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A NOISE STUDY OF THE A-6 AIRPLANE AND TECHNIQUES FOR REDUCING ITS AURAL DETECTION DISTANCE

By David A. Hilton, Andrew B. Connor
and Harvey H. Hubbard

April 1975

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16. Abstract

A study was undertaken by the NASA Langley Research Center to determine the noise reduction potential of the A-6 airplane in order to reduce its aural detection distance. Static and flyby noise measurements were taken to document the basic airplane signature. The low-frequency noise which is generally most critical for aural detection was found to be broad-band in nature from this airplane, and its source is the turbojet engine exhaust. High-frequency compressor noise, which is characteristic of turbojet powerplants, and which is prominent at close range for this airplane, has no measurable effect on aural detection distance.

The use of fluted-engine exhaust nozzles to change the far-field noise spectra is suggested as a possible means for reducing the aural detection distances. Detection distances associated with eight-lobe and four-lobe nozzles are estimated for a 1,000-foot altitude and grassy terrain to decrease from 4 miles to about 3 miles, and from 3 miles to about 2 miles for a 300-foot altitude and grassy terrain.

The above modifications are estimated to add 199 and 155 pounds, respectively, to the aircraft weight, and result in a 10 and 15-knot decrease in V_{max} (roughly 2%). Rate of climb and velocity for rate of climb are affected by about the same proportion as V_{max}, but the cruise performance and stability characteristics are relatively unaffected by these changes.

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SUMMARY

A study was undertaken by the NASA Langley Research Center to determine the noise reduction potential of the A-6 airplane in order to reduce its aural detection distance. Static and flyby noise measurements were taken to document the basic airplane signature. The low-frequency noise which is generally most critical for aural detection was found to be broad band in nature from this airplane, and its source is the turbojet engine exhaust. High-frequency compressor noise, which is characteristic of turbojet powerplants, and which is prominent at close range for this airplane, has no measurable effect on aural detection distance.

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The above nozzle modifications are estimated to add 199 and 155 pounds, respectively, to the aircraft weight, and result in a 10 and 15-knot decrease in V_{max} (roughly 2 percent). Rate of climb and velocity for rate of climb are affected by about the same proportion as V_{max}, but the cruise performance and stability characteristics are relatively unaffected by these changes.

INTRODUCTION

NASA, in response to a Department of Defense request, has undertaken a study of the noise reduction potential of the A-6 airplane in terms of its aural detection distance. This effort specifically involves: (1) documenting the noise characteristics of the basic airplane, (2) evaluating possible modifications and their associated noise reductions, (3) estimating the effects of some selected modifications on the aural detection distance of the aircraft, and (4) estimating the effects of such noise reduction modifications on the performance and stability of the aircraft. This paper documents the NASA efforts in accomplishing the above objectives. The results contained herein do not necessarily represent the optimum solution to the problem of noise reduction for the A-6 airplane, but are indicative of those believed to be achievable.

SYMBOLS

C_D	drag coefficient, $\frac{\text{drag}}{1/2\rho V^2 S}$
C_{D_o}	drag coefficient at zero lift
C_L	lift coefficient, $\frac{\text{lift}}{1/2\rho V^2 S}$
M	Mach number
N	revolutions per minute
S	wing area, square feet
T	thrust
V	velocity, true airspeed, knots
$V_{R/C}$	velocity for maximum rate of climb, knots
X	slant range distance from airplane to observer
dB	decibels, re 0.0002 dynes/cm^2
f	frequency, cps
n	revolutions per second
q	dynamic pressure, pounds/ft^2
ψ	azimuth angle measured from the thrust axis (0° is in front)
ρ	mass density of air
δ_f	flap deflection, degrees
cps	cycles per second
MAC	mean aerodynamic chord

MRP	military rated power
NRP	normal rated power
TAS	true airspeed
THP	thrust horsepower
$(R/C)_{max}$	maximum rate of climb, feet/minute
TO	takeoff
℄	centerline

APPARATUS AND METHODS

Test Airplane

The A-6 airplane which was tested for the studies of this report is a two-place twin-turbojet midwing monoplane with a design gross weight of about 55,000 pounds. The turbojet engines are each rated at 8,500 pounds thrust at takeoff. Photographs of the test airplane are shown in figure 1, and a three-view drawing of the airplane with a list of its principal physical features is presented in figure 2. The airplane and the test pilots came from the All Services Evaluation Group, Patuxent River Naval Air Station.

Test Conditions

Noise measurement tests were conducted at the NASA Wallops Island test facility where use was made of the main paved runway surface and the associated flat terrain for locating the instrumentation for both static and flyby tests. The terrain features of the test area are shown in the photograph of figure 3(a) which is a view of the microphone array looking north from the runway centerline, and figure 3(b) which is a view to the south. Schematic diagrams of the microphone arrays for these tests are included in figure 4. Airplane operating conditions for all noise measurement tests are listed in table I.

Noise-Measuring Equipment

The noise measuring instrumentation used for these tests is illustrated by the block diagram of figure 5. The microphones were of a conventional piezoelectric ceramic type having a frequency response flat to within ± 3 dB over the frequency range of 20 to 12,000 cps. The outputs of all the microphones at each station were recorded on multichannel tape recorders. The entire sound measurement system was calibrated in the field before and after the measurements by means of conventional discrete frequency calibrators supplied by the microphone manufacturers. The data records were played back from the tape (using the playback system shown schematically in fig. 5) to obtain the sound pressure level time histories and both broad-band and narrow-band spectra.

AIRCRAFT OPERATION

Static and flyover noise measurements were taken of the test airplane at the conditions listed in table I with the noise measurement apparatus positioned as shown in figure 4. Static noise tests were conducted with only one engine operating. Engine test conditions for static runs two and three were chosen by the pilot as representative of normal flight operations. The low-speed case (61 percent rpm) was included as an aid to analysis if required.

The flight tests were conducted at the two selected power settings of 85 and 96 percent over an altitude range from 200 to 3,000 feet. Airspeed ranged from 305 to 520 knots. The flight course and altitude were plotted by a GSN-5 radar tracking unit and some of these data were relayed for information to the pilot. The airplane was maintained on the desired flight path for about 3 miles prior to, and 1 mile beyond, the overhead position.

ATMOSPHERIC CONDITIONS

Some surface weather measurements and atmospheric sounding data were recorded in the vicinity of the test site during the taking of these measurements. Winds were out of the southwest at 6 knots on the surface and 25 knots at 3,000 feet. The temperature was 16.7° C at the surface and 11.7° C at 3,000 feet, and relative humidity was 48 percent and 36 percent over the above altitude range.

MEASURED NOISE CHARACTERISTICS OF THE BASIC AIRPLANE

Flyover noise data for this airplane were measured at altitudes of 750 feet, 1,500 feet, and 3,000 feet for both the cruise and climb power conditions of table I. Noise levels associated with cruise power were markedly lower than those associated with takeoff power and hence, detection distance studies were based on cruise power conditions. Analysis of the noise data from static runup tests indicated that the main noise components were broad band in nature and that there were no discrete frequencies present that were significant in aural detection.

AIRCRAFT MODIFICATIONS ANALYZED

Inspection of the measured noise signatures of the A-6 aircraft indicates that the main source of noise is the mixing of the jet engine exhausts with the surrounding ambient air. The present studies have been made for the purpose of evaluating the possibility of altering the exhaust noise spectrum to reduce aural detection distance. One of the approaches to altering the exhaust noise spectrum is to make use of a corrugated or lobed exhaust nozzle to increase the rate of mixing of the jet exhaust with the ambient air. (See, for example, sketches of fig. A-1 of appendix A.) In this regard the data produced during extensive jet exhaust suppressor research studies, as for example in references 1 and 2, were reviewed.

A rather extensive series of lobed nozzle studies was conducted by the Rolls Royce Company, and the results are given in reference 1. In that work it was found that the noise reductions obtained from such nozzles varied systematically as a function of the number of lobes or corrugations. The results of the above parametric study are plotted in figure 6 in such a way as to indicate the octave band in which the maximum noise attenuation was observed for nozzles having different numbers of corrugations. It can be seen that the largest noise attenuations were observed in the higher frequency bands for the larger numbers of corrugations. As the number of corrugations decreases, the frequency band for which the maximum noise level reduction occurs also decreases.

Experimental inflight evaluation data for a nozzle having eight corrugations or lobes are given in reference 2. The above nozzle was designed for operation on the J-65 engines of the B-57 aircraft and produced sizable changes in the radiated jet noise spectra.

A summary of the results from the flight tests of reference 2 are presented in figure 7. The data of figure 7 are the average noise reductions from three separate evaluation flybys for each of the octave bands and are plotted in figure 7 as a function of the octave band center frequency. The solid curve of figure 7 relates directly to the eight-lobe suppressor of reference 2 whereas the dashed curve is estimated for an equivalent four-lobe suppressor according to the data of reference 1. The above curves represent the estimated jet noise reduction performance of two possible jet nozzle configurations. The eight-lobe suppressor is of particular interest because this configuration has been tested in flight at an airspeed in excess of 200 knots on an engine of about the same thrust level as that of the A-6 aircraft, and thus the results are expected to be directly applicable. The similarities of the powerplant installation used in the studies of reference 2 to the A-6 airplane used for this noise study are discussed in more detail in appendix B. The four-lobe suppressor is proposed for the purpose of achieving greater noise reductions in the lower frequencies which are significant in aural detection, at the expense of probable increases in the noise generation at the higher frequencies which are not significant in aural detection.

ESTIMATED NOISE CHARACTERISTICS

Estimated noise spectra at a distance of 1,000 feet for the basic aircraft and the two nozzle configurations described above are given in figure 8. The overall sound pressure level for each of the three configurations is indicated at the left-hand side of the figure adjacent to the ordinate scale. The octave band spectrum in each case represents the maximum value of sound pressure level in each octave band during the flyover cycle, regardless of the time at which it occurs. It is estimated that the eight-lobe configuration nozzle would produce the largest noise reduction in the fourth octave band, whereas the four-lobe nozzle would produce the largest noise reduction in the third octave band.

DETERMINATION OF AURAL DETECTION DISTANCES

Basic Assumptions Relating to Detection

In addition to the noise source characteristics (see refs. 3 and 4), it is well-known that the aural detection of a noise involves such factors as the transmission characteristics of the path over which the noise travels (see refs. 5, 6, 7, 8, and 9), and the acoustic conditions at the observer location (see refs. 6 and 10) as well as the hearing ability of the observer (see ref. 11). Attempts have been made to account for all of the pertinent factors in the above categories for the calculations of detection distance which follow.

Attenuation factors.- The attenuation factors associated with the transmission of noise from the source to the observer are assumed to involve the well-known inverse distance law, atmospheric absorption due to viscosity and heat conduction, small-scale turbulence, and terrain absorption which is weighted to account for the elevation angle between the source and the observer. For the purposes of this paper these factors are taken into account as determined by the following equation:

$$\text{P.L.}\ (f,x) = 20 \log_{10} \frac{x}{A} + \left[K_1 + K_2 + (K_3 - K_1)\ K_4\right] \frac{x}{1000}$$

where propagation loss (P.L.) is computed for each frequency and distance combination and where the first term on the right-hand side of the equation accounts for the spherical spreading of the waves. In this connection x is the distance for which the calculation is being made and A is the reference distance for which measured data are available. The remaining terms which represent propagation losses and which are given in coefficient form are defined as follows:

K_1 represents the atmospheric absorption due to viscosity and heat conduction and is expressed in dB per 1,000 feet. The values of K_1 vary as a function of frequency and for the purposes of this paper are those of the following table. For frequencies up to 500 cps data are taken from reference 5 and for the higher frequencies from reference 8.

Octave band no.	Center freq.	Decibel loss per 1000 feet
1	31.5	0.1
2	63	0.2
3	125	0.3
4	250	0.5
5	500	0.7
6	1000	1.4
7	2000	3
8	4000	7.7
9	8000	14.4

K_2 is the attenuation in the atmosphere due to small-scale turbulence. A value of 1.3 dB per 1,000 feet is assumed independent of frequency for the frequency range above 250 cycles (see ref. 9).

K_3 also is expressed in dB per 1,000 feet and includes both atmospheric absorption and terrain absorption. The values used are those of reference 6 which are listed for widely varying conditions of vegetation and ground cover. The data of reference 6 have been reproduced in a more convenient form in reference 7. Calculations included herein make use of the data of reference 7 particularly curve (b) of figure 1 which represents the condition of thick grass cover (18 in. high) and the upperbound of curve 3 of figure 2 which represents conditions of leafy jungle with approximately 100 feet "see through" visibility. K_4 is a weighting factor to account for the angle, measured from the ground plane, between the noise source and the observer. The values of K_4 assumed for the present calculations were taken from figure 3 of reference 7 and are seen to vary from zero for angles greater than 7° to 1.0 for an angle of 0°.

Ambient noise level conditions and human hearing.- The detectability of a noise is also a function of the ambient masking noise conditions at the listening station and the hearing abilities of the listener. Since they are somewhat related, they will be discussed together.

The ambient noise level conditions assumed for these studies were based on data from references 6 and 10 which were obtained in jungle environments. The resulting octave band spectra have been adjusted to account for critical bandwidth of the human ear, according to the following equation, to give masking level values for each band.

$$\text{Masking level, dB} = \text{octave band level, dB} - 10 \log_{10}\left[\frac{\Delta f_{octave}}{\Delta f_{critical}}\right]$$

where the Δf_{octave} and $\Delta f_{critical}$ values corresponding to standard octave band center frequencies are given in the following table:

Octave band center freq., cps	31.5	63	125	250	500	1000	2000	4000	8000
Δf_{octave}, cps	22	44	88	177	354	707	1414	2828	5656
$\Delta f_{critical}$, cps	--	--	50	50	50	66	100	220	500
$10 \log_{10} \frac{\Delta f_{octave}}{\Delta f_{critical}}$	--	--	2.5	5.5	8.5	10.7	11.5	11.1	10.5

The values of the last line in the above table have been subtracted from the octave band values to adjust them to the masking level spectra which define the boundaries of the jungle noise criteria detection region used in the subsequent determination of aural detection distances.

