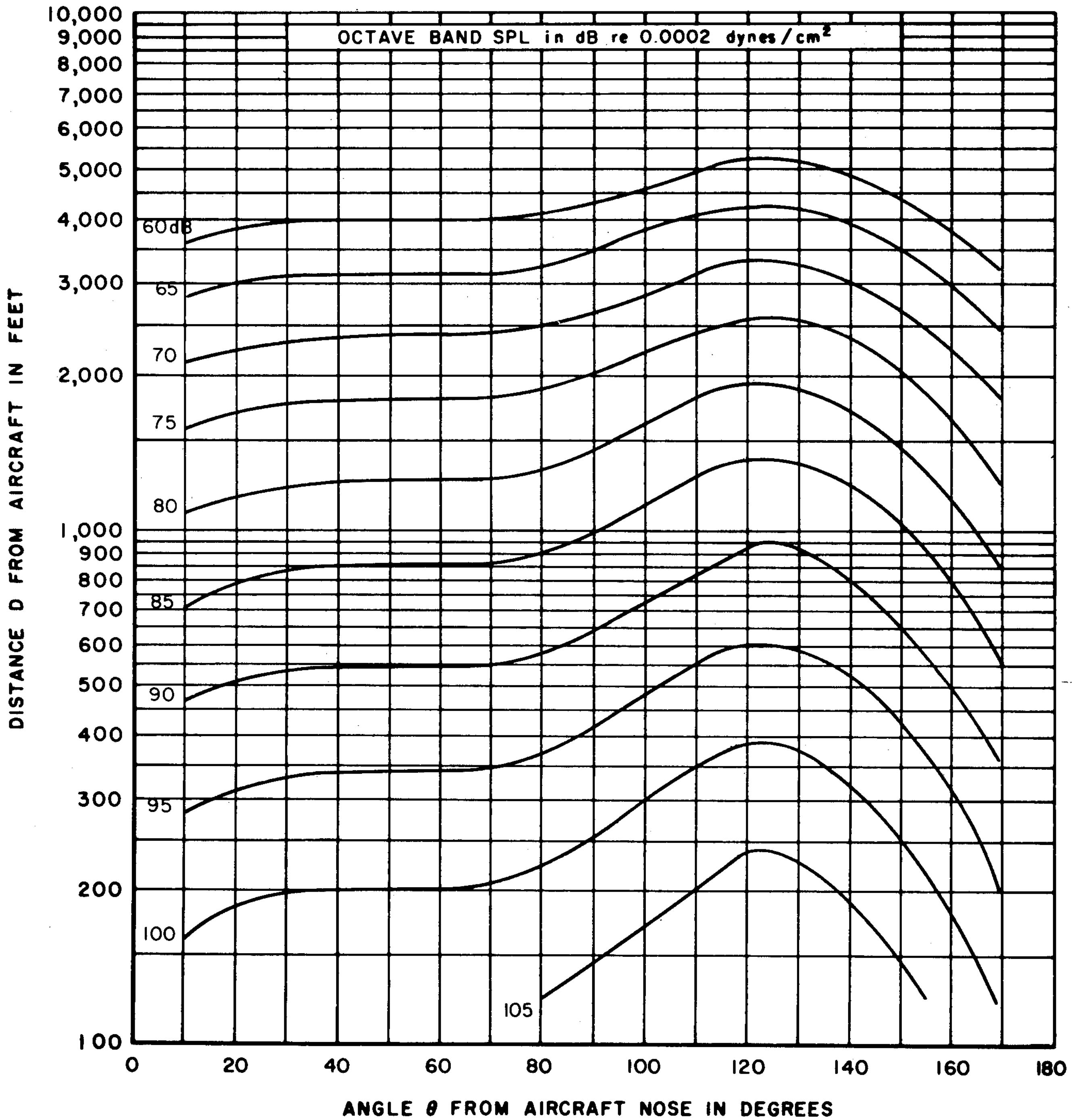

Figure 9h. F-111A Equal Sound Pressure Level Contours-Center Frequency 4 Kc, Two Engines at Military Power

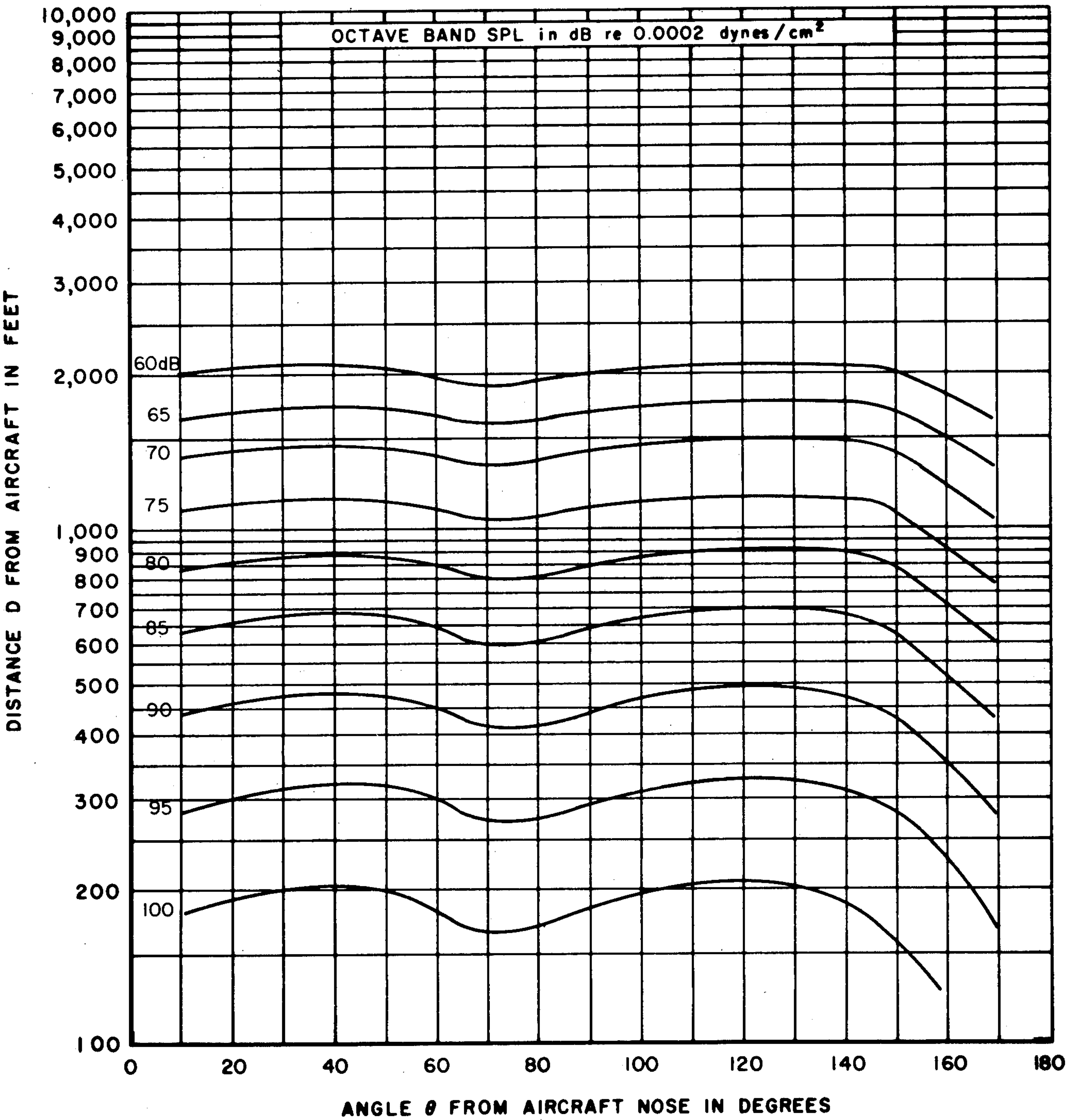

Figure 9i. F-111A Equal Sound Pressure Level Contours-Center Frequency 8 Kc, Two Engines at Military Power

