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NOISE DATA FOR A TWIN-ENGINE COMMERCIAL JET AIRCRAFT FLYING CONVENTIONAL, STEEP, AND TWO-SEGMENT APPROACHES

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16. Abstract

Center-line noise measurements of a twin-engine commercial jet aircraft were made during steep (-5° and -4°) landing approach profiles, and during a two-segment (-5°/-3°) approach profile for comparison with similar measurements made during conventional (-3°) approaches. The steep and two-segment approaches showed significant noise reductions when compared with the -3° base line.

The measured noise data were also used to develop a method for estimating the noise under the test aircraft at thrust and altitude conditions typical of current landing procedures and of landing procedures under development for the Advanced Air Traffic Control System.

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and John R. Hamilton*
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SUMMARY

Noise measurements of a twin-engine commercial jet aircraft were made during steep (-4° and -5°) approach profiles and during a two-segment (-5°/-3°) approach profile at distances between about 2 km (1.08 n. mi.) and 6 km (3.24 n. mi.) from the runway threshold. Noise levels for the -4° and -5° profiles were 7 dB(A) and 10 dB(A), respectively, below base-line noise measurements, made for a conventional -3° profile. Noise reductions from the -5°/-3° profile were about the same as for the -4° profile at about 6 km (3.24 n. mi.) but were less than either of the steep profiles at closer distances.

Effective perceived noise levels at reference conditions, determined at a point 1.85 km (1 n. mi.) from the threshold, were reduced by about 9 EPNdB and 5 EPNdB by the -5° and -4° approach profiles, respectively, when compared with the standard -3° base line. At this distance, the noise reduction benefit for the two-segment profile was about 3 EPNdB.

These noise measurements were also used to develop a noise-thrust-altitude relationship for the test aircraft at the reduced thrust levels required for advanced approach techniques. For this analysis it was determined that at these reduced levels, single-point noise measurements may be confidently extrapolated to other altitudes according to a method commonly used for conventional approach noise analyses.

A large (42 percent) reduction in approach thrust at a given altitude did not significantly reduce the center-line noise below this test aircraft. The reduction amounted to only about 3.5 dB(A) in the altitude range between 61 m (200 ft) and 610 m (2000 ft).

INTRODUCTION

Methods for reducing aircraft noise in the terminal area have been studied for many years by NASA, other government agencies, and industry. Much of this effort has been involved with developing advanced approach techniques and procedures for noise abatement. Steep approaches, two-segment approaches, and decelerating approaches are some of the techniques which have been studied. Some of the research conducted with these techniques is described in references 1 to 4.

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NASA Langley Research Center is using the twin-engine jet aircraft shown in figure 1 to establish a measured noise data base for use in the development of improved noise prediction methods. This report presents the results of noise measurements made during conventional, steep, and two-segment approaches with this aircraft. In addition, a noise-thrust-altitude (NTA) correlation established from these data is also presented. This correlation compares multipoint measurements with values obtained by single-point measurement extrapolation at an approach thrust level typical of advanced approach techniques.

SYMBOLS AND ABBREVIATIONS

Values are given both in the International System of Units (SI) and in U.S. Customary Units. Measurements and calculations were made in U.S. Customary Units.

EPNL	effective perceived noise level, EPNdB
EPR	engine pressure ratio
F_n	net thrust, N (lbf)
ILS	Instrument Landing System
L_A	A-weighted sound pressure level, dB(A) (re 20 μPa)
NTA	noise-thrust-altitude
RH	relative humidity
Sta.	microphone stations
T	temperature, K (°F)
t	time, sec
V_C	cross-wind velocity, knots
V_W	wind velocity, knots
x	longitudinal distance from projected touchdown point along extended runway center line, km (n. mi.)
y	lateral distance from extended runway center line, m (ft)
z	vertical distance above extended runway center line, m (ft)
γ	approach flight-path angle, deg
δ	atmospheric pressure ratio
δ_f	flap deflection, deg