Likewise, a threshold of hearing curve (taken from ref. 5) is made use of since it represents the levels of pure-tone noise that are just detectable on the average by healthy young adults. The implication here is that noises having levels lower than those of the threshold of hearing curve at corresponding frequencies will not be detectable. Thus, the threshold of hearing curve is the determining factor of detection at the lower frequencies.

No attempt is made to account for possible binaural effects in the studies of the present paper.

ESTIMATED AURAL DETECTION DISTANCES

Reference detection distances for each of the three aircraft configurations (basic plus two modifications) for flight altitudes of 1,000 feet and 300 feet and for ground-cover conditions representative of both 18-inch high grass and 100-foot "see-through" leafy jungle have been determined with the aid of figure 9 and the basic noise signature estimates of figure 8. In figure 9 the octave band noise levels at various distances have been estimated by taking into account the appropriate atmospheric and terrain losses. Also shown in the figure is a threshold of hearing curve and a band labeled "jungle noise detection criteria." The low boundary of this area represents masking levels in a relatively quiet jungle location in the Canal Zone (ref. 3). The upper boundary on the other hand represents a relatively more noisy masking level condition in Thailand (ref. 2). These data have been compared with and found to be generally compatible with results of recent, but unpublished, jungle noise surveys taken at Fort Clayton in the Canal Zone. In the determination of the maximum distance at which the aircraft can be detected aurally it was assumed that such detection was possible at distances at which the level of aircraft noise in any octave band equaled or exceeded either the masking level curve or the threshold of hearing curve, whichever was appropriate. The results of such estimates are included in table III for each aircraft configuration and for two altitudes and ground cover conditions.

EFFECTS OF AIRCRAFT OPERATING AND GROUND OBSERVER CONDITIONS

In general, detection distances were noted to be shorter for lower aircraft altitudes and for the more dense ground cover conditions. These results are in agreement with those of other similar studies as in references 1 and 2.

THE EFFECTS OF AIRCRAFT CONFIGURATION MODIFICATIONS

The aircraft configurations of table III have progressively decreasing values of overall noise level and the associated detection distances decrease in the same manner, reading from left to right in the table. For given conditions of altitude and ground cover the effects of nozzle configuration are illustrated in figure 9. The addition of the eight-lobe suppressor results in a reduction of detection distances from about 1/2 mile to about 1 mile, depending on the aircraft operating conditions and the ground cover conditions, and has associated with it an increase in weight of about 199 pounds (see table IV). The minimum detection distance is estimated as 1.3 miles for the aircraft flying at 300 feet over leafy jungle ground cover.

The modification involving the four-lobe suppressor results in a decrease in the aural detection distance from about 3/4 mile to about a mile and a half depending again on the aircraft operating and ground cover conditions. In this latter case the increase in weight of the aircraft over the basic configuration is about 155 pounds (see table IV). The minimum detection distance is estimated as 1-1/4 miles for the aircraft flying at 300 feet over leafy jungle ground cover.

It is interesting to note that the use of the four-lobe suppressor in each case is approximately as effective in reducing the aural detection distance of the aircraft as is operation over the most dense ground cover. The implications of the results of the present study are that an exhaust suppressor nozzle modification to the A-6 aircraft may be useful in making modest reductions in aural detection distances. Such a modification is relatively simple to make and will result in relatively small performance penalties. It should be noted, however, that the present studies were not in sufficient detail to define an optimum suppressor nozzle configuration and that more definitive studies would be required for this purpose.

CONCLUDING REMARKS

A study has been conducted to evaluate the effects of possible modifications to the A-6 aircraft to reduce its aural detection distance in cruise flight. This study involved documenting the noise characteristics of the basic airplane, devising modifications to reduce the noise, and defining the detection-distance and aircraft-performance penalties as a result of each modification. It was found that the main source of noise on this aircraft is the mixing of the exhaust jets with the ambient air and hence, only modifications to the exhaust nozzle are proposed. Nozzle modifications studied included eight-lobed and four-lobed corrugated configurations.

The addition of either eight-lobed or four-lobed corrugated nozzles to the basic aircraft results in modest reductions in aural detection distance. In this regard the four-lobed nozzle was judged to be slightly more effective than the eight-lobed nozzle. It was found that the reductions in detection distance associated with the four-lobed nozzle are about equivalent to those obtained from operation of the basic aircraft over the most dense ground cover conditions of this study. The minimum aural detection distance estimated for the four-lobe suppressor was 1-1/4 miles, and corresponded to the aircraft flying at an altitude of 300 feet over leafy jungle ground cover.

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Table I.-List of airplane operating conditions for both the static and flyby noise measurements.

Run no.	Engine speed, % RPM	Exhaust gas temp. ^{0}C	Fuel flow, #/hour	Estimated* static thrust, lbs.	Estimated** total thrust, lbs.	Indicated airspeed, kts.	Altitude above runway, ft.	Lateral displacement from runway, ft
STATIC (left engine only)								
1	61	—	800	435	—		—	—
2	85	410	2,950	2,600	—	—	—	—
3	95.5	610	6,500	6,500		—	—	—
Flight (both engines)								
1	85	—	—	—	4,550	305	3,000	0
2	96	—	—	—	11,470	510	3,000	0
3	86	—	—	—	4,500	330	1,500	0
4	96	—	—	—	11,600	515	1,500	0
5	85	—	—	—	4,500	335	750	0
6	96		—		11,700	550	750	0
7	96	—	—	—	11,700	550	200	0

* Single engine only
** Both engines including ram effect

Table II.- Summary of aircraft modifications with estimates of overall noise reductions.

Configuration	Suppressor type	Estimated net weight increase, lbs.	Estimated overall noise level (dist.=1,000 ft.)
Basic	---	---	91.1 dB
Mod. I	4-lobed	155	84.9 dB
Mod. II	8-lobed	199	83.3 dB

Table III.- Reference aural detection distances in feet for the basic A-6 aircraft and for two proposed modifications. Data are presented for two aircraft altitudes and for two ground cover conditions.

Aircraft Altitude, ft.	Ground Cover	Reference Detection Distance, ft.		
		Aircraft Configuration		
		Basic Measurement	8-Lobe Suppressor	4-Lobe Suppressor
1000	grassy	21,900 (b)	16,400 (b)	15,200 (b)
1000	leafy	14,500 (b)	12,000 (b)	11,600 (b)
300	grassy	13,000 (b)	9,800 (b)	9,300 (b)
300	leafy	8,400 (b)	6,900 (b)	6,600 (b)

(b) data from 3rd octave band

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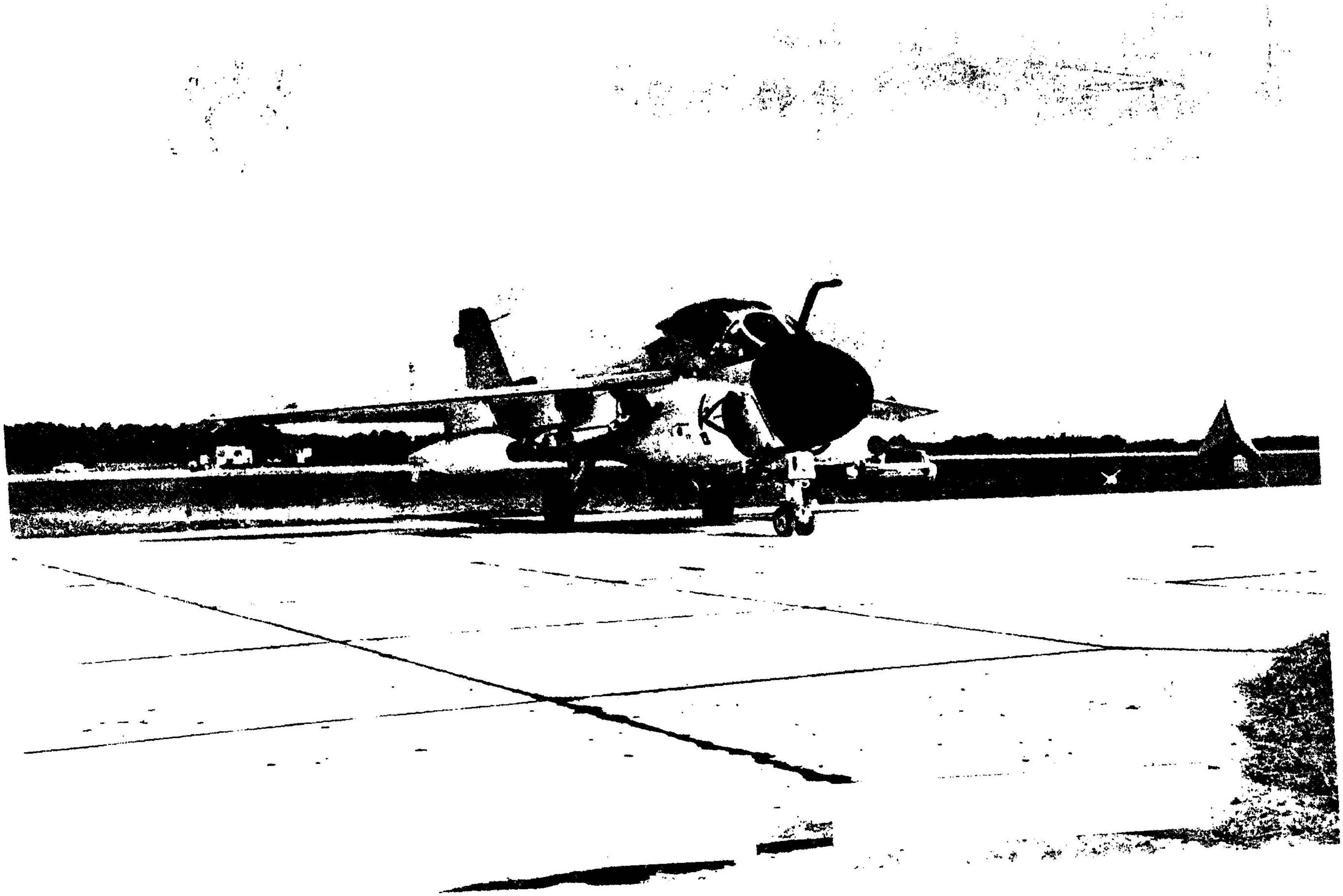