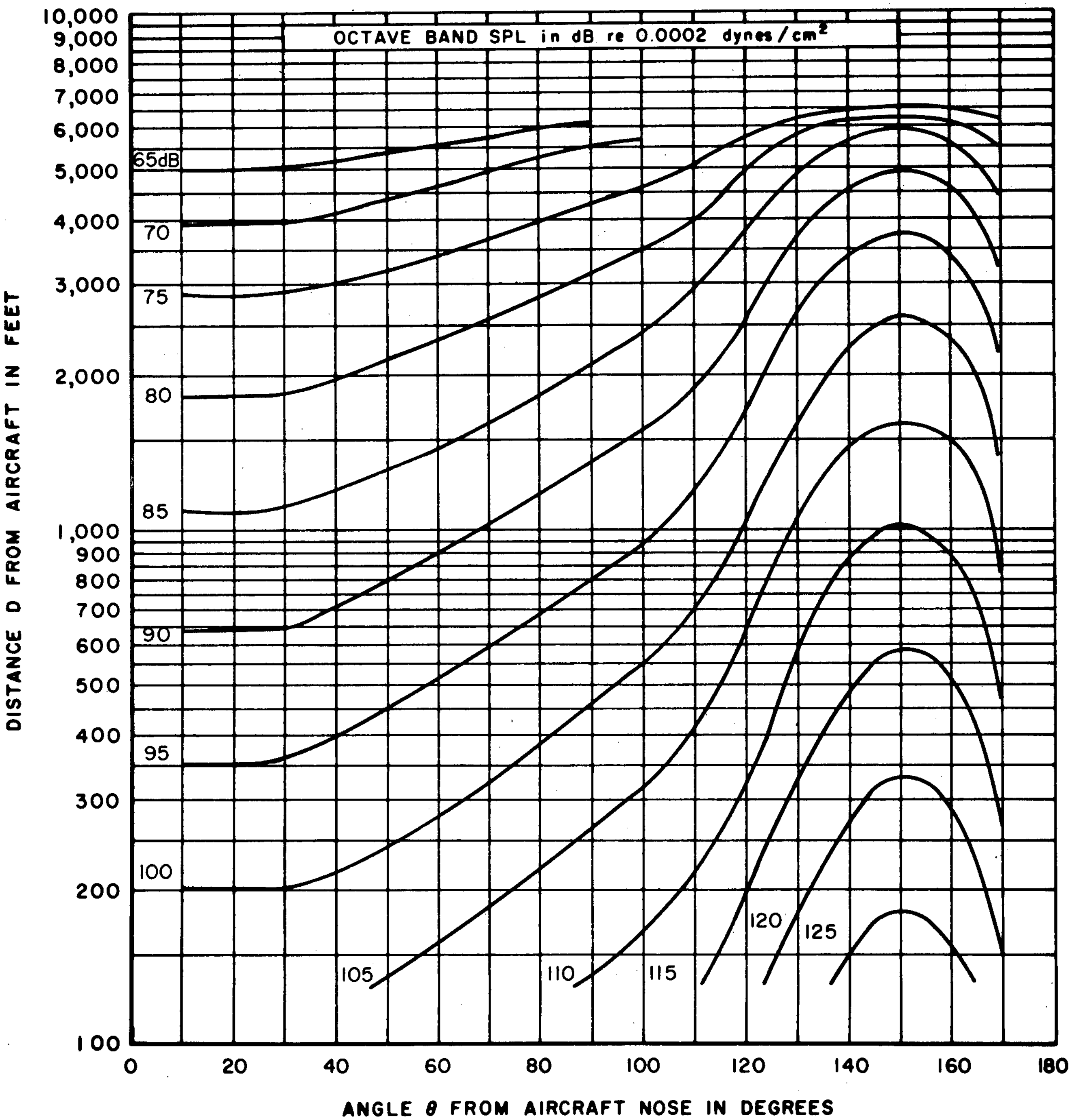

Figure 10a. F-111A Equal Sound Pressure Level Contours-Center Frequency 31.5 Hz, One Engine With Afterburner

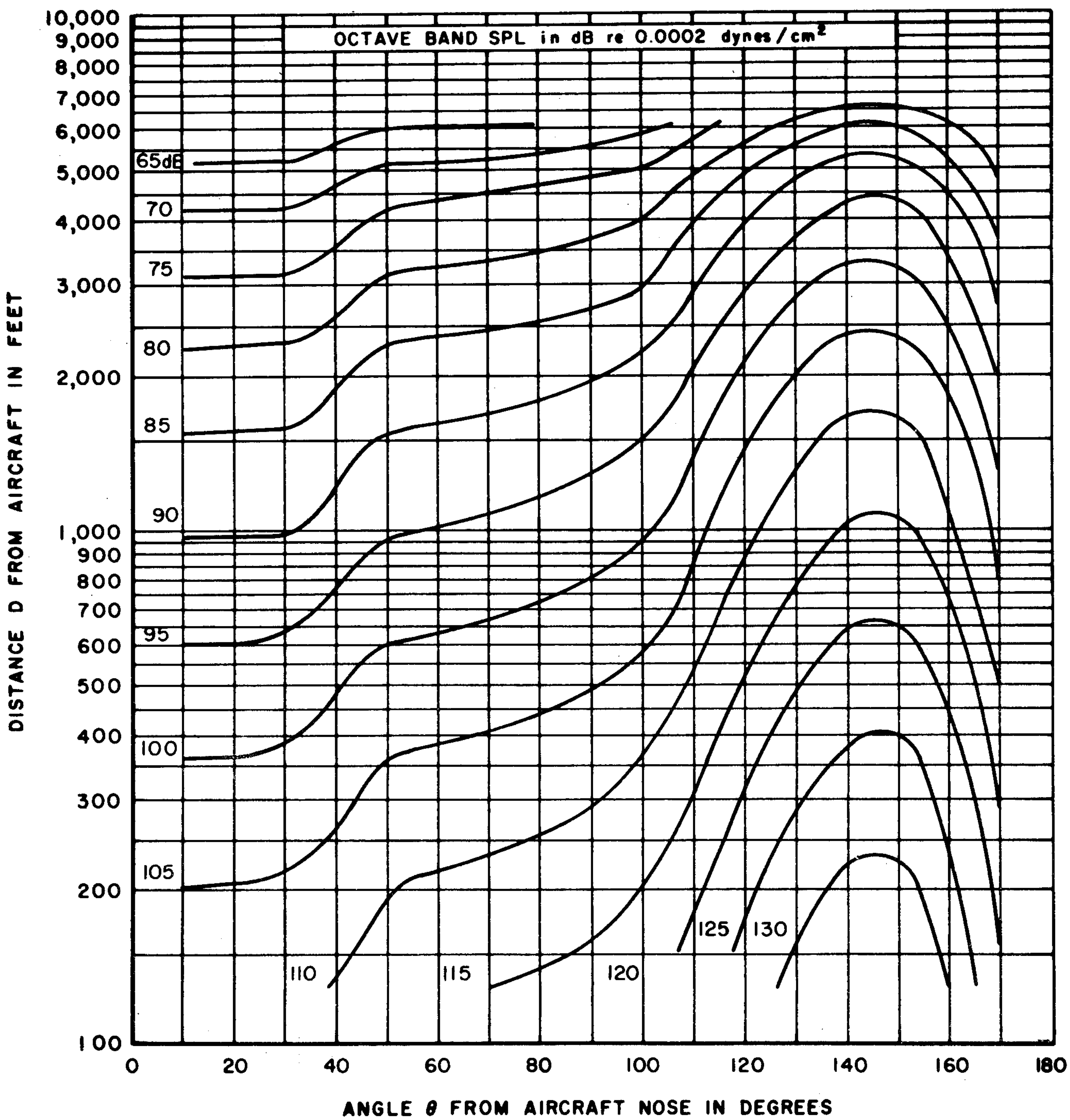

Figure 10b. F-111A Equal Sound Pressure Level Contours-Center Frequency 63 Hz, One Engine With Afterburner