Subscripts:

max	maximum value
ref	data corrected to reference conditions

DESCRIPTION OF AIRCRAFT AND DATA SYSTEMS

Aircraft

The test aircraft is the Boeing 737-100 twin-engine jet transport shown in figure 1. Equipped with triple-slotted trailing-edge flaps, leading-edge slats, and Krueger leading-edge flaps, the aircraft was designed for short-haul operations into existing small airports with short runways. Longitudinal control and trim are achieved by the elevator and movable stabilizer, respectively, while lateral control is obtained by a combination of ailerons and spoilers. The spoilers also function as speed brakes when so selected by the pilot. A single-surface rudder provides directional control. Aircraft dimensions, propulsion-system data, and design data are presented in table I and figure 2.

Data Systems

These experiments required time-synchronized data systems to measure noise, meteorological conditions, aircraft position, and certain aircraft parameters. These systems are all discussed in detail in reference 5 and are summarized briefly here.

The noise measurement system consisted of 1.27-cm (1/2-in.) condenser-type pressure microphones, cables, signal-conditioning equipment, and recording equipment needed to obtain noise data in accordance with appendixes A, B, and C of reference 6. The system equipment and calibration procedures are described in detail in reference 5. Figure 3 shows the microphone locations used in these tests. The microphones were mounted 1.2 m (3.9 ft) above ground level and perpendicular to the vertical projection of the flight path of the aircraft.

Meteorological measurements were made at a site near the runway threshold. Surface measurements consisted of temperature, relative humidity, static pressure, and wind direction and speed. The wind data were measured 10 m (32.8 ft) above ground level. Meteorological data obtained from radiosonde balloons released every 30 min during the tests were relative humidity, temperature, and wind speed and direction. The aircraft x, y, and z position data were determined from radar and were all referenced to the extended runway center line and to a projected touchdown point 305 m (1000 ft) from the threshold of the test runway.

The aircraft performance parameters measured during these tests included weight, engine pressure ratios (related to net thrust), flap and gear positions, glide slope and localizer deviations, airspeed, body axial rates and attitudes, and column and wheel forces. Weight data were determined by manually adding weight indicated by the fuel quantity gages to the dry weight of the aircraft.

The other parameters were recorded onboard on a wide-band magnetic tape recorder. The nominal test weight was 39 463 kg (87 000 lbm) ± 1361 kg (3000 lbm).

FLIGHT PROFILES AND TEST PROCEDURES

Flight Profiles

The nominal flight profiles are illustrated in figure 4 and tabulated in table II. The nominal two-segment profile had a sharp transition point at $z = 214$ m (700 ft) and $x = 4.07$ km (2.20 n. mi.). This geometry placed the test aircraft on a -5° glide slope over stations 3 and 4 and a -3° glide slope over stations 1 and 2.

All approaches were made with the landing gear, slats, and flaps extended. The flap deflection for all profiles was 30°, with the exception of the -3° profile, for which flap deflections of both 30° and 40° were used.

Test Procedures

The flight-test procedure for the -3°, -4°, and -5° approach profiles was to establish the desired configuration, airspeed, thrust, and approach path prior to reaching $x = 9.25$ km (5 n. mi.). From this point inbound the EPR and configuration were held constant as the aircraft flew over the microphone stations. In all these tests, both the EPR and the approach speed were pilot options. However, once the EPR was selected and the glide slope acquired, the EPR was not changed and approach speed during descent was controlled with speed brakes. Approach guidance information was provided by the system shown schematically in figure 5. Aircraft position data from radar were recorded during each approach run and compared with the desired coordinates of the flight path by a computer. Cross-track and vertical deviations were computed and transmitted to the test aircraft in real time. This information was displayed in standard ILS format on the aircraft's Flight Director System.

For the $-5^{\circ}/-3^{\circ}$ approaches the test procedure was the same as for the other approaches with the exception that the initial approach speed (on the -5° segment) was higher than the nominal approach speed for the -3° approaches. After transition had been achieved, this excess airspeed was allowed to dissipate as the aircraft descended on the -3° segment of the profile. As in the other approaches, speed brakes were used as required for speed control.