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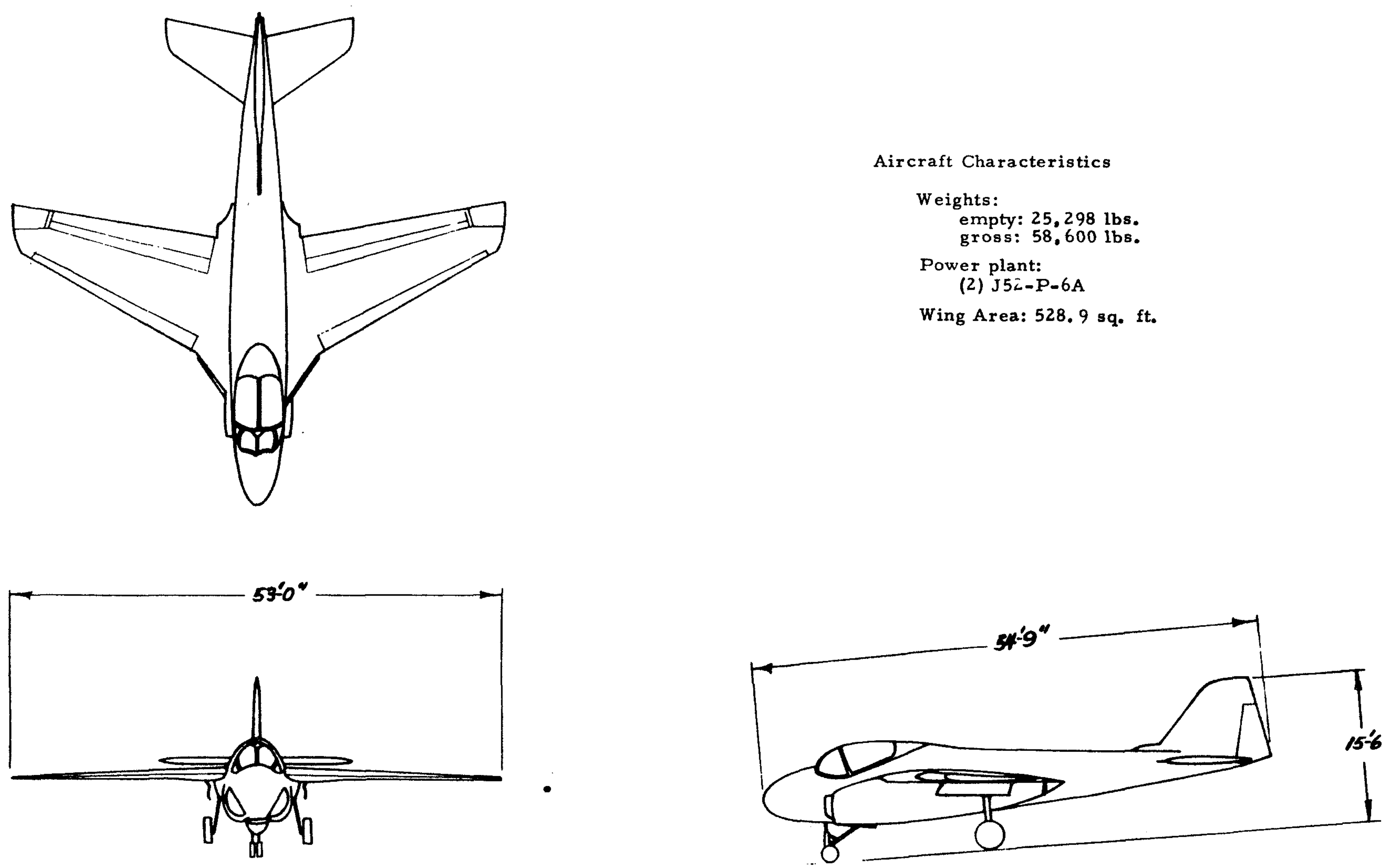
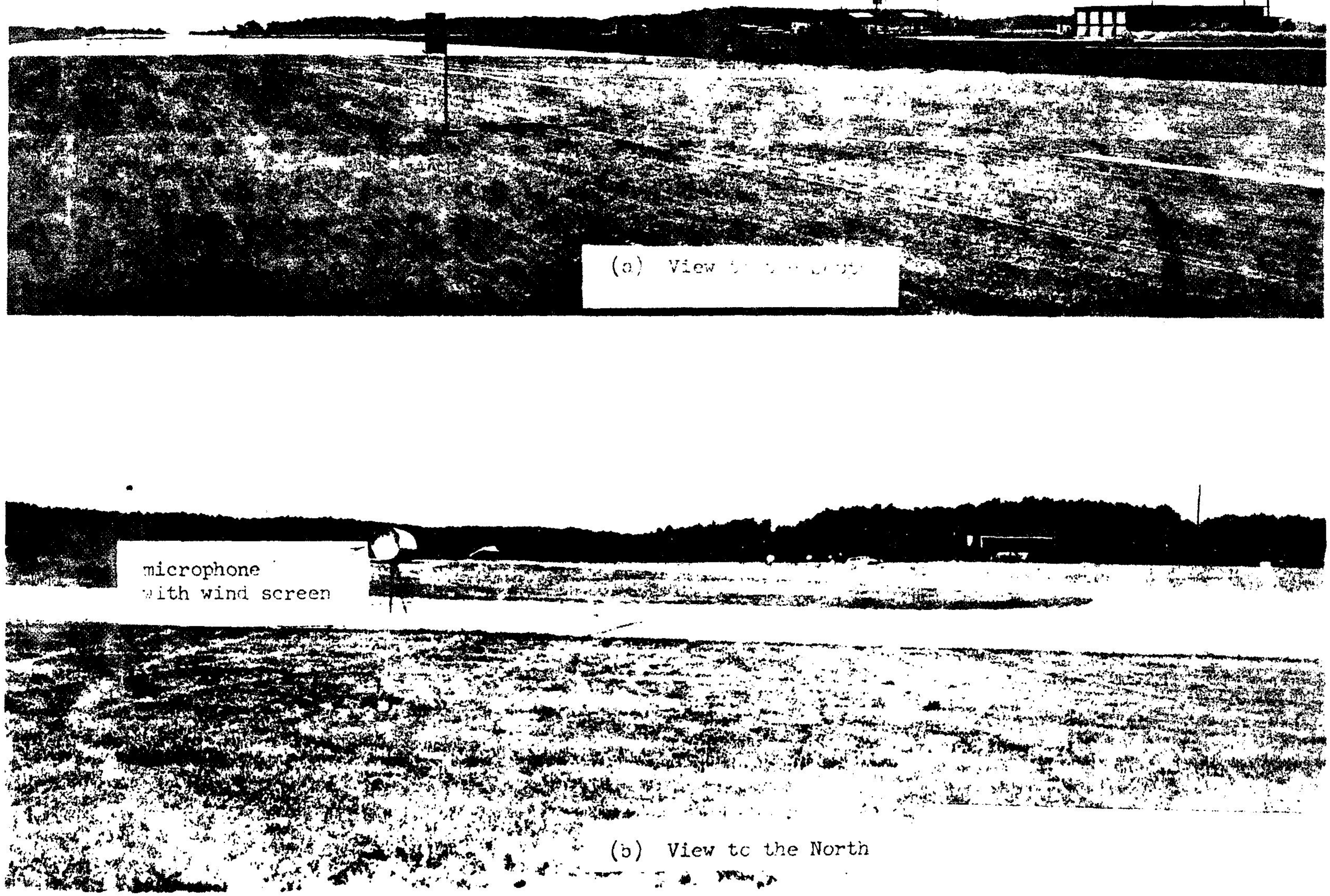


Figure 2.- Three view sketches of the test airplane with a listing of its principal physical features.



(a) View

(b) View to the North

Figure 3.- Photographs of the NASA Wallops Island test area showing the runway and flat terrain.

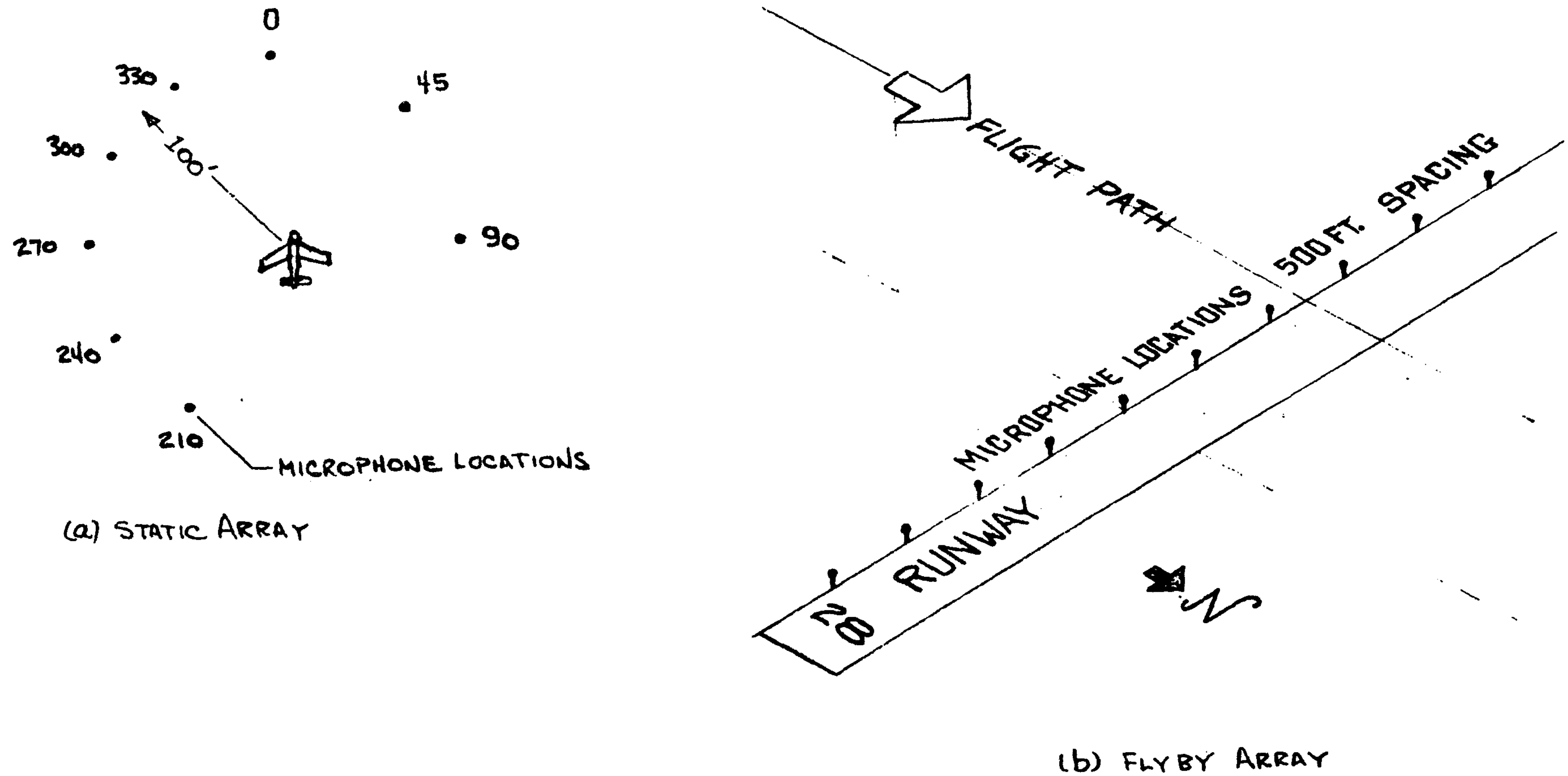
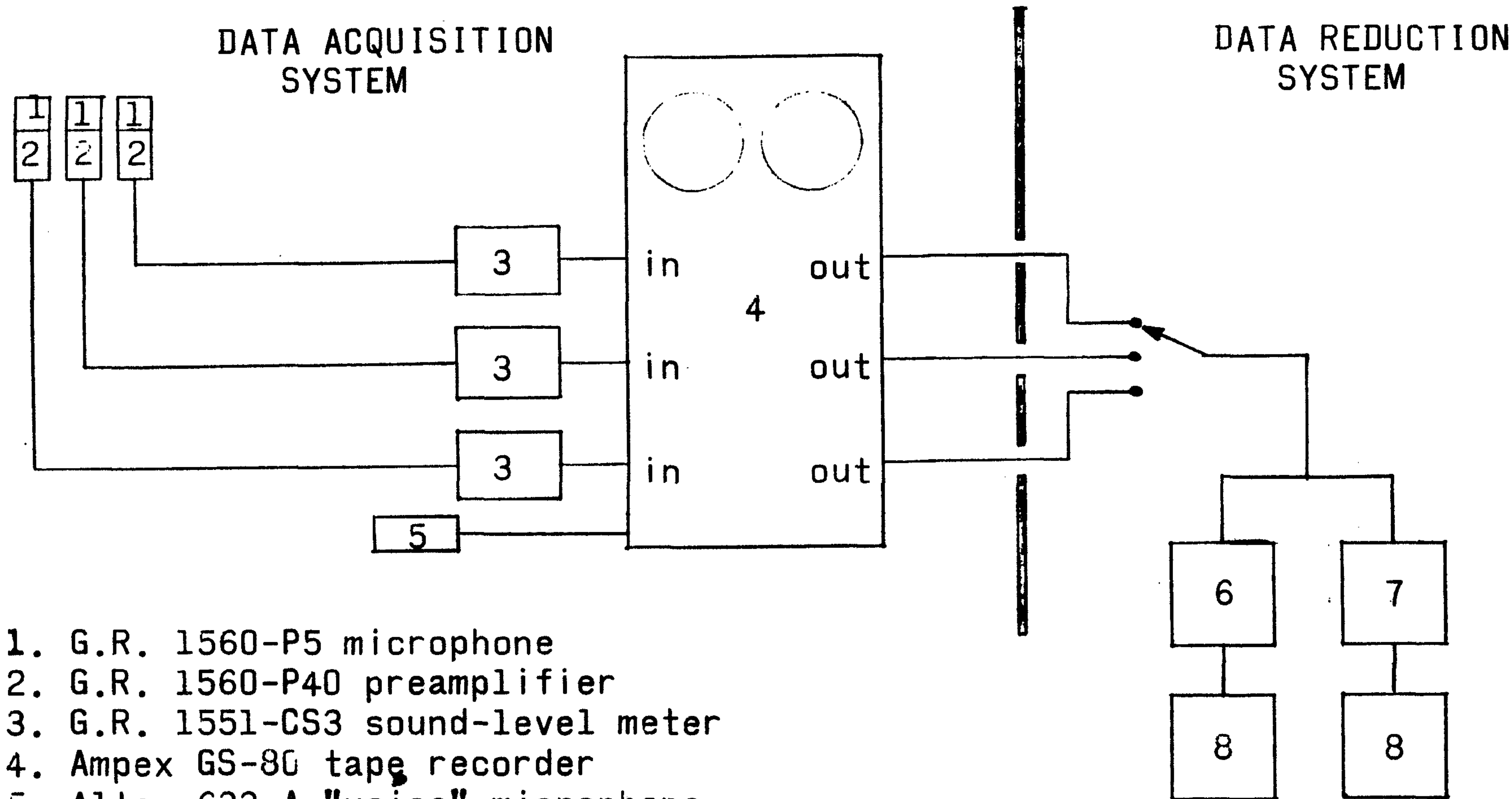


Figure 4.- Diagram of the microphone arrays illustrating the aircraft location for noise measurement during both static and flyby operations.



1. G.R. 1560-P5 microphone
2. G.R. 1560-P40 preamplifier
3. G.R. 1551-CS3 sound-level meter
4. Ampex GS-80 tape recorder
5. Altec 633-A "voice" microphone
6. G.R. 1558-AP octave-band analyzer
7. G.R. 1900-A wave analyzer
8. G.R. 1521-B graphic level recorder

Figure 5.- Block diagram showing system layout for noise data acquisition and reduction.