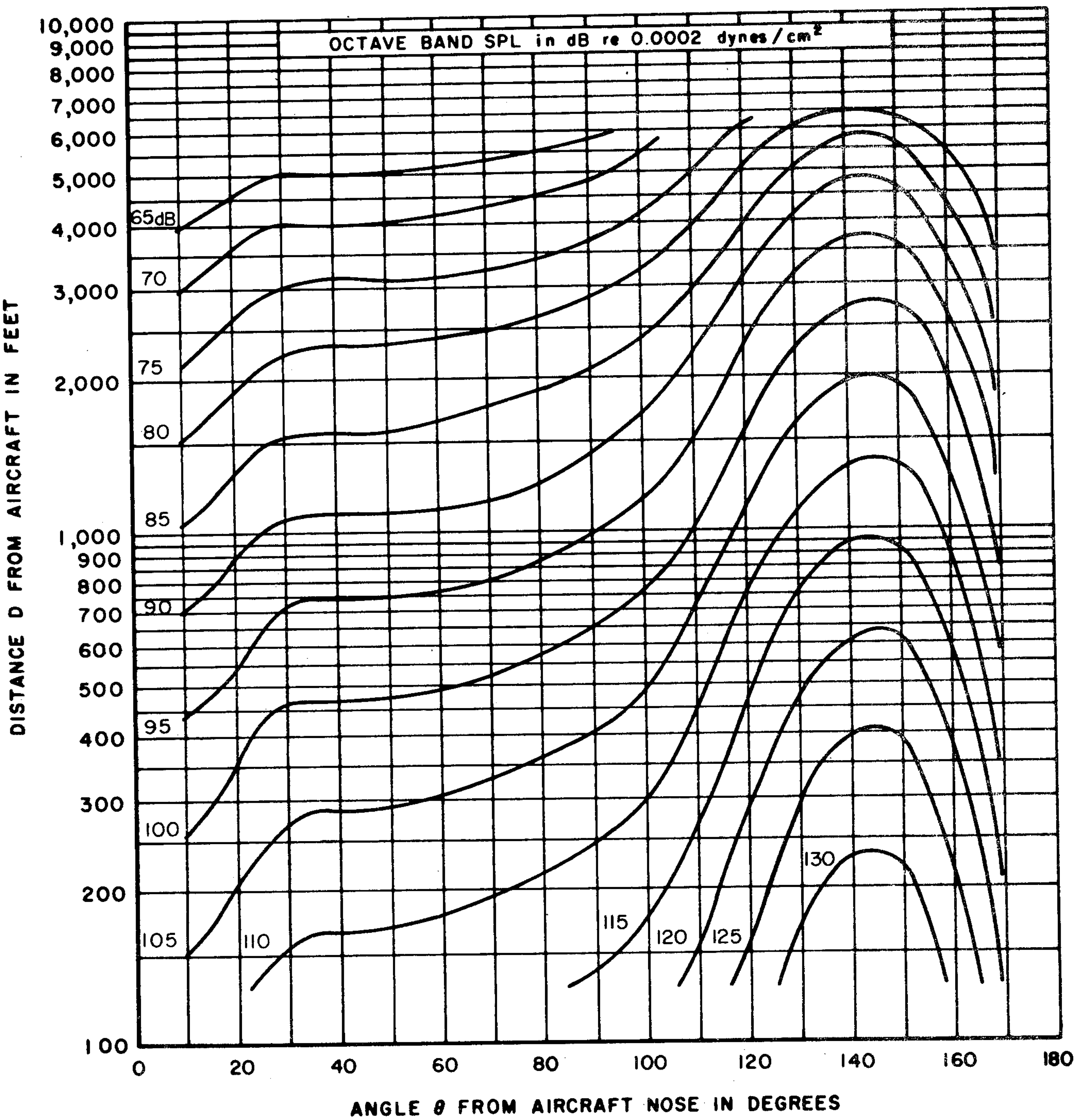

Figure 10c. F-111A Equal Sound Pressure Level Contours-Center Frequency 125 Hz, One Engine With Afterburner

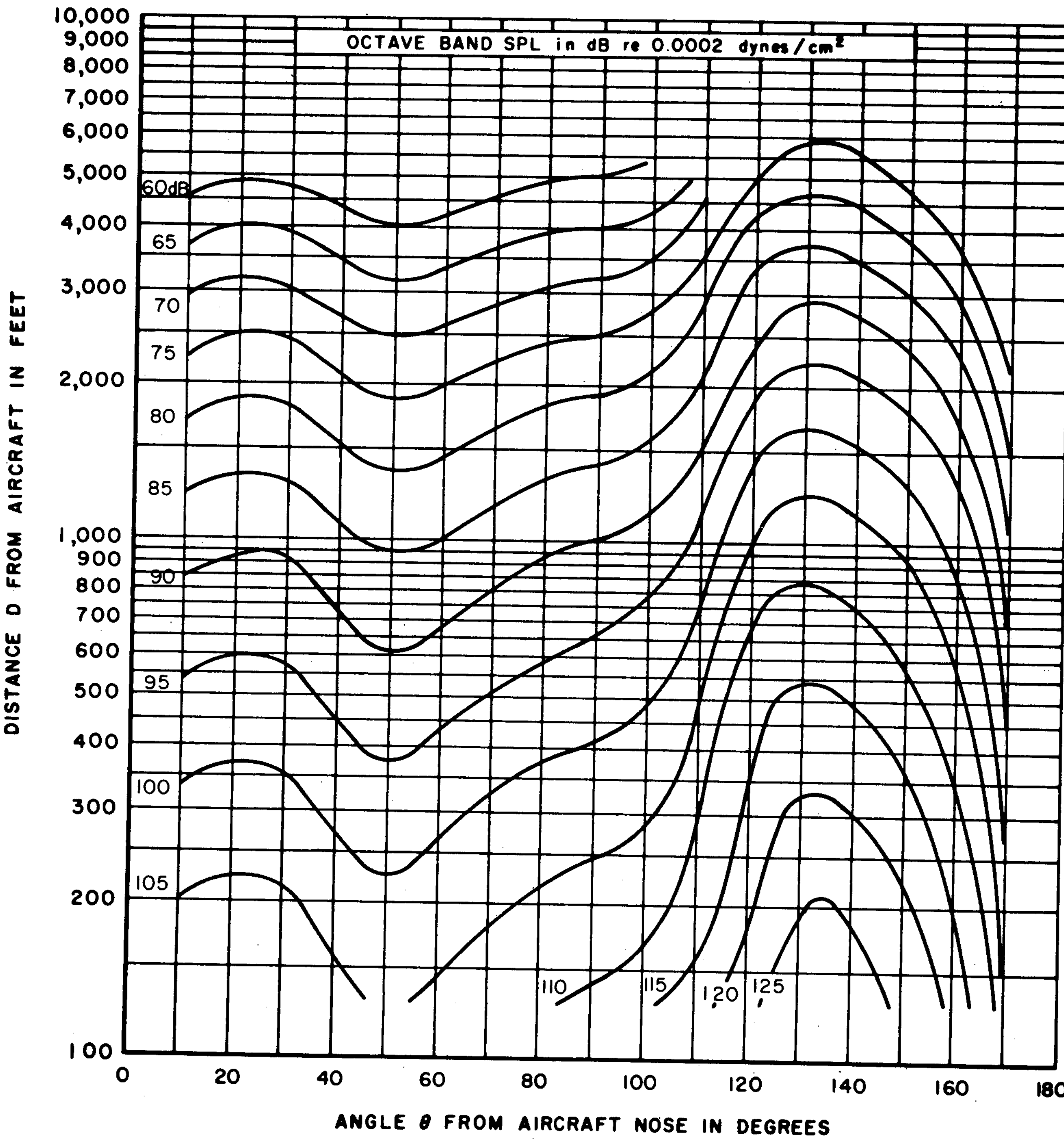

Figure 10d. F-111A Equal Sound Pressure Level Contours-Center Frequency 250 Hz, One Engine With Afterburner