DATA REDUCTION AND ANALYSIS

The basic stages of the acoustic data-reduction procedure are shown in figure 6. The analog (FM) tapes from the field were processed by a one-third-octave analyzer to yield one-third-octave sound pressure levels between 3.2 Hz and 31.5 kHz with a resolution of 0.25 dB. These spectra, determined at 0.5-sec intervals, were then entered into the computer, where system and ambient-condition corrections were applied for the one-third-octave bands between 25 Hz and 20 kHz. Corrected spectra were then used to calculate the desired acoustic parameters.

Prior to the analysis of any data runs, systems corrections were made for microphone calibration, wind screen, and pink noise. The microphone calibration and pink noise correction were both recorded at the beginning of each tape. The wind screen correction was determined from manufacturer's data (ref. 5). In addition to these system corrections, a slow meter response was simulated by calculating a running linear average over 1.5 sec for each one-third-octave band as described in reference 7.

Corrections for the contribution of background sound pressure levels were also applied. Before each flyover, an ambient condition was recorded and its spectrum was calculated by averaging from 5 to 10 continuous 0.5-sec spectra. This spectrum was compared with each data spectrum during the flyover. If any one-third-octave band in the data spectrum was less than 5 dB above the ambient conditions, that band was replaced by the power average of the frequency bands above and below it. If the data band was between 5 and 10 dB above the ambient condition, it was replaced by the difference in power between the data and ambient levels. If the data band was more than 10 dB above the ambient condition, no correction was applied.

The noise data in this report are in terms of the parameters L_A and EPNL. Values of L_A and EPNL were determined from measured data according to the methods of reference 8.

In order to provide a direct comparison between tests, and with other sources of data, the method of reference 6 was used to adjust the L_A data to a reference temperature of 298.2 K (77° F) and a relative humidity of 70 percent. In addition, the geometric relationships in reference 7 were used to further adjust EPNL data to reference weight, airspeed, and altitude. These adjusted data are designated $L_{A,ref}$ and $EPNL_{ref}$ in this report.

RESULTS AND DISCUSSION

Noise Measurements

Test conditions.- The test conditions at which the noise data were taken are given in table III. The meteorological conditions were measured when the aircraft was over station 1 and the position data (y and z) were measured when the aircraft was directly over each station. Values of F_n/δ for each approach profile were determined from the averages of the EPR values recorded during each run. It can be noted that F_n/δ had the same value for the steep and two-segment profiles.

The meteorological data in table III indicate that all tests were made at temperatures between 299.8 K and 304.1 K (80° F and 88° F), relative humidities between 38 percent and 51 percent, and wind velocities (10 m (32.8 ft) above ground level) not in excess of 10 knots. The cross-wind component was generally less than 6 knots, although 9 knots was the maximum value encountered. An examination of the radiosonde data indicated that there were no temperature inversions during these tests.

The noise data recorded at the test conditions in table III were all corrected to the nominal flight profiles (table II) and to the reference conditions noted in the preceding section. The total correction due to the test conditions was generally less than ±1 dB(A) or ±1 EPNdB.

Typical time histories and spectral measurements.- Typical time histories of L_A at stations 1 and 4 are shown for the base-line ($\gamma = -3^{\circ}$, $\delta_f = 40^{\circ}$) profile in figure 7. Similar data are also shown for the -5° profile since this profile had the greatest impact on the noise levels at both stations. In this figure, $t = 0$ denotes the time that the aircraft was over the station. The histories for $\gamma = -3^{\circ}$ show the same general characteristics observed in noise tests of other commercial turbojet aircraft (refs. 9 and 10) and are discussed in reference 5. At both stations, the maximum value of L_A for $\gamma = -5^{\circ}$ was about 10 dB(A) less than for $\gamma = -3^{\circ}$. At station 1, this reduced level was recorded between $t \approx -1$ sec and $t \approx +2$ sec. At station 4, however, the same reduction in noise level was recorded over a considerably longer time interval ($t \approx -4$ sec to $t \approx +6.5$ sec).