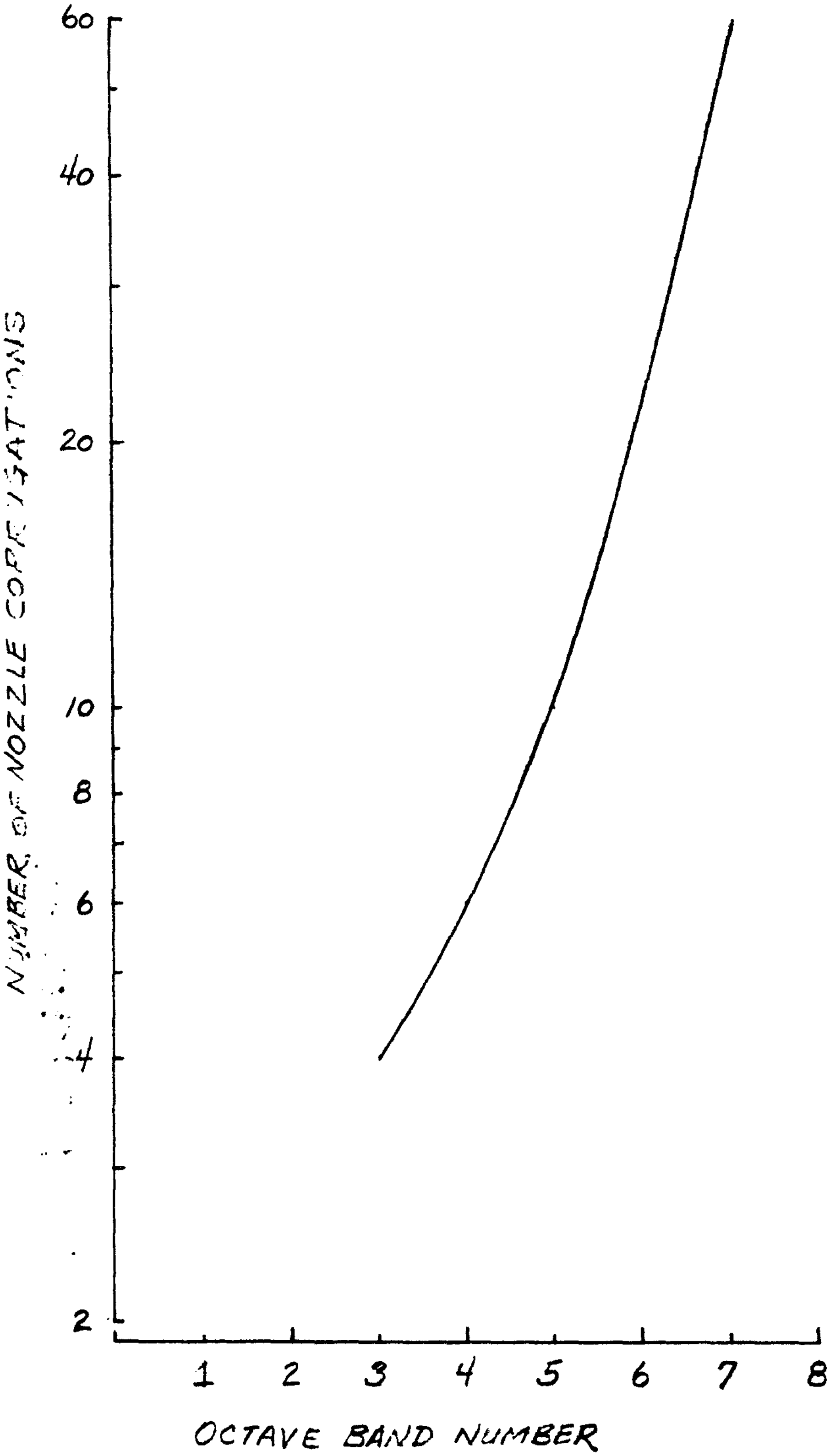


Figure 6.- Octave band in which maximum noise reduction occurs for nozzles having various numbers of corrugations. (from Ref. 1)

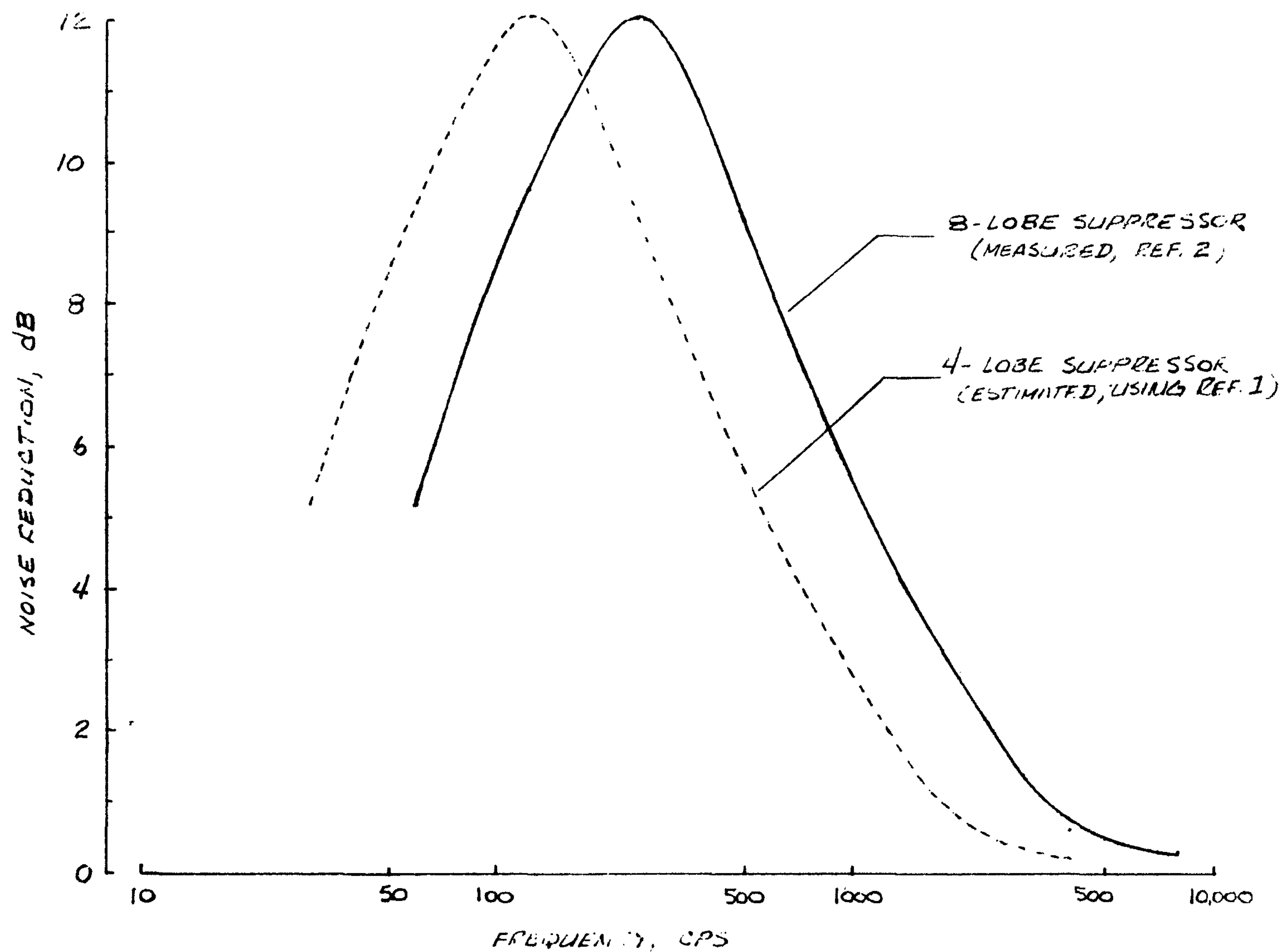


Figure 7.- Noise level reductions in various octave bands for 8-lobe and 4-lobe corrugated nozzles.

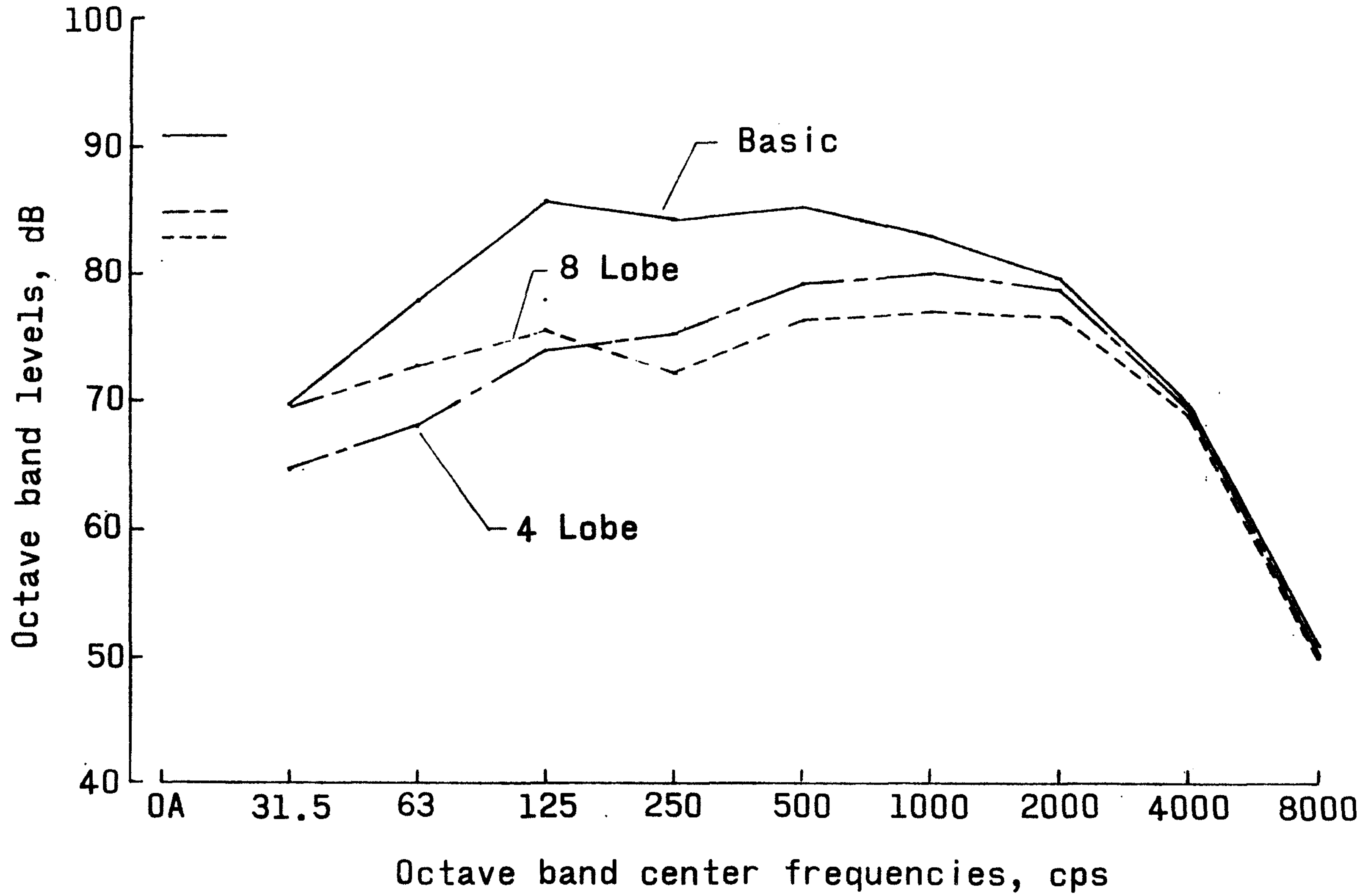


Figure 8.- Octave band spectra for the basic test airplane and for each of the proposed modifications. Altitude = 1,000 ft.

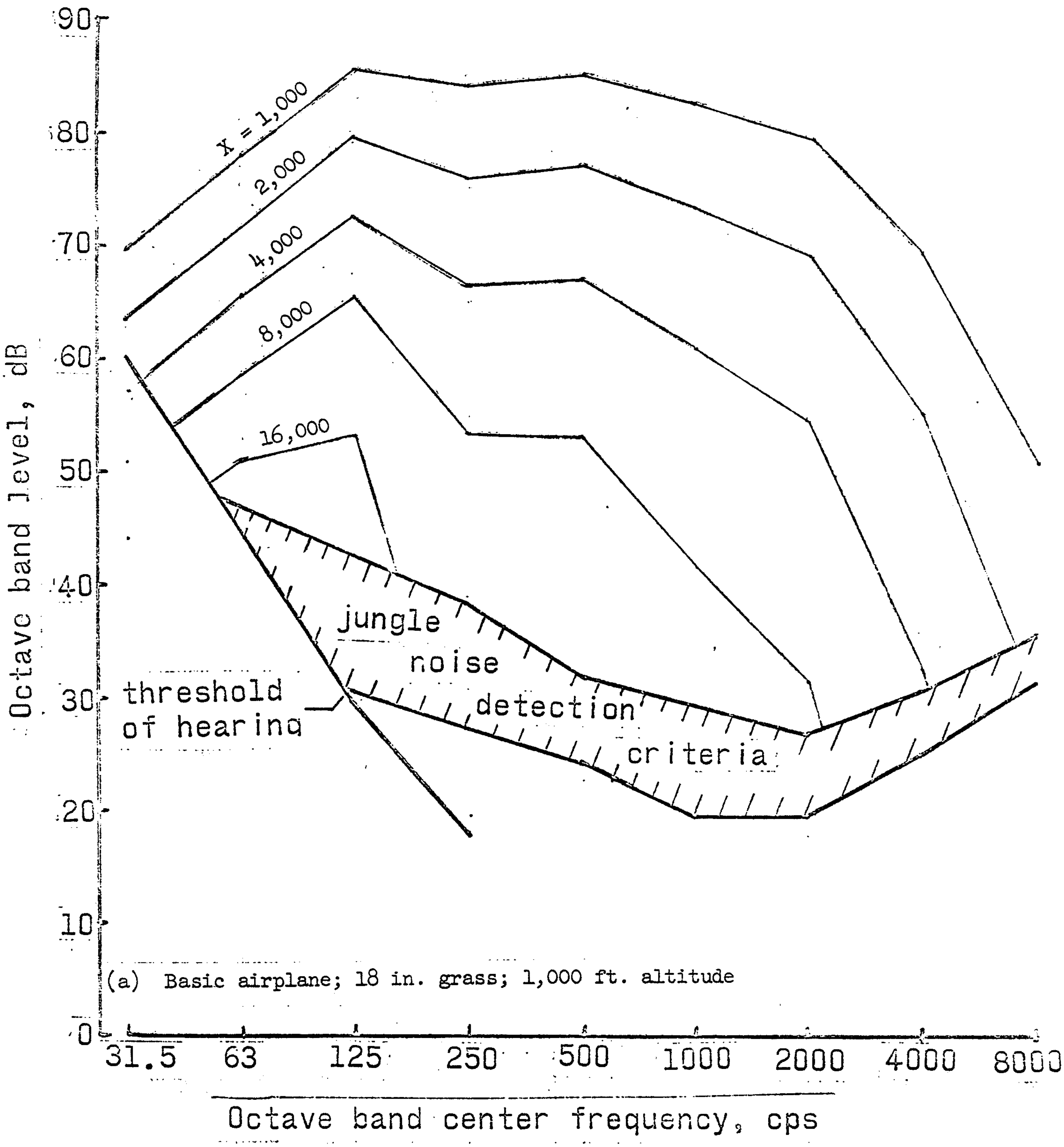


Figure 9.- Effect of slant range and types of terrain on A-6 noise signature.