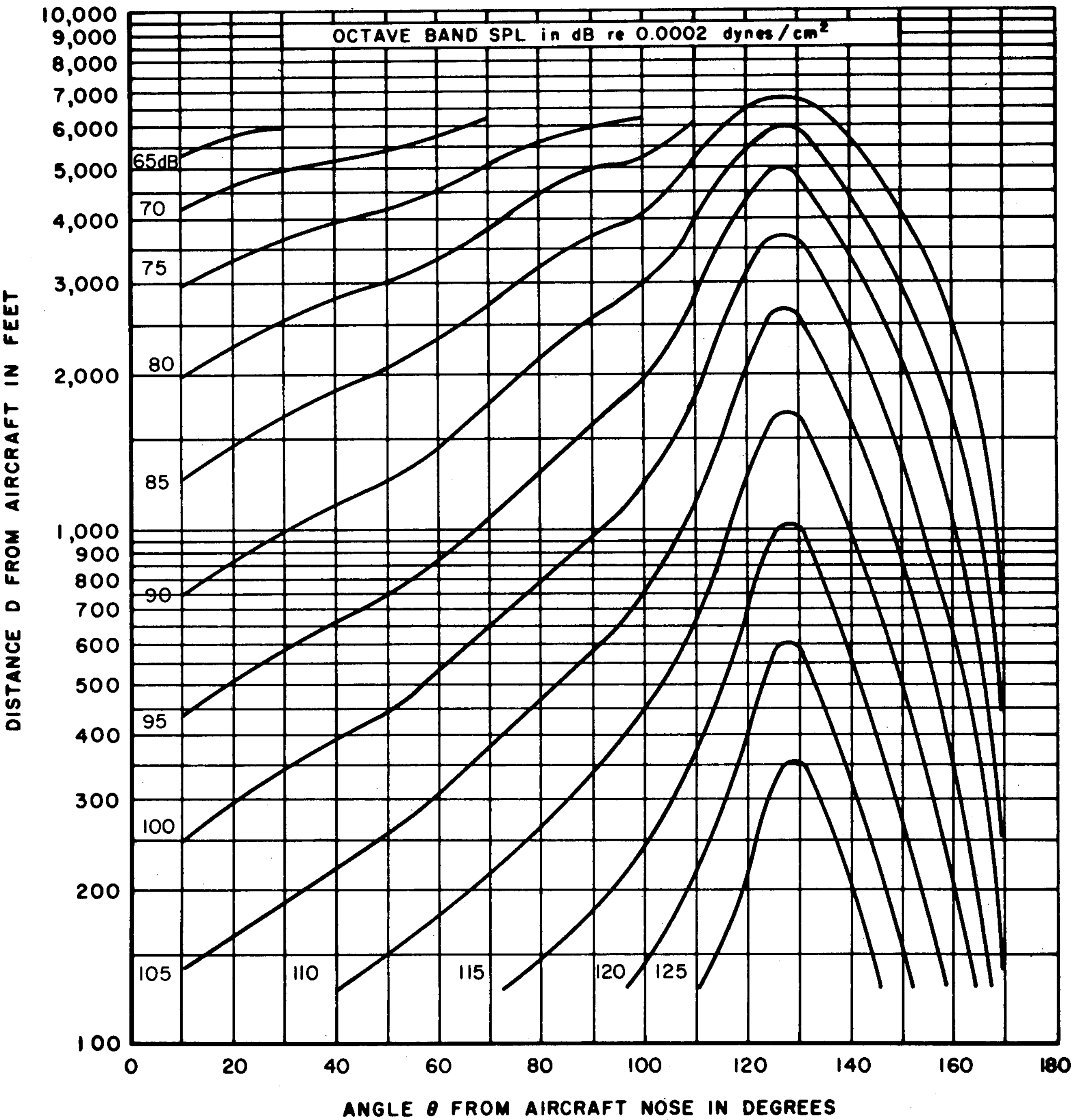

Figure 10e. F-111A Equal Sound Pressure Level Contours-Center Frequency 500 Hz, One Engine With Afterburner

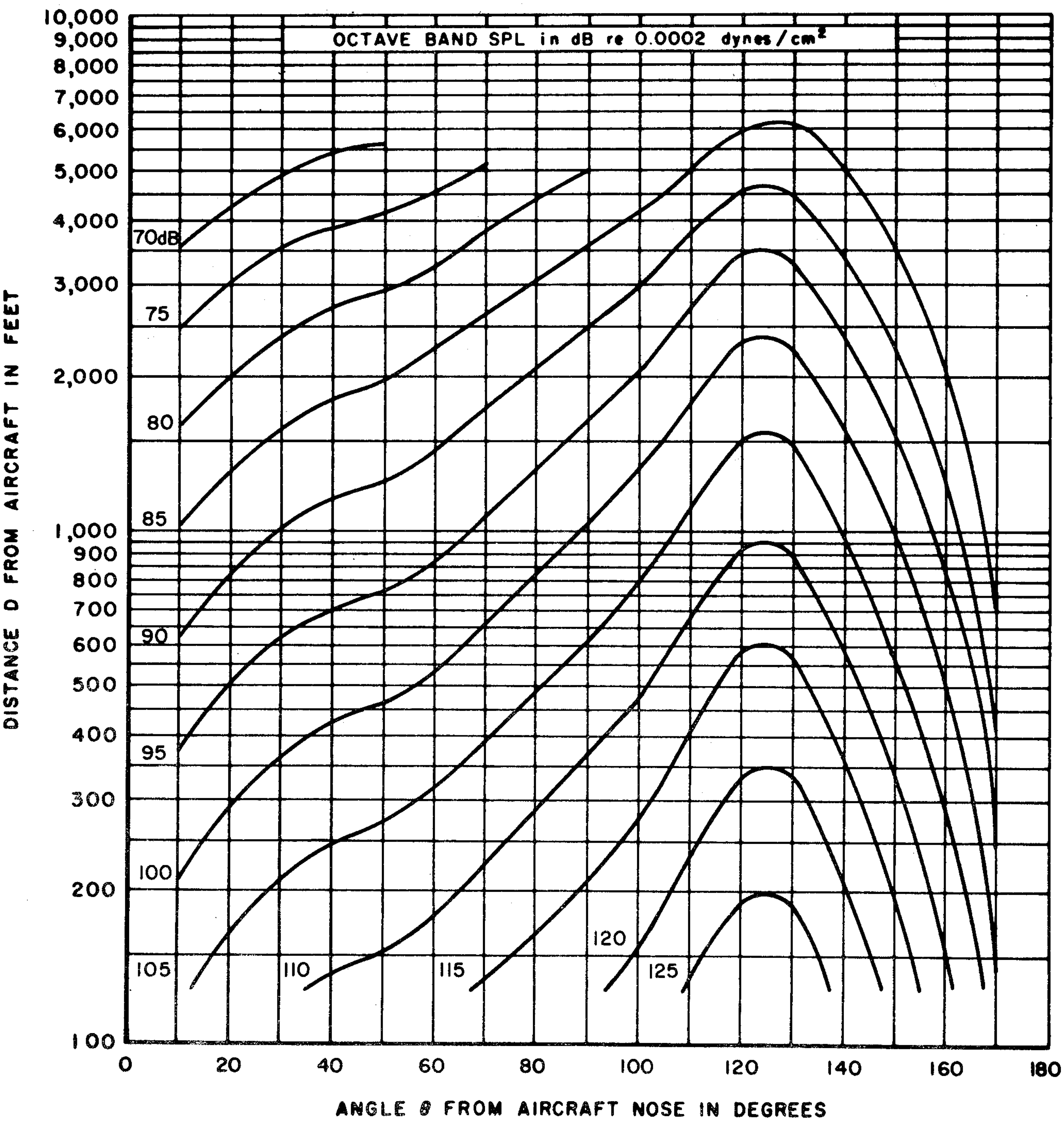

Figure 10f. F-111A Equal Sound Pressure Level Contours-Center Frequency 1 Kc, One Engine With Afterburner