The effect of approach profile on the noise spectrum of this aircraft is shown by the typical data in figure 8. This figure shows the measured spectra at the maximum value of L_A, at stations 1 and 4, and for $\gamma = -3^{\circ}$ and -5°. The data show that the steeper profile produced a nearly constant reduction in sound pressure level between center frequencies of 100 Hz and 10 kHz at both stations 1 and 4.

$(L_{A,max})_{ref}$ data.- Values of $(L_{A,max})_{ref}$ from the various flight tests are listed in table IV along with the mean values of the measured data. In some cases, no data are given for station 2 because of instrumentation difficulties. Since the sample size was small (less than 30 data points), confidence limit intervals were calculated to determine how well these data estimated the true population mean value for many flights (more than 30 data points). These results are shown in table V.

Table V lists the sample standard deviations and 90-percent confidence intervals for the population mean values associated with the sample size. The 90-percent confidence interval was chosen since this is most often used in aircraft noise studies, and the values were computed using the student's t-distribution method of reference 11.

The data in table V show that, in general, the sample standard deviations and the confidence intervals were small. These results indicate that the sample mean values well represent the true population mean values and will lie within the indicated confidence intervals 90 percent of the time. The data for $\gamma = -5^{\circ}$ exhibit somewhat larger standard deviations than the other data, although these values are not unreasonable for measurements of this type. (See refs. 12 and 13.) As would be expected, the size of the confidence interval at station 2 for the base-line data is larger as a consequence of the limited sample size resulting from the previously noted instrumentation difficulties.

The measured mean values of $(L_{A,max})_{ref}$ from table IV are plotted in figure 9. The data show that the -5° profile produced the lowest noise levels, about 10 dB(A) less than the base-line ($\gamma = -3^{\circ}$, $\delta_f = 40^{\circ}$) noise levels. The noise data presented for $\gamma = -4^{\circ}$ are about 7 dB(A) less than the base-line data. The $\gamma = -5^{\circ}/-3^{\circ}$ data were not significantly different from the $\gamma = -4^{\circ}$ data at about 6 km (3.24 n. mi.) from the threshold; but smaller noise reductions resulted for $\gamma = -5^{\circ}/-3^{\circ}$ than for either of the steep approaches at closer distances.

$EPNL_{ref}$ data.- Table VI presents measured and mean values of $EPNL_{ref}$ at a distance 1.85 km (1 n. mi.) from the threshold. The standard deviations and 90-percent confidence intervals for these data are presented in table VII. As with the $(L_{A,max})_{ref}$ data, the sample standard deviations and the 90-percent confidence intervals were small, and the confidence intervals were well within the criteria of ±1.5 EPNdB established in reference 6.

A comparison of the mean values in table VI with the base-line mean value shows that there was a reduction of about 9 EPNdB for $\gamma = -5^{\circ}$ and about 5 EPNdB for $\gamma = -4^{\circ}$. The reduction offered by the two-segment approach ($\gamma = -5^{\circ}/-3^{\circ}$) was about 3 EPNdB.

Data assessment.- In general, the noise data presented clearly show that the steep approach profiles offered significant reductions in center-line noise, since the noise propagation paths were longer and the normalized thrust values were lower than for the base-line profile. For the two-segment profile, however, the path lengths were the same at distances from the threshold less than about 4 km (2.16 n. mi.), and the noise reductions (which resulted from reduced F_n/δ alone) were smaller.

Noise-Thrust-Altitude Relationship

Background.- Noise-thrust-altitude (NTA) relationships are commonly developed for individual aircraft as noise prediction tools. Both test data and analyses are usually used in establishing these relationships. However, the currently existing relationships do not generally apply to approaches at low thrust levels which will characterize advanced approach techniques. This section describes the derivation of such a relationship for this aircraft, as well as a comparison of multipoint noise measurements with an extrapolated single-point measurement at a much lower than normal thrust level.