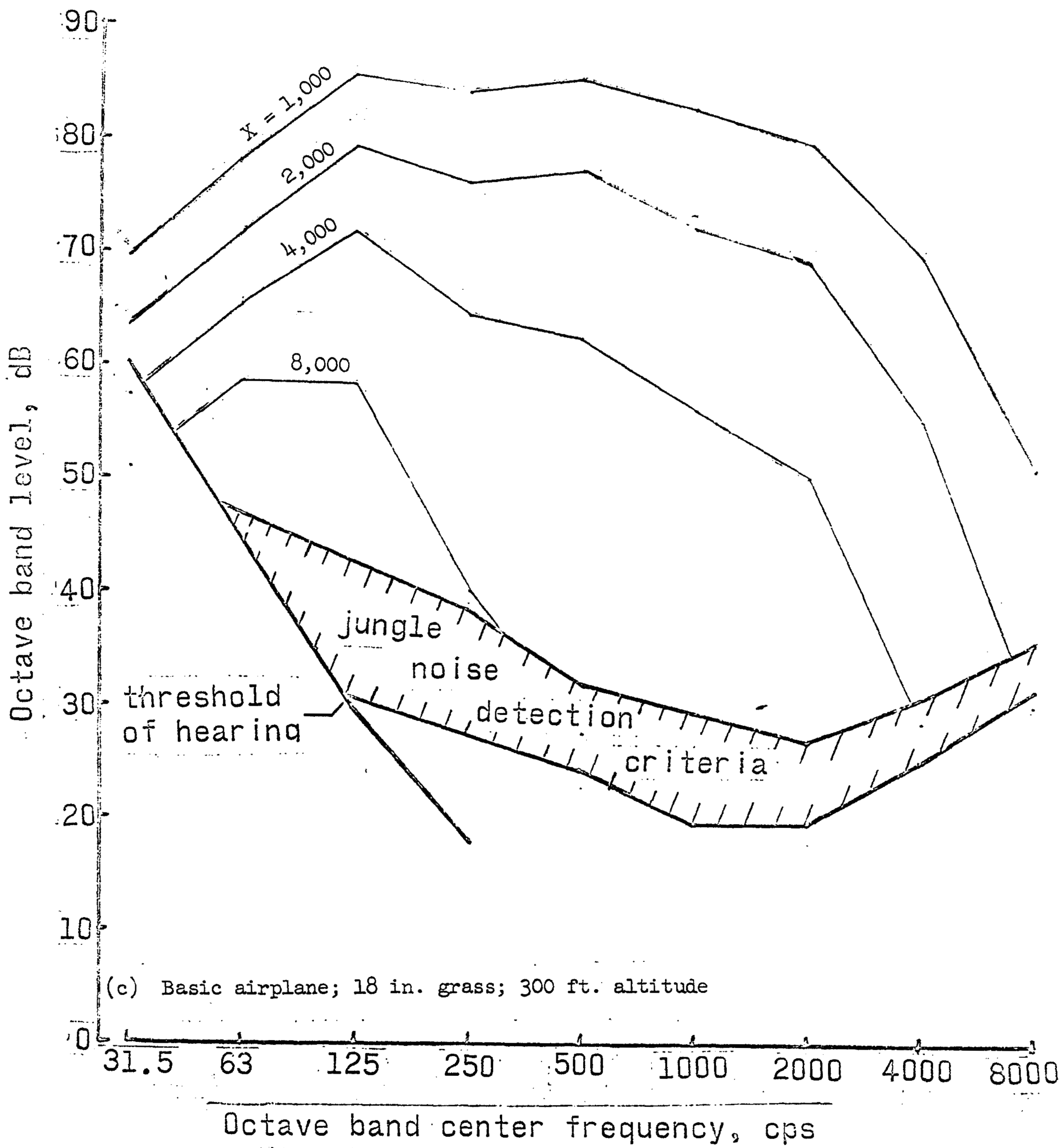
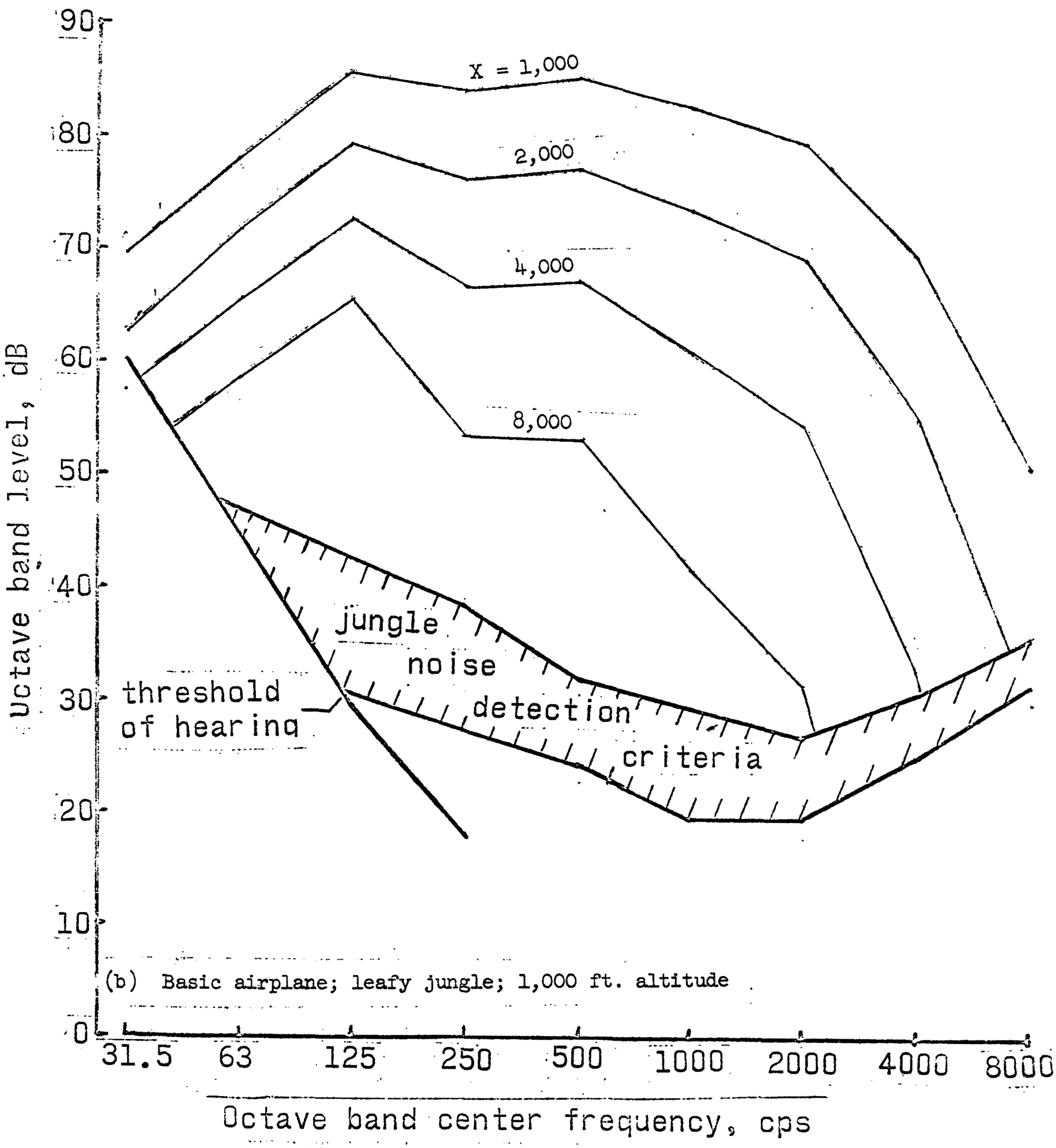


Figure 9.- Continued.



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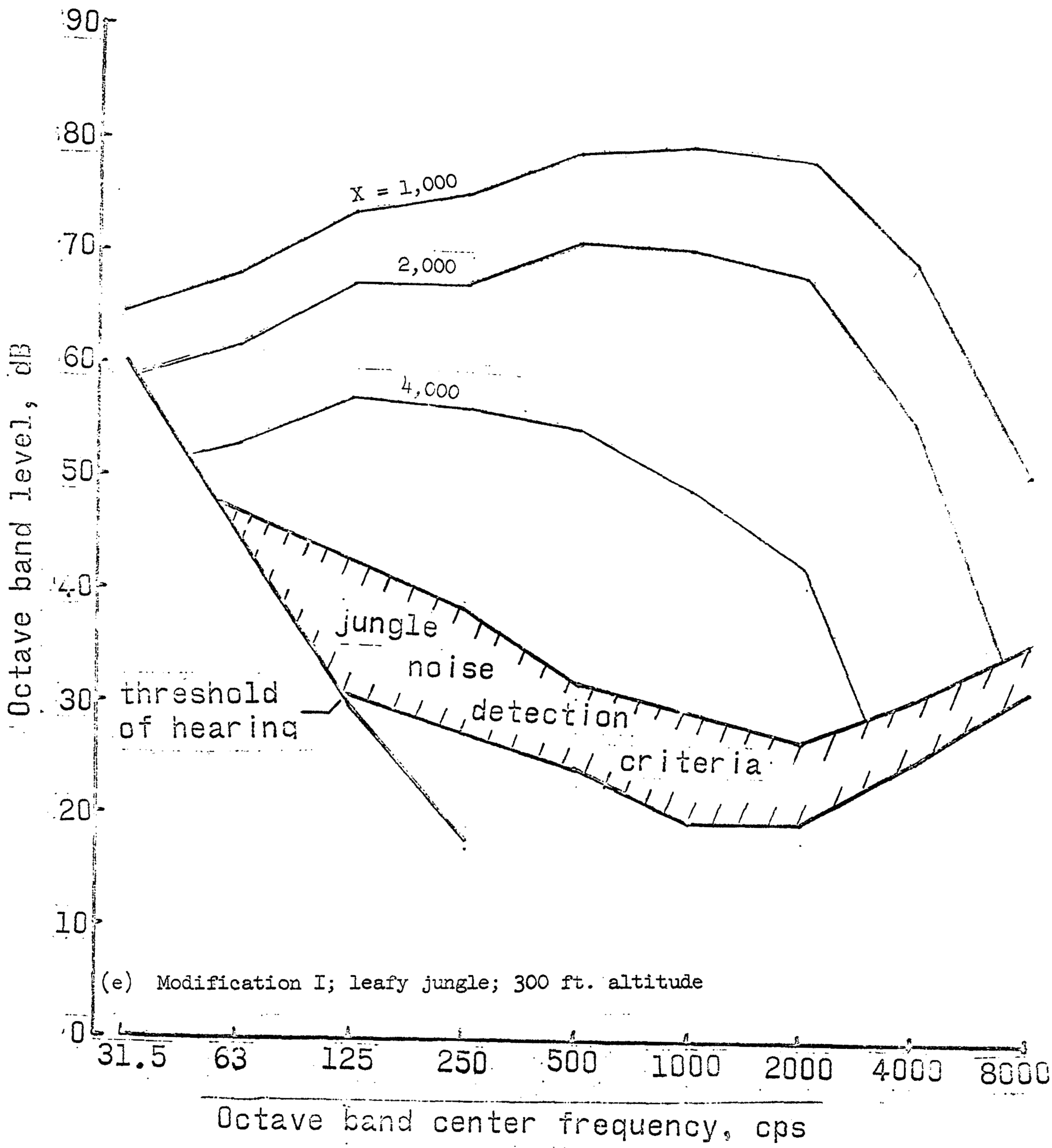

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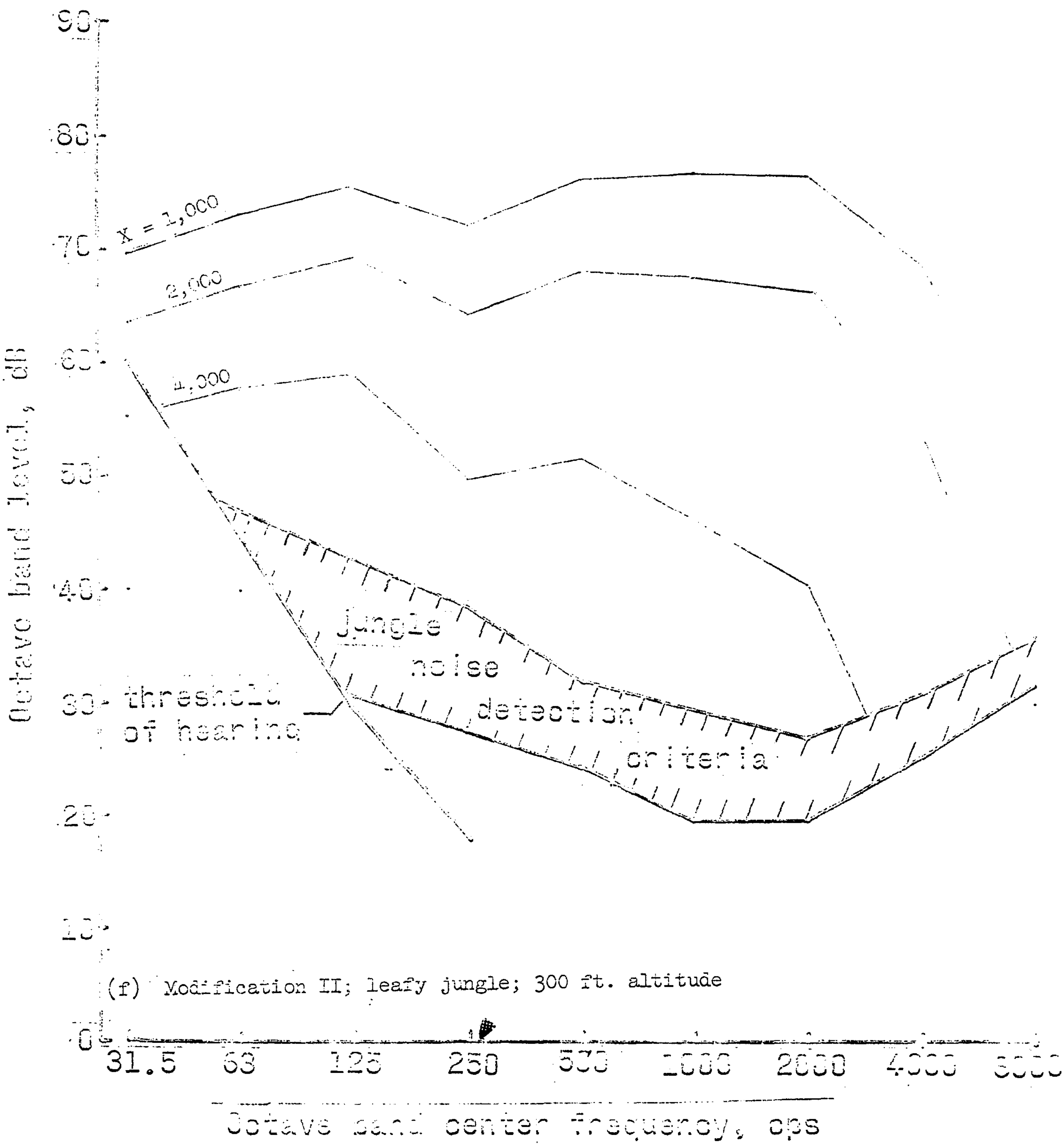

(f) Modification II; leafy jungle; 300 ft. altitude

Figure 9.- Concluded.