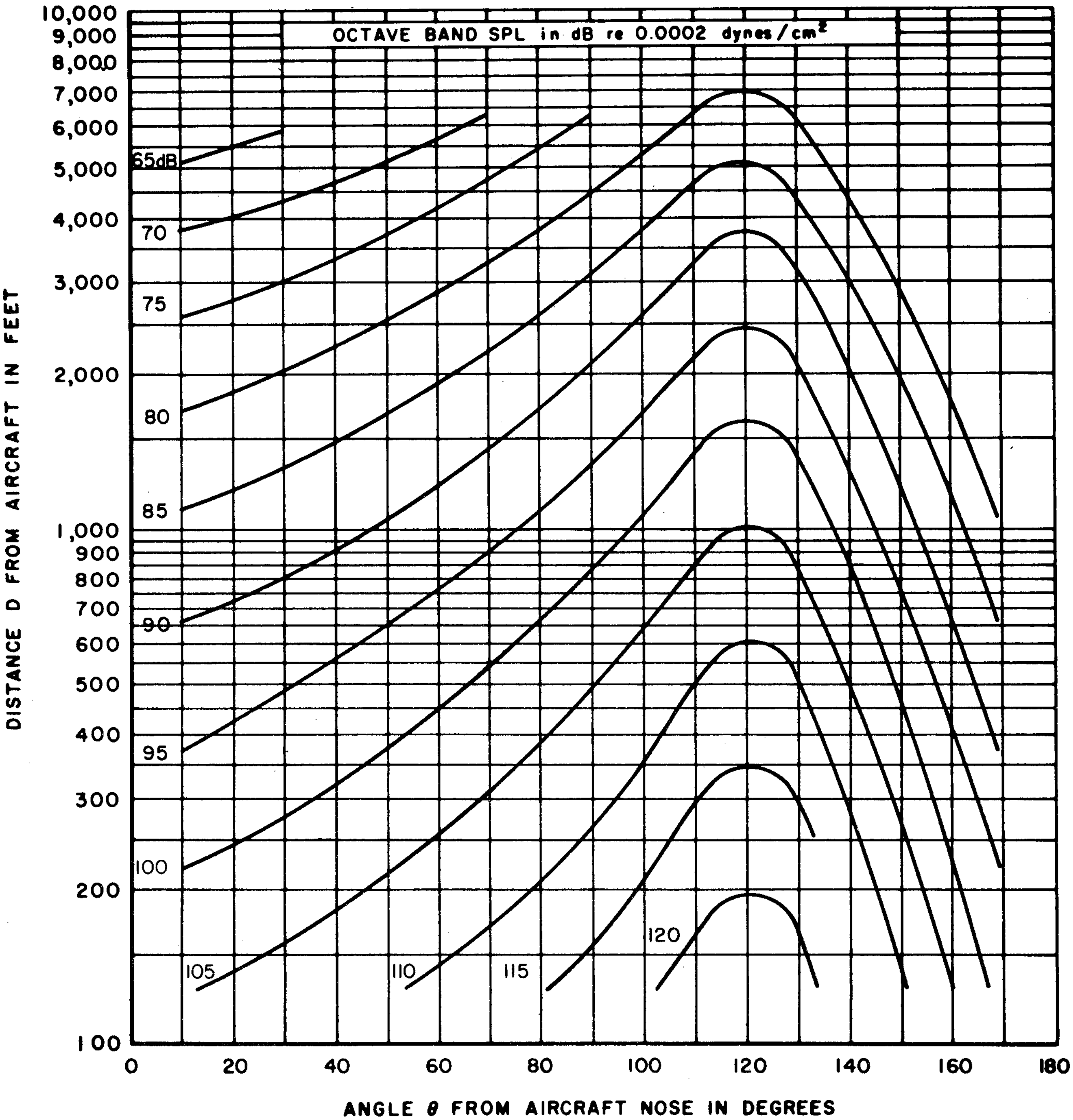

Figure 10g. F-111A Equal Sound Pressure Level Contours-Center Frequency 2 Kc, One Engine With Afterburner

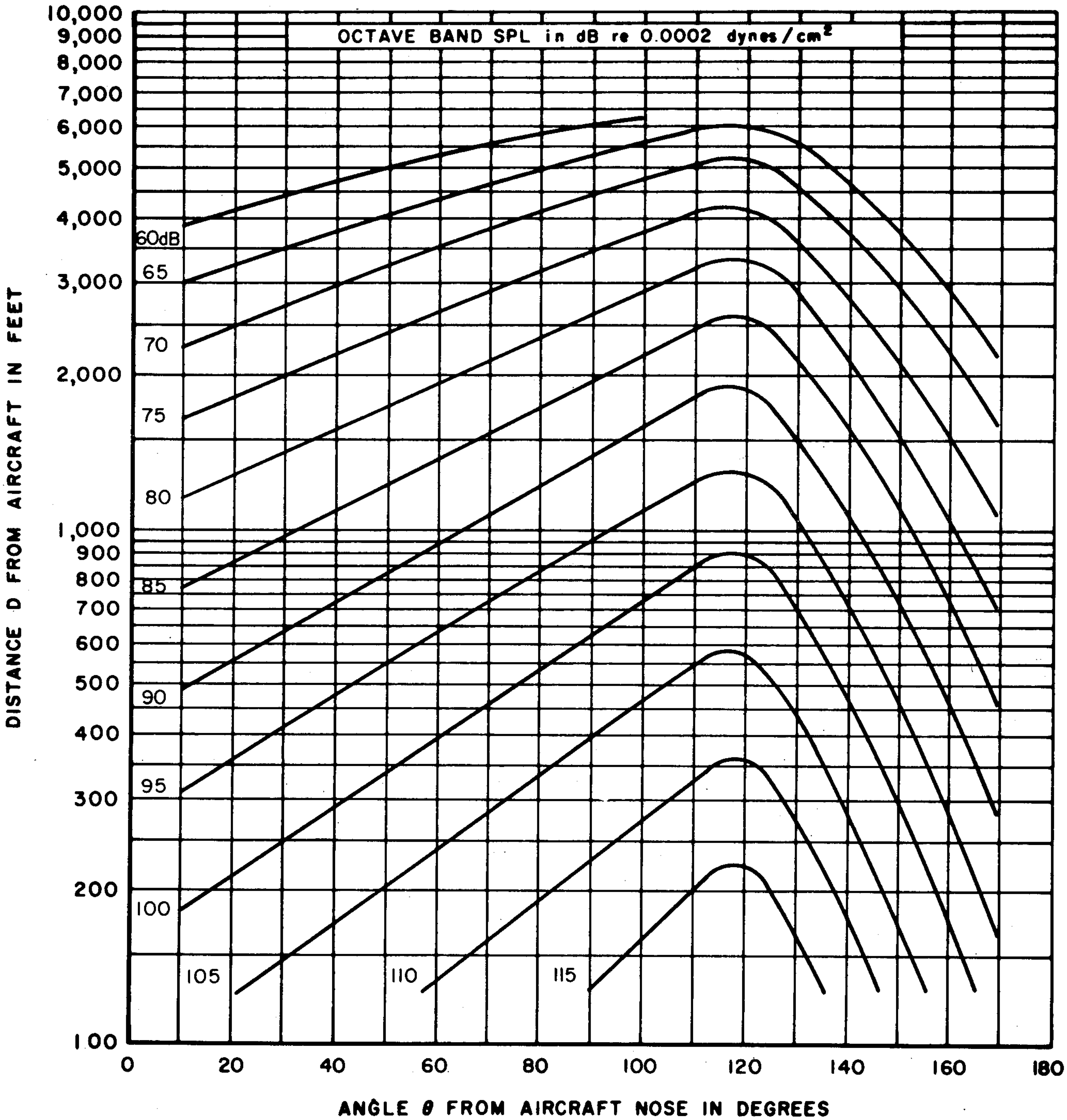

Figure 10h. F-111A Equal Sound Pressure Level Contours-Center Frequency 4 Kc, One Engine With Afterburner

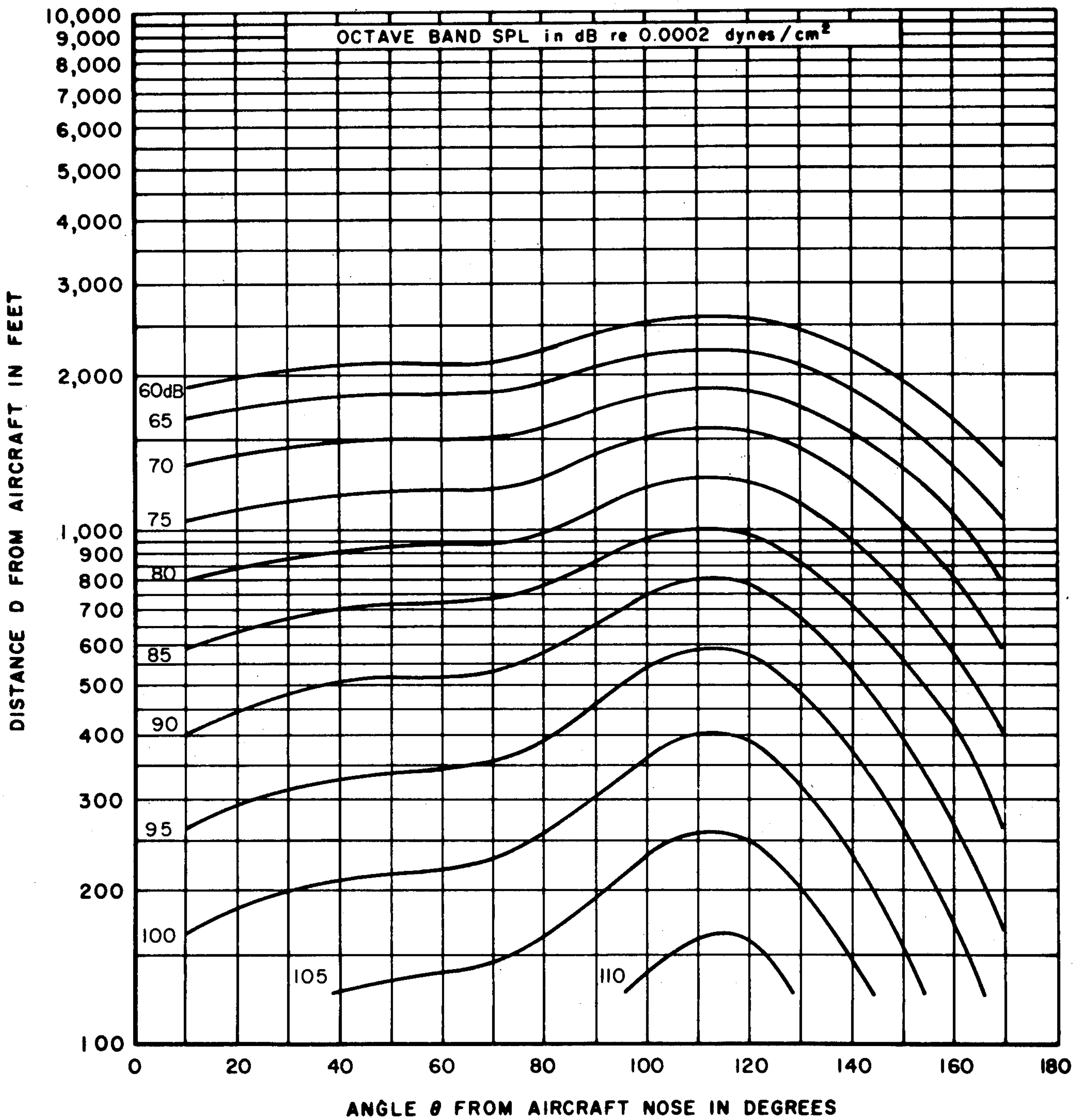

Figure 10i. F-111A Equal Sound Pressure Level Contours-Center Frequency 8 Kc, One Engine With Afterburner