Methods.- As noted in the preceding section, the steep and two-segment profiles were all flown at a thrust level of 11 342 N/engine (2550 lbf/engine). This was the minimum test thrust level, about 42 percent below F_n/δ for the base-line profile. Noise-thrust-altitude relationships were established for these maximum and minimum values of approach F_n/δ as well as for the intermediate F_n/δ value for $\gamma = -3^{\circ}$ and $\delta_f = 30^{\circ}$.

The data were analyzed by two methods. In the first method, $(L_{A,max})_{ref}$ flight data measured at all four stations (table IV) were plotted as a function of altitude for each value of F_n/δ. This multipoint measurement method was constrained to the altitude range from 121 m (397 ft) to 562 m (1840 ft), where measured data were available. In the second method, data measured at only one station (station 1) were analytically extrapolated over a range of altitude from 61 m (200 ft) to 610 m (2000 ft).

This single-point measurement extrapolation method used a well-known physical relationship to adjust spectra measured at the time of $(L_{A,max})_{ref}$ to different noise propagation path lengths. The analysis used the following equation from reference 7 (in the notation of ref. 7):

$$SPL_{ic} = SPL_{ia} + (\alpha_{ia} - \alpha_{ir})SR_a + \alpha_{ir}(SR_a - SR_r) + 20 \log\left(\frac{SR_a}{SR_r}\right)$$

where the SPL_{ia} and SPL_{ic} are the actual and corrected sound pressure levels, respectively, in the ith one-third-octave band. The first correction term accounts for the effects of change in atmospheric sound absorption for the entire actual propagation path (slant range) SR_a. The coefficients α_{ia} and α_{ir} are the sound absorption coefficients for the actual and the reference atmospheric conditions, respectively, for the ith one-third-octave band and were determined by the method of reference 2. The second correction term accounts for the excess or shortage of atmospheric absorption due to the change in path from the actual to the reference slant range SR_r. The third correction term accounts for the effects of the inverse square law when correcting from the actual to the reference slant range. The corrected spectra determined from this analysis were then used to determine new values of $(L_{A,max})_{ref}$ at the various altitudes.

Results.- The results obtained from the two analyses were in good agreement at all three thrust levels. This agreement is illustrated in figure 10, which shows the variation of $(L_{A,max})_{ref}$ with z for F_n/δ = 11 342 N/engine (2550 lbf/engine) determined from the multipoint measurements method and from the single-point measurement extrapolation method. The NTA relationship determined from these two methods is also shown. This same procedure was used to determine the NTA relationships at the other two normalized thrust values. These NTA analysis procedures are not unique and have been employed in investigations in the past. The point of significance here, however, is that noise data from the two methods are compared at an approach thrust level typical of advanced approach requirements. The good agreement at this condition (fig. 10) indicates that single-point noise measurements can be accurately extrapolated to different altitudes (within the limits of this investigation) according to a relationship quite commonly used for conventional approach noise analyses.

Values from the NTA relationship for each thrust level are listed in table VIII and compared with the flight measurements. The agreement is generally quite good. The NTA curves are plotted in figure 11 for altitudes between 61 m (200 ft) and 610 m (2000 ft). These curves can be used to estimate the noise under the flightpath of this aircraft when altitude and normalized thrust are known. The data also show that an appreciable reduction in the approach thrust of this aircraft does not greatly reduce the center-line noise at a given altitude. For example, a reduction of 42 percent in approach F_n/δ reduced $(L_{A,max})_{ref}$ by about 3.5 dB(A) in the altitude range of the investigation.