APPENDIX A

WEIGHT ESTIMATES

M. L. Sisson

The eight-lobed suppressor was assumed to be geometrically similar to that used on a B-57 by Lewis Research Center, reference A-1. This suppressor was made of .040 inch corrosion-resistant steel, AISI 321. The weight of the B-57 suppressor was computed from drawings. The suppressor for the A-6 was sized to provide the same exit area as the existing A-6 tailpipe. The weight of the A-6 suppressor was calculated as proportional to the square of the linear dimensional ratio to the B-57 suppressor. A four-lobed suppressor having the same cross section areas as the eight-lobed suppressor was sketched. Its weight was computed using the same material, .040 inch corrosion-resistant steel.

Ejector-cooling jackets were sketched which would provide approximately the same cooling air flow around the engine and tailpipe as the existing A-6 ejector. These units were assumed to extend eight inches behind the suppressor outlet. Their weights were based on the use of .040 inch corrosion resistant steel. It is estimated that no appreciable airframe weight change is involved in this modification.

The suppressor-ejector could be fitted to the airplane as shown in figure A-1. Table A-I presents a summary of the weight estimates for the eight-lobed suppressor-ejector assemblies.

REFERENCE

A-1. Coles, Willard D., Mihaloew, John A., and Swann, William H.: Ground and In-Flight Acoustic and Performance Characteristics of Jet-Aircraft Exhaust Noise Suppressors. NASA Technical Note D-874.

TABLE A-I

Weight Summary

Eight-lobed suppressor

Suppressor	47.5 lbs.
Ejector	53.0
Total weight per engine	100.5 lbs.
Less existing ejector and 3 inches of tailpipe	1.0
Total weight increase per engine	99.5 lbs.

Four-lobed suppressor

Suppressor	38.0 lbs.
Ejector	40.6
Total weight per engine	78.6 lbs.
Less existing ejector and 3 inches of tailpipe	1.0
Total weight increase per engine	77.6 lbs.

APPENDIX B

PERFORMANCE, STABILITY AND CONTROL

By James L. Hassell, Jr., and Ernie L. Anglin

The EA-6A version of the Grumman Intruder Navy airplane is powered by two Pratt and Whitney J52-P-6A nonafterburning jet engines, military rated at 8500 pounds static thrust each at standard sea level conditions. These engines are located side-by-side in the fuselage belly beneath the wing carry-through structure as shown in figure B-1. The installation embodies a rather unusual pair of crooked tailpipes which route the engine exhausts to the lower sides of the fuselage just beneath the wing trailing edge at the wing-fuselage juncture as illustrated in figure B-2. The EA-6A is equipped with a pair of large speed brakes positioned on the lower sides of the fuselage a short distance aft of the jet exits such that the exhausts impinge on the speed brakes when they are actuated outward. This general arrangement provides for rapid deceleration or acceleration as a function of rapidly deflecting or retracting the speed brakes without need for changing engine thrust, and is shown in the line sketch of figure A-1 of appendix A. The geometry of the exit end of the basic EA-6A tailpipes consists of conical convergent nozzles having half-cone angles of 17^{o} ringed by short cylindrical ejectors. The manufacturer's estimated installed engine performance for the installation described above is given in reference B-1 and was used in this analysis as the basis for thrust available for the basic EA-6A airplane.

Noise suppressor modifications proposed in this study consist of four or eight-lobe convergent nozzles with cooling air shrouds which replace the standard 17^{o} conical nozzles and cylindrical ejectors at the end of the tailpipes. As shown in figure A-1 the suppressor modifications involve considerable extensions of the tailpipes and thereby bring the jet exits in closer proximity to the speed brakes. Based on results presented in reference B-2 no detrimental effects are anticipated either to the engines or to the speed brakes due to this arrangement, nor should there be any loss of speed brake effectiveness. The length of the cooling air shroud shown in figure A-1 is longer than would actually be needed to provide the pumping action for cooling air requirements. It is intended that the shroud overhang length be trimmed to provide only the required quantity of cooling air inasmuch as test results (ref. B-3) have indicated minimized performance losses with very short shroud overhang length.

The noise suppressor configurations selected for modifications I and II are very similar to the type installed on a Martin B-57 airplane for the experimental investigation reported in reference B-4. The results of the B-57 experimental tests provide full-scale data for both static and inflight performance and noise characteristics for eight-lobe suppressor nozzles, and should correspond directly to the eight-lobe configuration of modification II. As pointed out in reference B-4, the choice of the lobed-type noise suppressor was made on the basis of extensive experience gained in earlier studies (refs. B-5 and B-6, for example) which had indicated, along with some other

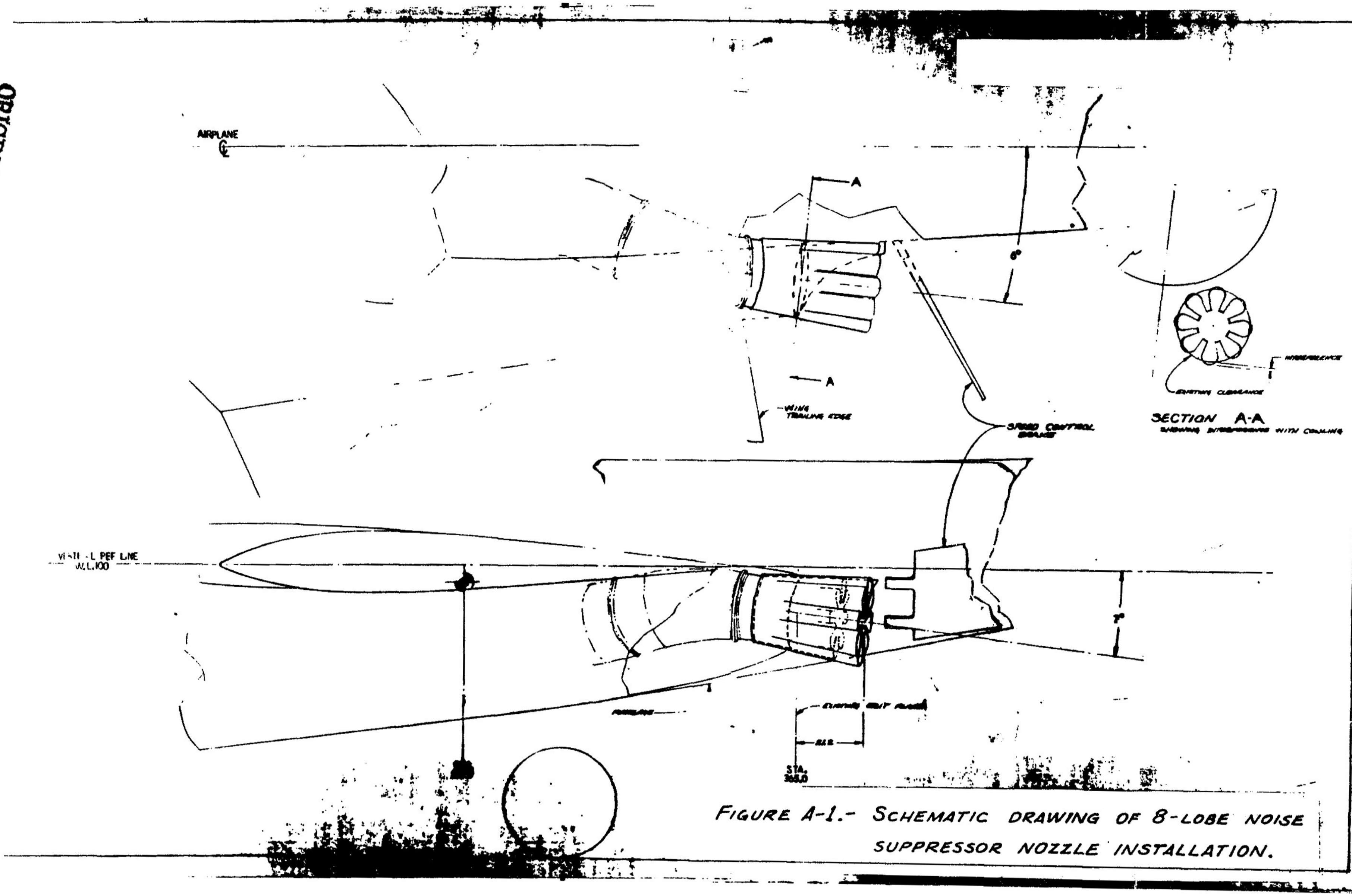

FIGURE A-1.- SCHEMATIC DRAWING OF 8-LOBE NOISE SUPPRESSOR NOZZLE INSTALLATION.

advantages, that minimum performances losses would be incurred while providing the best known acoustic attenuation characteristics. The performance and noise characteristics of the four-lobe configuration (modification I) were estimated on the basis of skin friction losses and the results of reference B-7.

The compatibility of the proposed noise suppressor modifications to the EA-6A aircraft is illustrated by the following comparison with the B-57 noise suppressor installation:

	EA-6A	B-57
Tailpipe length:	Long because of buried engines in fuselage	Long because of buried engines in wing
Standard nozzle:	Conical convergent	Conical convergent
Cooling air required:	Yes	Yes
Basic provision for cooling air:	Short ejector	Short overhang shroud
Rated static thrust of jet engine, lb:	8500	7800
Jet exit diameter, in.	18.71	20.18
Jet exit area, sq in.	256	319
Noise suppressors	Four- or eight-lobe type	Eight-lobe type
Cooling air provision with noise suppressors:	Short shroud	Short shroud

Based on the results of the full-scale flight tests of reference B-4 and the wind-tunnel data of reference B-3 the thrust losses and drag penalties due to the proposed modifications are estimated as follows:

	Modification I	Modification II
Static thrust loss	1.5 percent	2.5 percent
Inflight thrust loss	2.0 percent	3.0 percent
Incremental C_{D_o}	0.00032	0.00036

It should be noted that A-6 type aircraft are currently being equipped with uprated J52-P-8 engines having 9300 pounds static thrust at standard sea level conditions - an increase of more than 9 percent over the J52-P-6A

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assumed in the present analysis. It would therefore be advantageous to use the J52-P-8 engines with the proposed modifications in order that the predicted losses in performance will be eliminated. The modified EA-6A aircraft should, in fact, have performance superior to published flight data in the EA-6A NATOPS Manual (ref. B-8).

Basic for performance analysis.- For the purpose of this study, a specific mission compatible with the intent of minimized aural detection distance was selected for performance analysis, although many other loadings and missions are feasible with this versatile attack aircraft. The loading and mission selected for this study are defined in reference B-8 as the EA-6A (Sea-Level Stores Delivery Attack Configuration" and consists of what is known as a "Hi Lo Lo Hi" flight profile. A pair of external wing-mounted ECM pods are considered a part of the EA-6A clean configuration and in this study are assumed to remain with the aircraft throughout the mission (these ECM pods may be jettisoned in an extreme emergency). For takeoff and on the outbound leg of this mission the EA-6A carries external stores consisting of four (4) 300-gallon fuel tanks under the wings and one (1) MK 28 bomb beneath the fuselage centerline. Prior to entering combat at low altitudes (near sea level) the four empty wing tanks are jettisoned; the performance for the combat portion of the mission is then based on the EA-6A with two (2) ECM pods and one (1) MK 28 bomb. On the return leg, performance is based on the EA-6A having only the two (2) ECM pods as external stores.

The basis for calculating the performance of the basic EA-6A aircraft is presented in figures B-3 through B-5 along with the aircraft weights at various stages along the mission profile as defined in reference B-8. The lift-drag polars of figure B-3 were obtained by adding the incremental drag due to the two (2) ECM pods as determined from wind-tunnel tests to the basic low-speed flight-test polars for the A6-A aircraft from reference B-1. The zero-lift drag rise with Mach number for the EA-6A with two (2) ECM pods (fig. B-4) was obtained by adding the incremental data for the pods as determined from wind-tunnel tests to the flight-test data for the A6-A aircraft (ref. B-1). Interference drag correction factors are included in both sets of data and are based on the wind-tunnel test results given in reference B-1. The incremental drag due to external stores (also presented in fig. B-4) were determined from wind-tunnel tests and likewise includes appropriate interference drag correction factors (ref. B-1). The variation of net-installed military-thrust per engine (J52-P-6A) with altitude and Mach number was also obtained from reference B-1 and is included here as figure B-5.