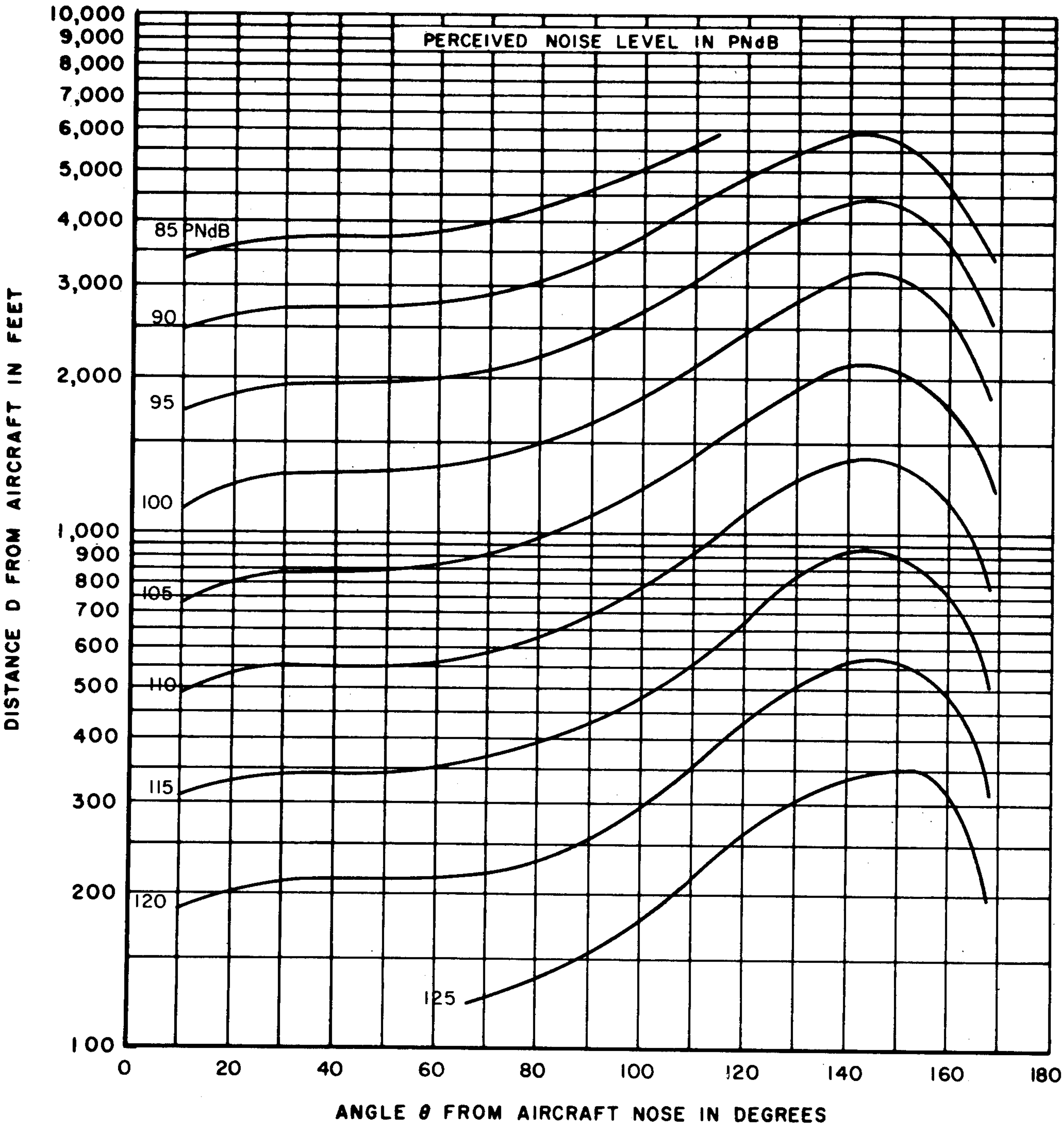

Figure 11a. F-111A Equal Perceived Noise Level Contours
One Engine at Military Power

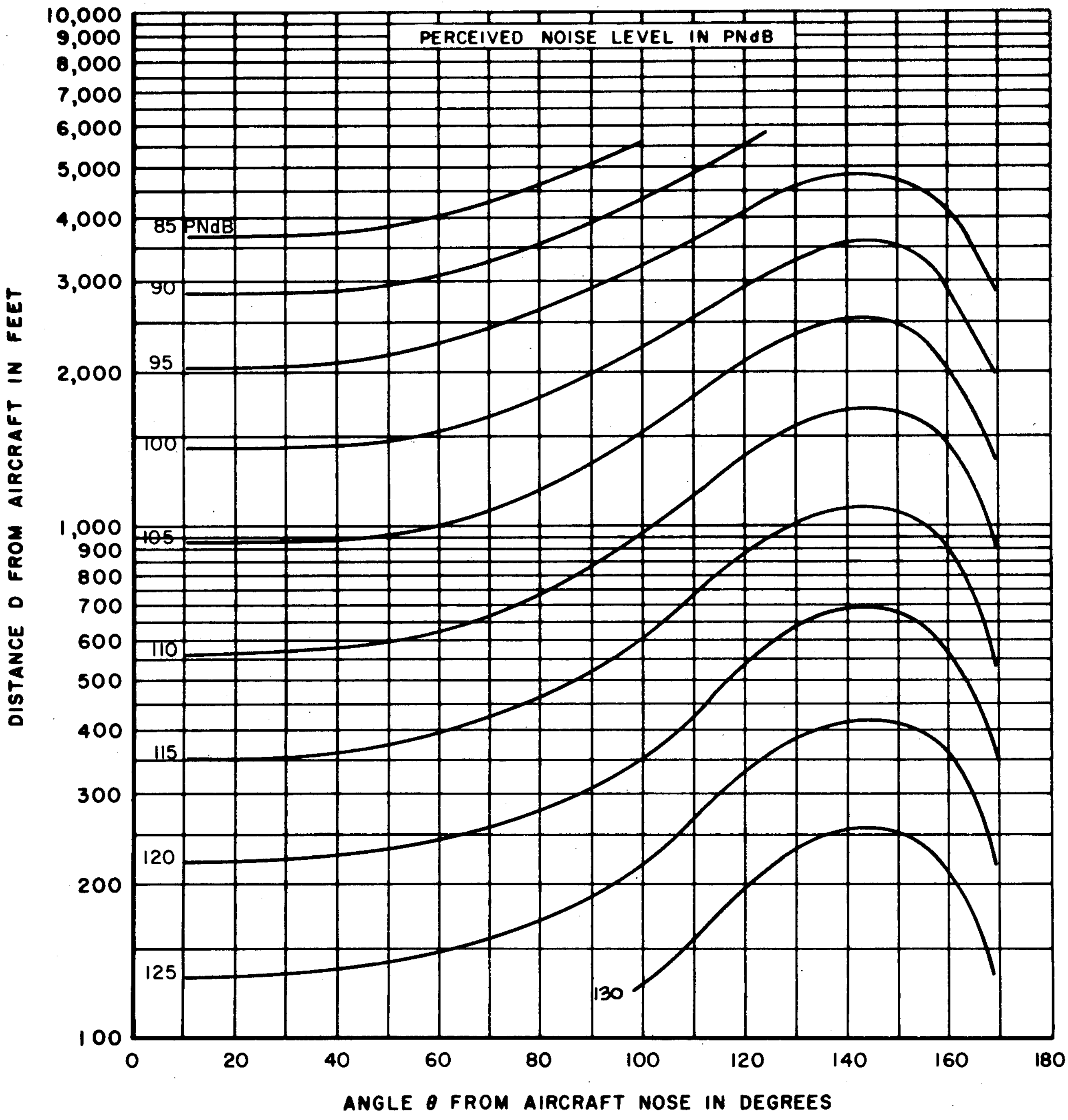

Figure 11b. F-111A Equal Perceived Noise Level Contours
Two Engines at Military Power