CONCLUSIONS

In this report, runway center-line noise measurements were made during steep (-4° and -5°), two-segment (-5°/-3°), and conventional (-3°) approaches. The noise measurements consisted of maximum A-weighted sound pressure levels and effective perceived noise levels corrected to reference conditions $\left((L_{A,max})_{ref}\right.$ and $\left.EPNL_{ref}\text{, respectively}\right)$. Results indicate the following:

1. Center-line $(L_{A,max})_{ref}$ data for the -4° and -5° approach profiles were 7 dB(A) and 10 dB(A), respectively, less than those for the conventional -3° profile.

2. The center-line $(L_{A,max})_{ref}$ value for the two-segment (-5°/-3°) approach profile was not significantly different from the -4° profile value at about 6 km (3.24 n. mi.) from the threshold. At closer distances, the two-segment profile resulted in smaller noise reductions than either of the steep profiles.

3. The center-line $EPNL_{ref}$ data from the steep and two-segment profiles were all lower than the -3° base-line data. At 1.85 km (1 n. mi.) from the threshold, the reductions for the -5° and -4° profiles were about 9 EPNdB and 5 EPNdB, respectively. The two-segment profile reduced the $EPNL_{ref}$ value by 3 EPNdB at this distance.

4. Multipoint measurements and single-point measurement extrapolation were used to develop a noise-thrust-altitude relationship at reduced approach thrust values. The good agreement noted between these methods indicates that a single-point extrapolation method, commonly used for conventional approach noise, can be used with confidence at greatly reduced thrust levels.

5. A 42-percent reduction in the approach thrust of the test aircraft, at a given altitude, reduced the center-line $(L_{A,max})_{ref}$ value by only about 3.5 dB(A).

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REFERENCES

1. Tanner, Carole S.: Measurement and Analysis of Noise From Four Aircraft During Approach and Departure Operations (727, KC-135, 707-320B, and DC-9). FAA-RD-71-84, Sept. 1971.

2. Burcham, Frank W., Jr.; Putnam, Terrill W.; Lasagna, Paul L.; and Parish, O. Owen: Measured Noise Reductions Resulting From Modified Approach Procedures for Business Jet Aircraft. NASA TM X-56037, 1975.

3. Denery, D. G.; Bourquin, K. R.; Drinkwater, F. J., III; Shigemoto, F. H.; and White, K. C.: Status Report on NASA Two-Segment Approach Program. [Preprint] 750594, Soc. Automot. Eng., May 1975.

4. Edwards, Fred G.; Bull, John S.; Foster, John D.; Hegarty, Daniel M.; and Drinkwater, Fred J., III: Delayed Flap Approach Procedures for Noise Abatement and Fuel Conservation. Aircraft Safety and Operating Problems, NASA SP-416, 1976, pp. 77-90.

5. Hastings, Earl C., Jr.; Shanks, Robert E.; and Mueller, Arnold W.: Noise Measurements for a Twin-Engine Commercial Jet Aircraft During 3° Approaches and Level Flyovers. NASA TM X-3387, 1976.

6. Noise Standards: Aircraft Type and Airworthiness Certification. Federal Aviation Regulations, pt. 36, FAA, June 1974.

7. Hosier, Robert N.: Some Comparisons of the Flyover Noise Characteristics of DC-9 Aircraft Having Refanned and Hardwalled JT8D Engines, With Special Reference to Measurement and Analysis Procedures. NASA TM X-72804, 1976.

8. Pearsons, Karl S.; and Bennett, Ricarda: Handbook of Noise Ratings. NASA CR-2376, 1974.

9. Copeland, W. Latham; and Clark, Lorenzo R.: Noise Measurements for a Three-Engine Turbofan Transport Airplane During Climbout and Landing Approach Operations. NASA TN D-6137, 1971.

10. Peery, H. Rodney; and Erzberger, Heinz: Noise Measurement Evaluation of Takeoff and Approach Profiles Optimized for Noise Abatement. NASA TN D-6246, 1971.

11. Neville, Adam M.; and Kennedy, John B.: Basic Statistical Methods for Engineers and Scientists. Intertext Books (London), c.1964.