All performance calculations are based on two-engine military power and rate-of-climb calculations include corrections for flight path acceleration. Takeoff calculations are based on a smooth flat runway with a coefficient of rolling friction of 0.025, with flaps deflected 30° and slats extended. An example of the variation of thrust available and thrust required (or drag) with Mach number is presented in figure B-6 for the basic EA-6A airplane and for modifications I and II, representing the climbout configuration. The drag for all three cases is shown as one curve, although the effect of skin friction drag due to modifications I and II actually is perceptible at the higher Mach numbers. The effects of the small weight penalties due to modifications I and II are not perceptible in the calculations; thus, the example of figure B-6 is presented for a median weight of 54,200 pounds applicable to all three cases.

Results of performance analysis.- A summary of the results of the performance analysis for the basic EA-6A and modifications I and II is given in table B-I for the "Sea Level Stores Delivery" mission. These results indicate that takeoff distance to clear a 50-foot obstacle would be increased by 2.5 to 4.0 percent, maximum rate of climb at sea level would be reduced by 2.5 to 3.8 percent and maximum speed at sea level would suffer by 2.1 to 3.3 percent for the climb-out leg of the mission which is the heaviest weight and also, aerodynamically, the "dirtiest" portion of the flight profile. Performance losses are somewhat more severe, percentage-wise, for the combat and return legs of the mission where rate of climb at sea level suffers by as much as 5 to 6 percent. Maximum speed is less affected, however, incurring penalties of the order of only 1 percent for the relatively clean configurations at sea level.

Comments on stability and control.- Inasmuch as the relatively minor increase in weight due to installation of the noise suppressors is concentrated fairly close to midship, the adverse effect on airplane center-of-gravity position is relatively insignificant. The proposed modifications should have no effect on the aerodynamic neutral points. Therefore, the recommended aft center-of-gravity limit with landing gear retracted is 30 percent MAC - the same as for the basic EA-6A airplane.

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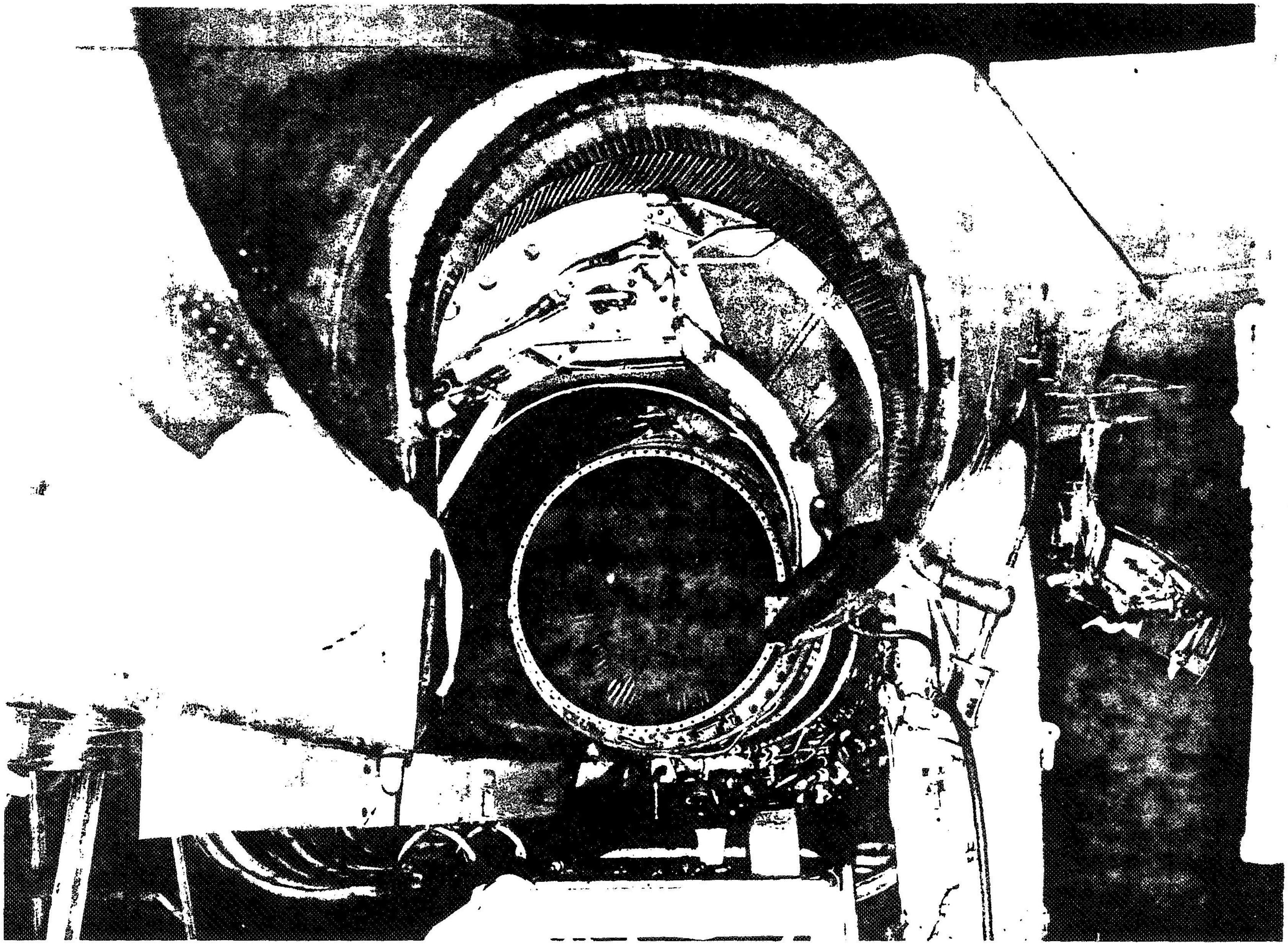

Figure B-1. - J52-P-6A engine installation in Grumman A-6A airplane viewed from rear.

TABLE B-I.- PERFORMANCE SUMMARY FOR SEA LEVEL STORES DELIVERY ATTACK CONFIGURATION (HI LO LO HI).

Configuration and Item			EA-6A Unmodified	Mod. I	Mod. II
Take-Off: gear down, $\delta_f = 30°$	T.O. gross weight, lb		55,060	55,215	55,259
	Ground distance, ft		5,350	5,480	5,560
	Air distance to 50 ft		720	740	750
	Total to clear 50 ft		6,070	6,220	6,310
	Stall speed power-off, kn		128	128	128
Climb out: gear up, $\delta_f = 0$, (2) ECM Pods, (4) 300 gallo n tanks, (1) Mk 28 Bomb	Weight, lbs		54,118	54,273	54,317
	Maximum rate of climb, fpm	SL	5,050	4,920	4,860
		15,000 ft	2,860	2,740	2,680
		20,000 ft	2,160	2,050	2,000
		25,000 ft	1,450	1,340	1,290
		30,000 ft	690	580	540
		35,000 ft	-110	-210	-260
	Velocity for maximum rate of climb, kn,TAS	SL	344	333	327
		15,000 ft	372	365	362
		20,000 ft	382	376	373
		25,000 ft	391	387	385
		30,000 ft	400	397	395
	Service ceiling, ft		33,800	33,000	32,800
	V_{max}, knots TAS	SL	522	511	505
		15,000 ft	515	508	505
		20,000 ft	507	501	498
		25,000 ft	492	486	484
		30,000 ft	470	464	460
Combat: (2) ECM Pods (1) Mk 28 Bomb	Weight, lbs		46,192	46,347	46,391
	$(R/C)_{max}$ at SL, fpm		6,900	6,550	6,500
	$V_{R/C}$ at SL, kn		384	374	370
	V_{max} at SL, kn		548	544	542
	Service ceiling, ft		37,600	36,900	36,650
Return: (2) ECM Pods	Weight, lbs		42,656	42,811	42,855
	$(R/C)_{max}$, fpm	SL	7,600	7,250	7,200
		25,000 ft	3,300	3,150	3,100
		40,000 ft	650	540	490
	Service ceiling, ft		42,500	42,000	41,600
	$V_{R/C}$, kn, TAS	SL	408	399	394
		25,000 ft	415	412	410
		4C,000 ft	418	417	417
	V_{max}, kn, TAS	SL	552	548	546
		25,000 ft	515	508	505
		40,000	420	418	418

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(a) Side view.

Figure B-2. - Exposed tailpipe including standard conical convergent nozzle and cylindrical ejector on A-6A airplane.

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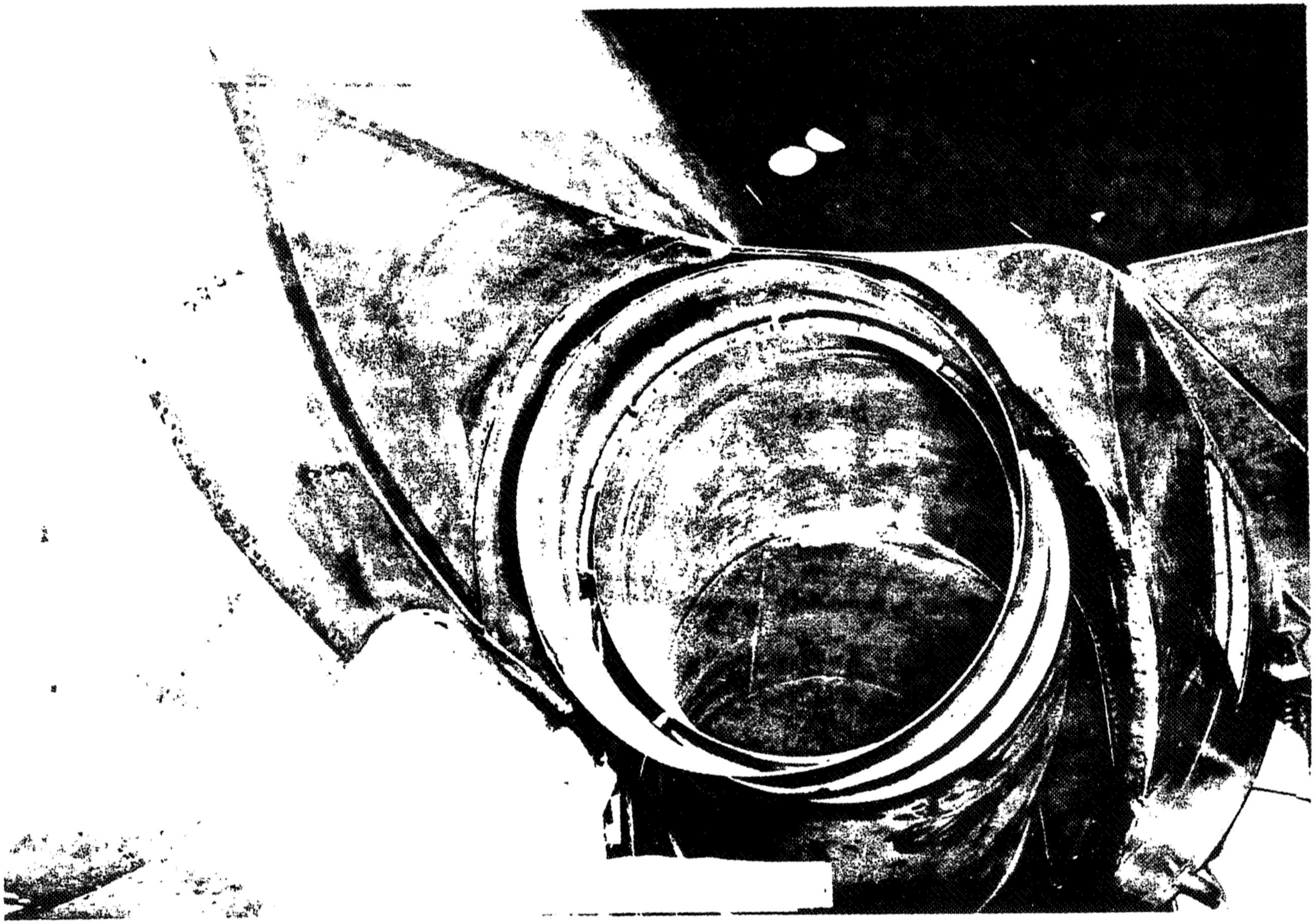

(b) View from rear.

Figure B-2. - Concluded.

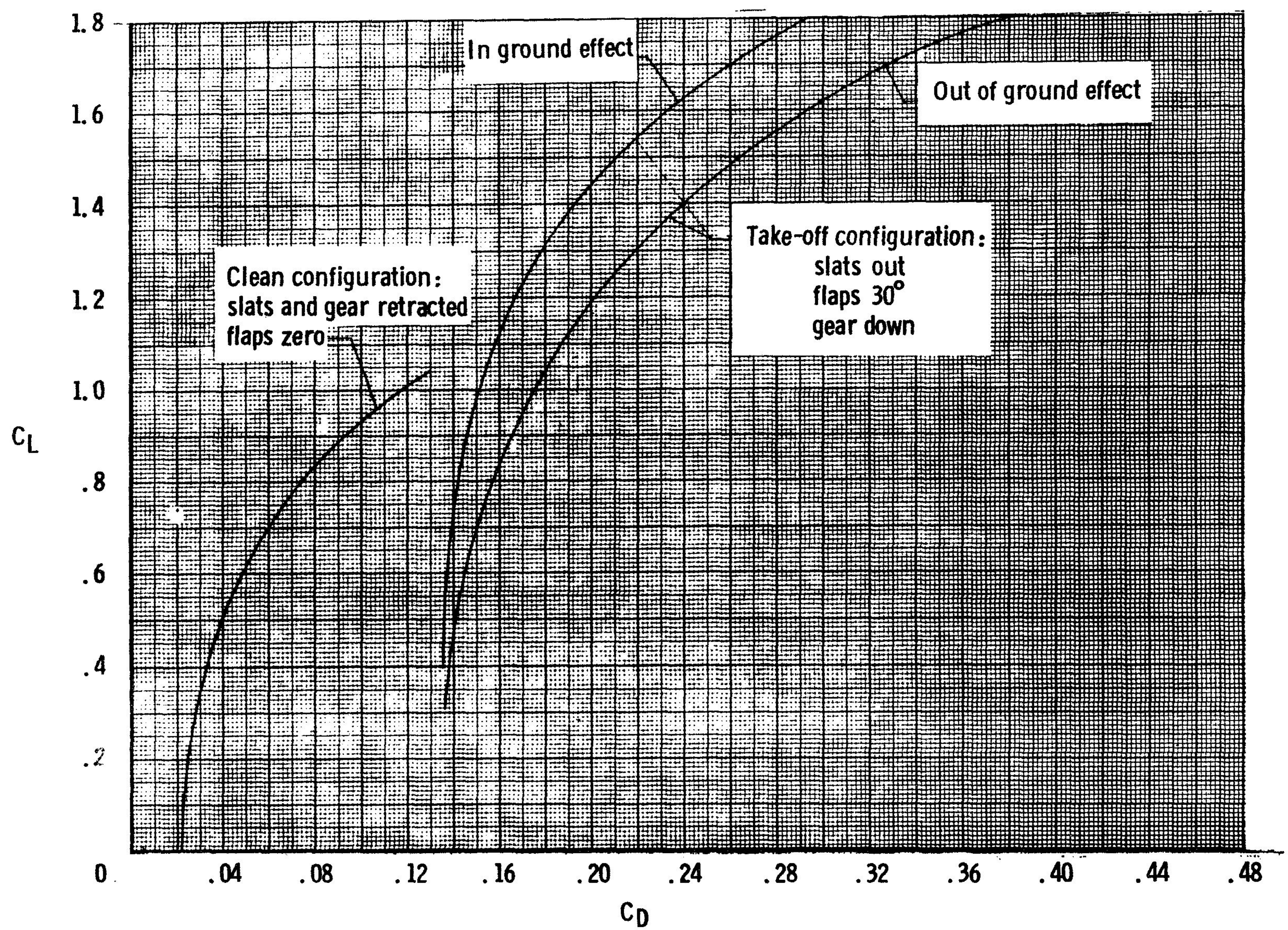

Figure B-3. - Low-speed lift-drag polars for the basic EA-6A airplane including two ECM pods but without other external stores. Data basis: A-6A flight test and EA-6A wind tunnel tests (ref. B-1).