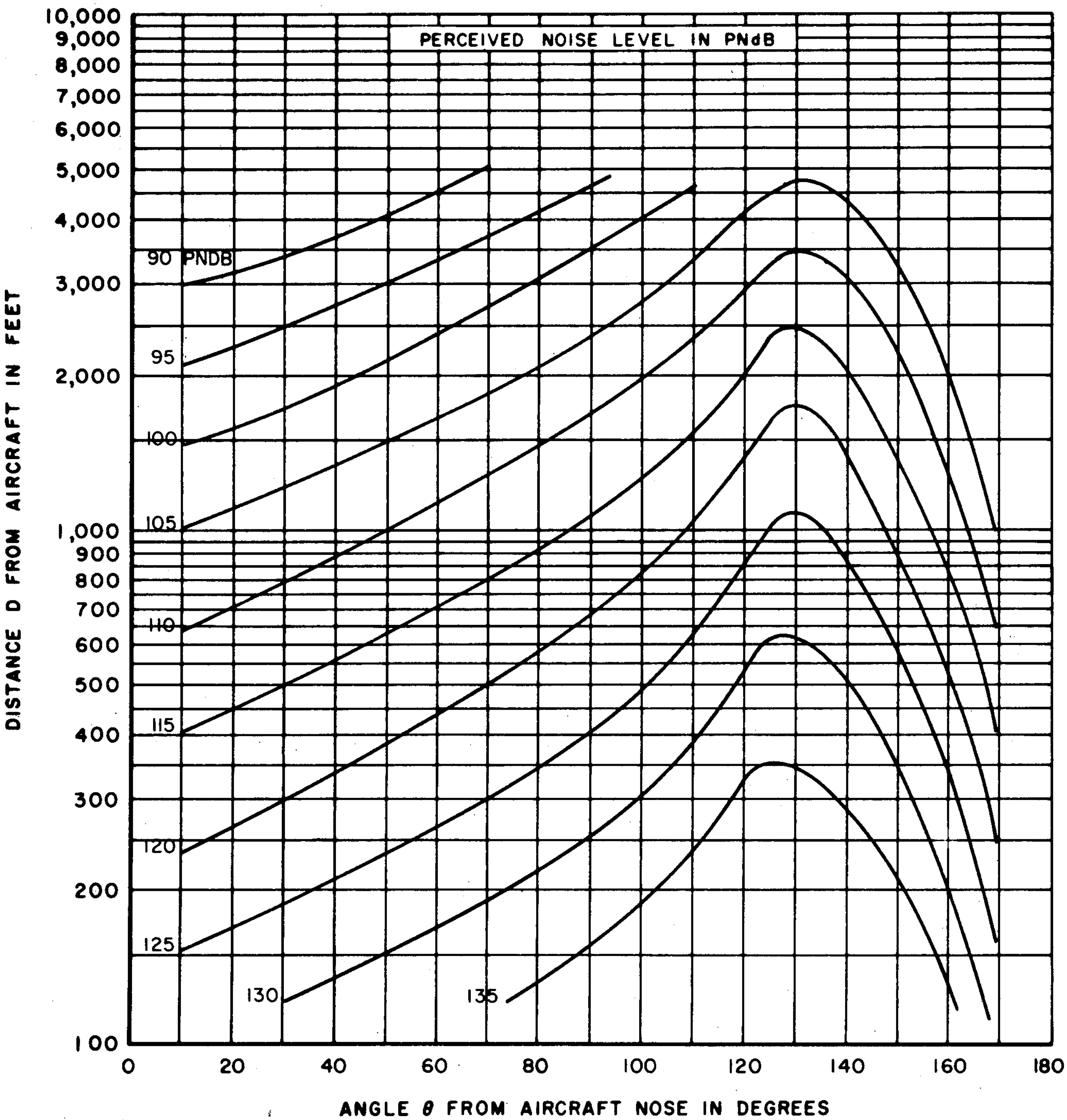

Figure 11c. F-111A Equal Perceived Noise Level Contours
One Engine With Afterburner

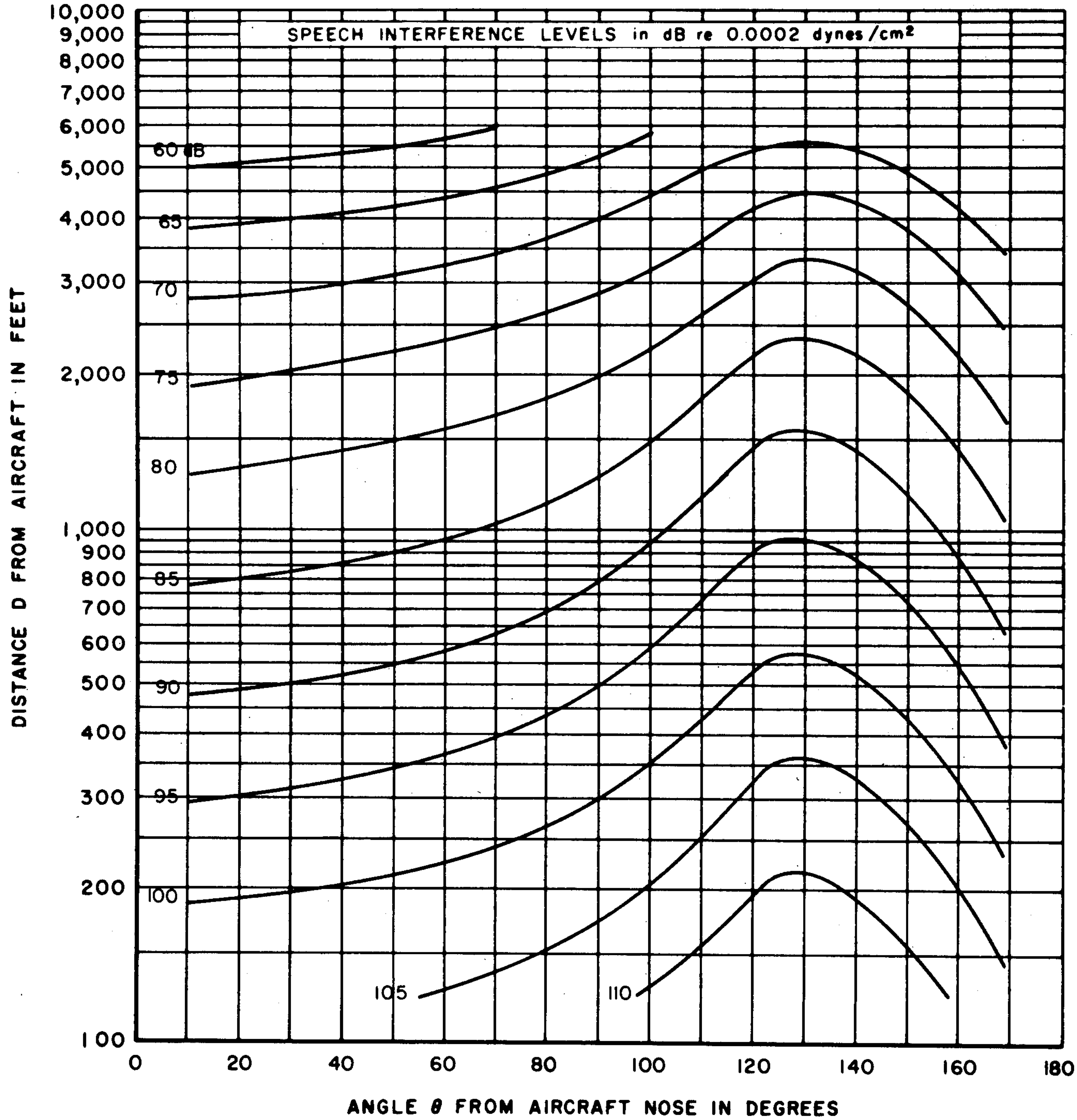

Figure 12a. F-111A Equal Speech Interference Level Contours
One Engine at Military Power