12. Williams, B. G.; and Yates, R.: Aircraft Noise Definition. Rep. No. FAA-EQ-73-7, 1, Dec. 1973.

13. Bishop, Dwight E.: Comparisons of Variability in Aircraft Flyover Noise Measurements. J. Acoust. Soc. America, vol. 58, no. 6, Dec. 1975, pp. 1211-1221.

TABLE I.- CHARACTERISTICS OF TEST AIRCRAFT

General:		
Length, m (ft)	28.65	(94.0)
Height to top of vertical fin, m (ft)	11.28	(37.0)
Wing:		
Area, m^2 (ft^2)	91.04	(980)
Span, m (ft)	28.35	(93.0)
Mean aerodynamic chord, m (ft)	3.41	(11.2)
Incidence angle, deg		1.0
Aspect ratio		9.07
Dihedral, deg		6
Sweep, deg		25
Flap deflection (maximum), deg		40
Flap area, m^2 (ft^2)	14.94	(160.8)
Aileron deflection (maximum), deg		±20
Spoiler defection, deg:		
Inboard		60
Outboard		40
Horizontal tail:		
Total area, m^2 (ft^2)	28.98	(312)
Span, m (ft)	10.97	(36.0)
Elevator area, m^2 (ft^2)	6.55	(70.5)
Elevator deflection (maximum), deg		±21
Stabilizer deflection, deg		12
Vertical tail:		
Total area, m^2 (ft^2)	20.9	(225)
Span, m (ft)	6.15	(20.16)
Rudder area, m^2 (ft^2)	5.22	(56.2)
Rudder deflection, deg		±24
Propulsion system:		
Pratt & Whitney JT8D-7 engines		2
Maximum uninstalled thrust per engine at sea level static pressure, N (lbf)	62 275	(14 000)
Weight:		
Maximum take-off gross weight, kg (lbm)	44 361	(97 800)
Maximum landing weight, kg (lbm)	40 687	(89 700)
Empty weight (zero fuel), kg (lbm)	28 803	(63 500)

TABLE II.- NOMINAL FLIGHT PROFILES

γ, deg	z at station -								y, m (ft)
	1		2		3		4		
	m	ft	m	ft	m	ft	m	ft	
-3	121	397	160	525	226	743	337	1104	0
-4	162	530	214	701	302	991	449	1472	0
-5	202	664	267	877	378	1240	562	1843	0
-5/-3	121	397	160	525	235	771	419	1374	0

TABLE III.- ACTUAL TEST CONDITIONS

(a) Base-line approach; $\gamma = -3^{\circ}$; $\delta_f = 40^{\circ}$; F_n/δ = 19 793 N/engine (4450 lbf/engine)

Flight	Run	Meteorological conditions					z at station -								$^a y$ at station -							
		V_C, knots	V_W, knots	T		RH, percent	1		2		3		4		1		2		3		4	
				K	°F		m	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft
R-060	3.1.1	1	4	299.8	80	47	129.5	425	177.7	583	246.3	808	348.7	1144	-0.9	-3	+2.7	+9	+9.1	+30	+6.7	+22
R-060	3.1.2	3	4	300.4	81	48	128.0	420	170.7	560	238.7	783	344.7	1131	-3.4	-11	-4.6	-15	+5.2	+17	-13.4	-44
R-060	3.1.3	3	4	300.4	80	48	135.6	445	168.6	553	249.9	820	353.9	1161	+3	+10	+7.3	+24	-14.9	-49	-2.4	-8
R-061	3.1.4	0	3	302.7	85	49	144.8	475	170.7	560	243.8	800	350.5	1150	-4.6	-15	-6.4	-21	-2.1	-7	+5.5	+18
R-061	3.1.5	1	5	303.2	86	48	134.1	440	172.2	565	240.8	790	350.5	1150	+3.7	+12	-3.7	-12	-14.6	-48	+4.0	+13

(b) $\gamma = -3^{\circ}$; $\delta_f = 30^{\circ}$; F_n/δ = 17 792 N/engine (4000 lbf/engine)