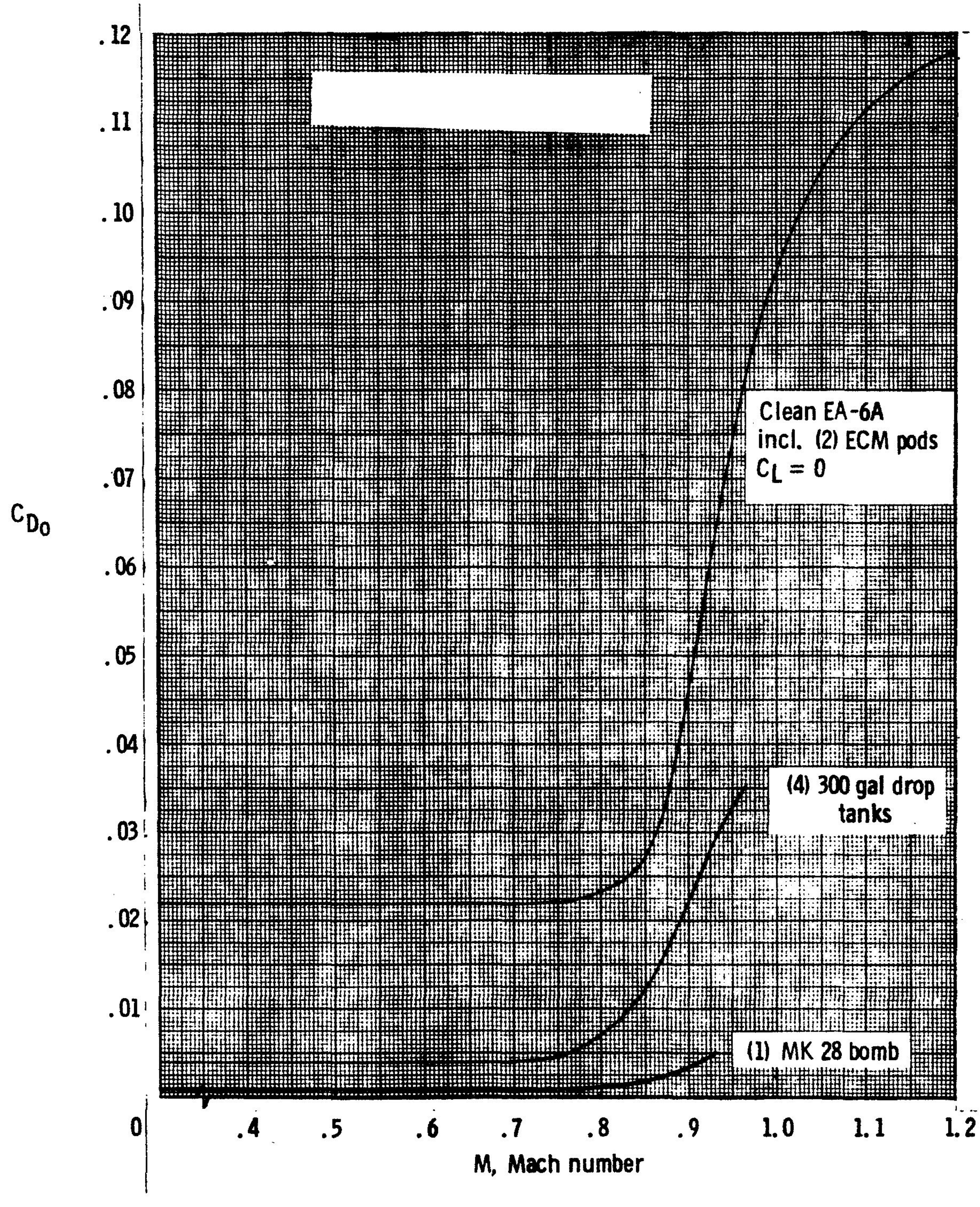

Figure B-4. - Variation of zero-lift and incremental drag due to external stores with Mach number for the unmodified EA-6A airplane. Data basis: A-6A flight test and EA-6A wind tunnel tests (ref. B-1).

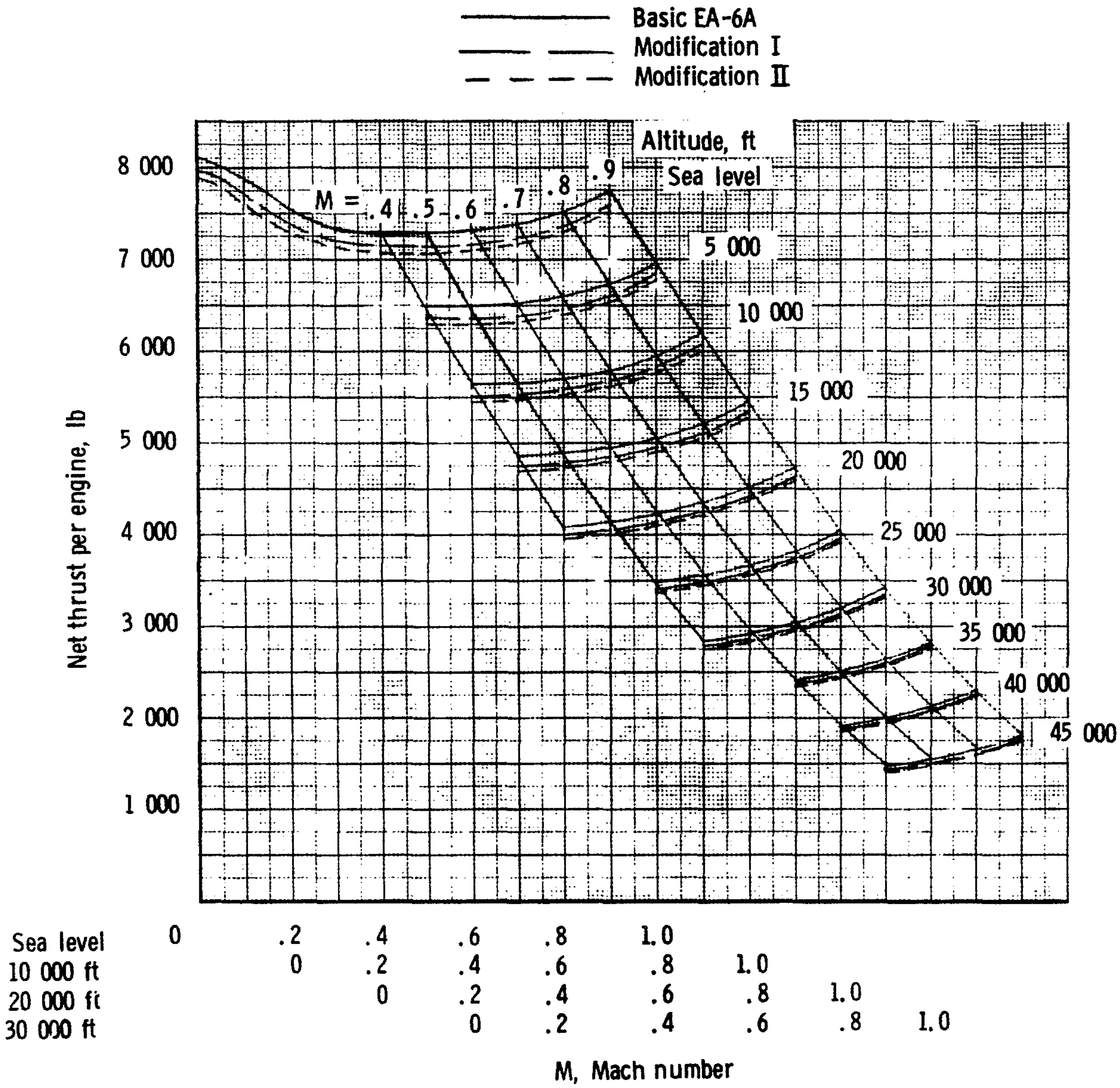

Figure B-5. - Variation of installed net military-rated thrust with Mach number and altitude for standard conditions.

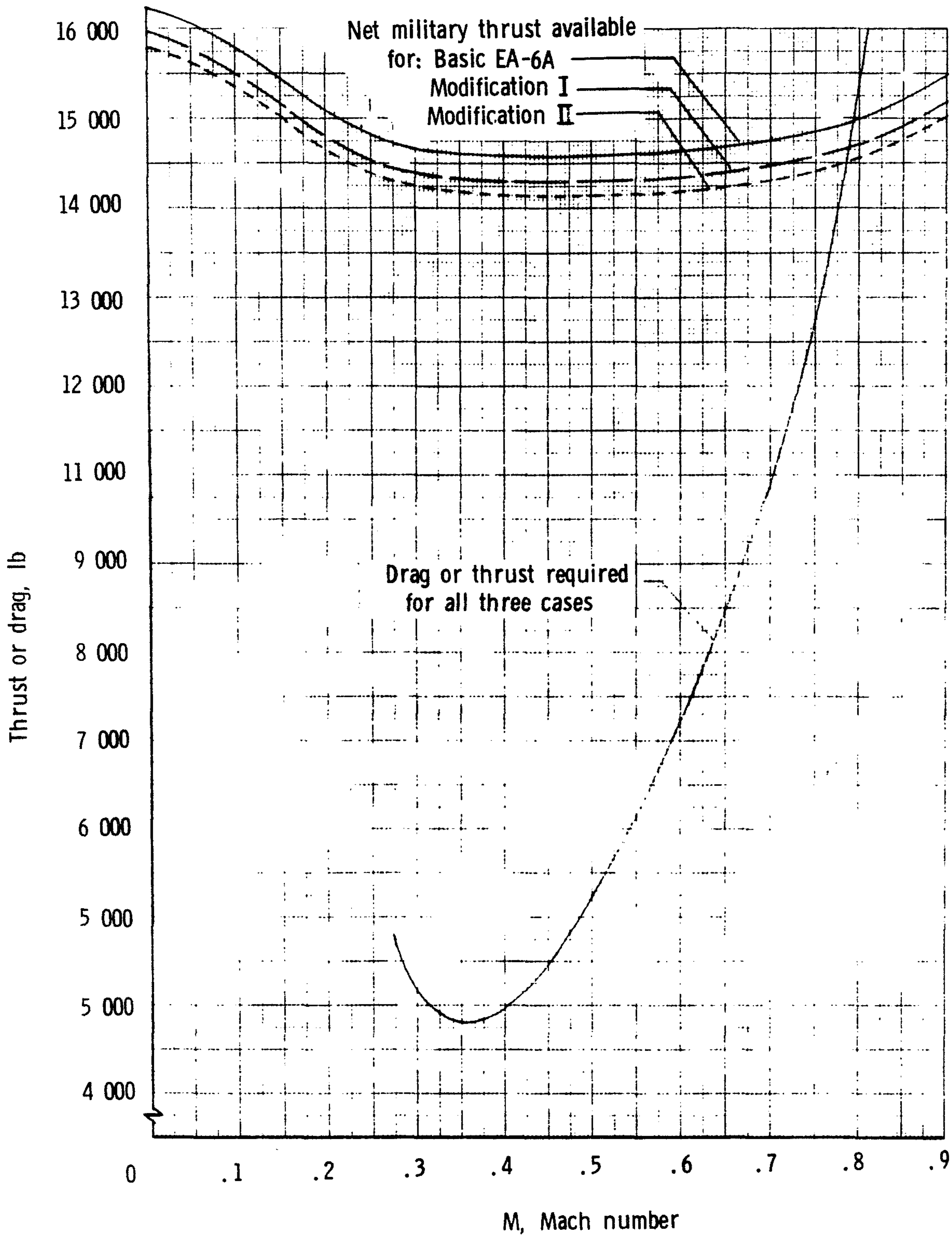

Figure B-6. - Example of the variation of net military-rated thrust available and thrust required with Mach number for the basic EA-6A airplane and modifications I and II. Gross weight = 54 200 lbs. Sea level standard conditions, climb-out configuration: (2) ECM pods, (4) 300 gallon wing tanks, (1) Mk28 bomb on ℄, flaps and gear retracted.