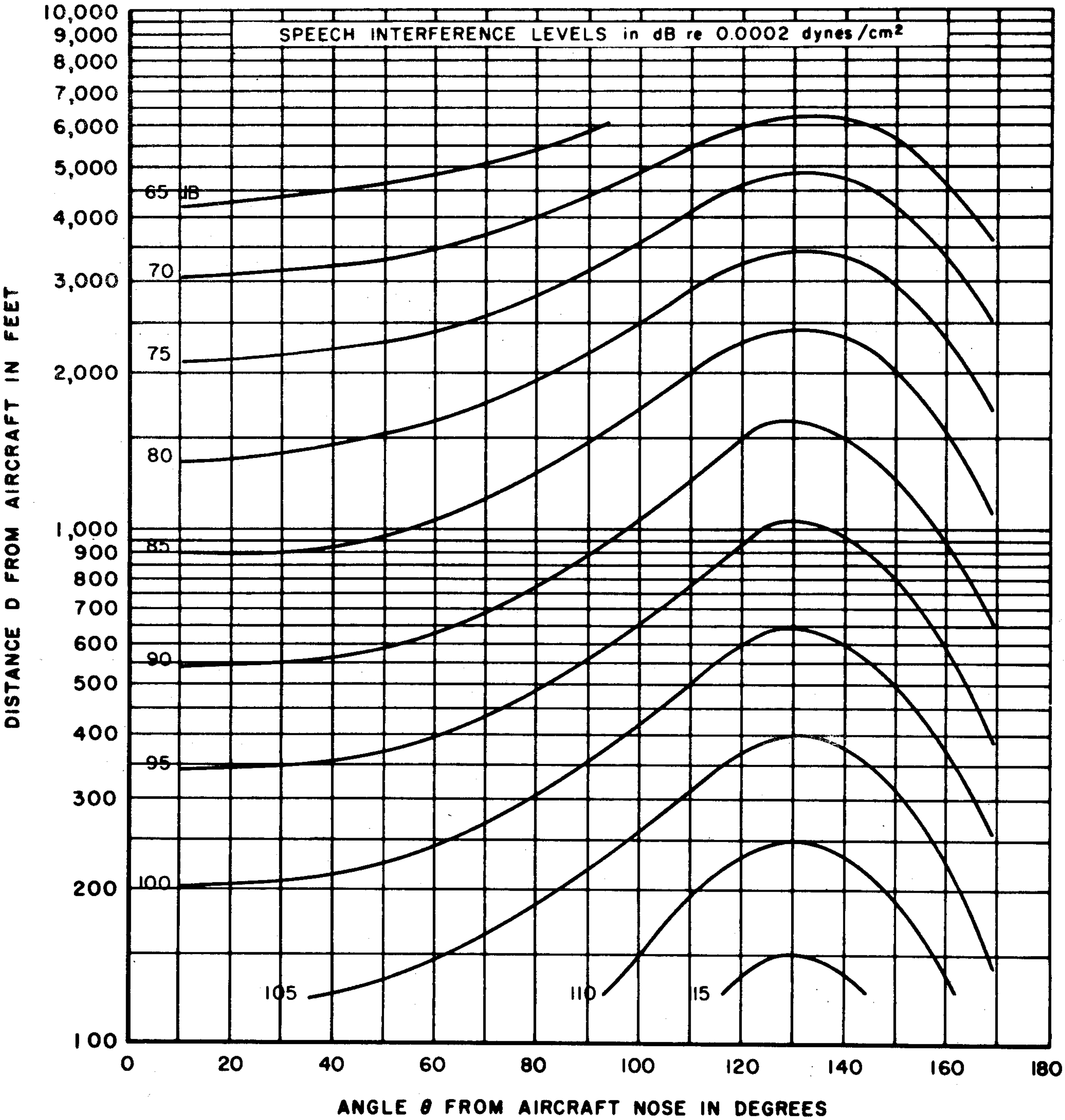

Figure 12b. F-111A Equal Speech Interference Level Contours
Two Engines at Military Power

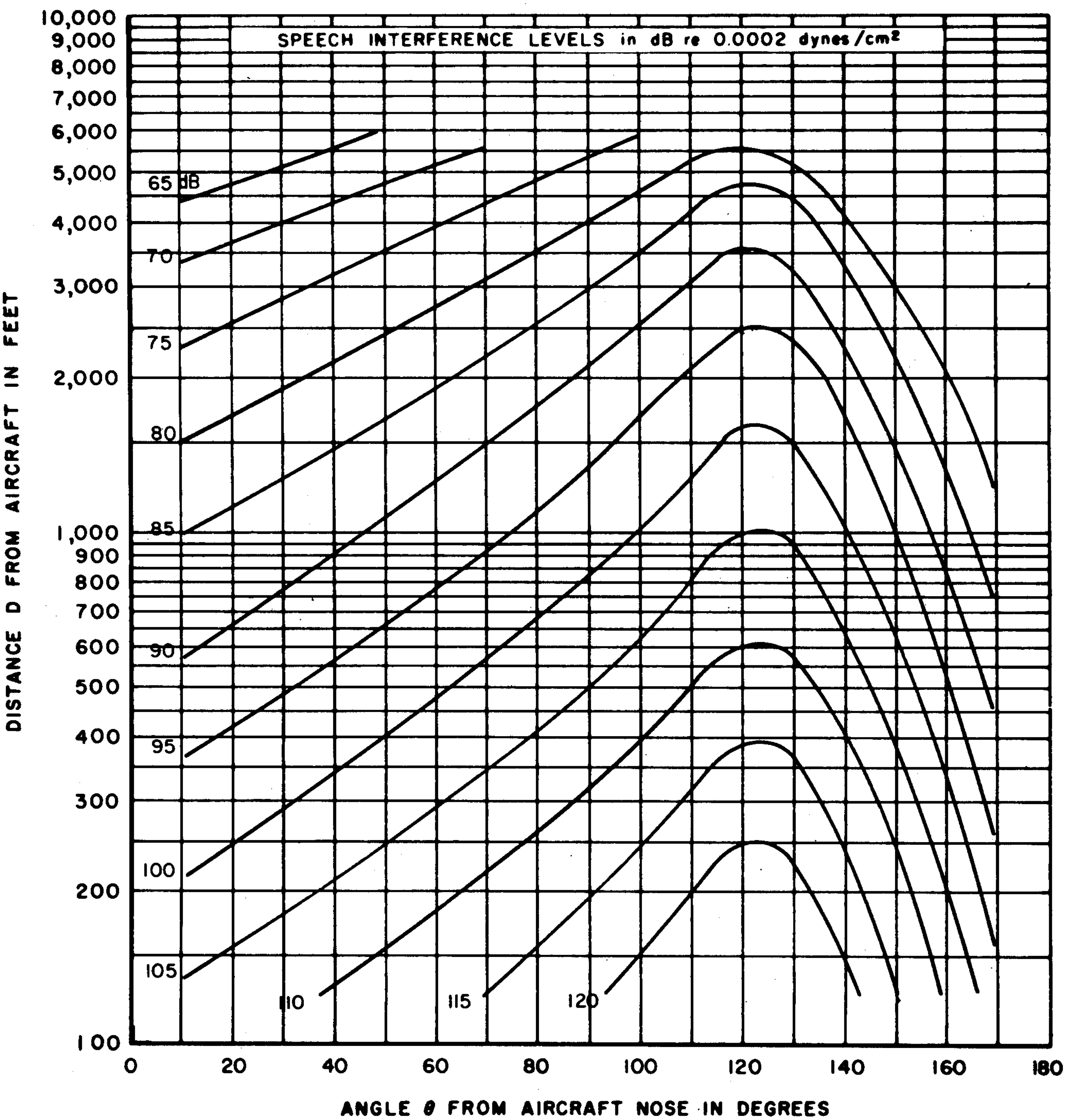

Figure 12c. F-111A Equal Speech Interference Level Contours
One Engine With Afterburner

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13. ABSTRACT

Sound pressure level measurements were made on an F-111A aircraft at 250-foot radial distance with three different engine power configurations at Wright-Patterson AFB, Ohio. In addition, sound level measurements were made at four maintenance positions where personnel would typically be located during normal ground operations. These data were used to compute the power spectra, directivity indices, equal sound pressure level contours, equal perceived noise level contours, and equal speech interference level contours. These results are presented in graphical form and can be used to determine the acoustic environments at distances from 125 to 6000 feet from the aircraft during ground operation.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Acoustics						
Noise						
Aircraft						
F-111A Aircraft						
Ground runup operations						
Prat and Whitney TF30-P-1 engines						