Flight	Run	Meteorological conditions					z at station -								$^a y$ at station -							
		V_C, knots	V_W, knots	T		RH, percent	1		2		3		4		1		2		3		4	
				K	°F		m	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft
R-060	3.2.1	1	1	299.8	80	50	143.6	471	177.7	583	241.4	792	342.3	1123	-7.0	-23	+5.2	+17	-0.6	-2	+6.7	+22
R-060	3.2.2	0	3	299.8	80	48	135.6	445	173.7	570	240.5	789	335.3	1100	-4.0	-13	-3.0	-10	+8.2	+27	-11.0	-36
R-061	3.2.3	1	2	302.1	84	49	131.1	430	172.2	565	243.8	800	342.9	1125	0	0	+0.9	+3	-7.0	-23	-14.9	-49
R-060	3.2.4	0	4	301.0	82	38	122.5	402	177.7	583	243.2	798	345.9	1135	-12.5	-41	-5.5	-18	-4.0	-13	-8.5	-28

[a] Positive to left of extended runway center line; negative to right of extended runway center line.

TABLE III.- Continued

(c) $\gamma = -4^\circ$; $\delta_f = 30^\circ$; $F_n/\delta = 11\ 342$ N/engine (2550 lbf/engine)

Flight	Run	Meteorological conditions					z at station -								[a]y at station -							
		V_C, knots	V_W, knots	T		RH, percent	1		2		3		4		1		2		3		4	
				K	°F		m	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft
R-061	3.3.1	0	1	303.6	87	39	173.4	569	235.9	774	314.2	1031	445.9	1463	+5.5	+18	-2.7	-9	+1.2	+4	+12.5	+41
R-061	3.3.2	6	6	303.2	86	42	171.9	564	231	758	307.8	1010	447.8	1469	-5.0	-16	+2.1	+7	-6.4	-21	+4.5	+15
R-061	3.3.3	7	7	303.2	86	49	163.7	537	245.4	805	305.4	1002	440.7	1446	-4.6	-15	+10.4	+34	+14.0	+46	-22.3	-73
R-061	3.3.4	6	6	303.2	86	50	166.1	545	225.6	740	306.0	1004	446.8	1466	+15.9	+52	+39.6	+130	-4.9	-16	-11.8	-39
R-061	3.3.5	8	8	303.2	86	51	172.8	567	206.0	676	305.1	1001	457.8	1502	±6.4	±21	-2.1	-7	+11.6	+38	+11.3	+37

(d) $\gamma = -5^\circ$; $\delta_f = 30^\circ$; $F_n/\delta = 11\ 342$ N/engine (2550 lbf/engine)

Flight	Run	Meteorological conditions					z at station -								[a]y at station -							
		V_C, knots	V_W, knots	T		RH, percent	1		2		3		4		1		2		3		4	
				K	°F		m	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft
R-050	1.1	5	5	303.6	87	42	214.9	705	273.1	896	342.0	1122	530.0	1739	-13.4	-44	-15.2	-50	-18.9	-62	-27.7	-91
R-050	1.2	5	5	303.6	87	41	211.8	695	271.9	892	392.0	1286	548.6	1800	+28.0	+92	+24.1	+79	-9.8	-32	-10.7	-35
R-050	1.3	7	9	304.1	88	40	210.0	689	267.9	879	383.1	1257	570.3	1871	+6.7	+22	-11.9	-39	-17.7	-58	-19.2	-63
R-050	1.4	6	7	304.1	88	39	210.3	690	274.6	901	367.6	1206	565.1	1854	-4.9	-16	-20.1	-66	+4.0	+13	-15.8	-52
R-050	1.5	6	8	304.1	88	40	205.7	675	272.2	893	385.0	1263	566.9	1860	-32.6	-107	-20.1	-66	-41.1	-135	-16.5	-54
R-050	1.6	7	8	304.1	88	40	204.8	672	280.1	919	367.3	1205	557.5	1829	+6.1	+20	+4.6	+15	-19.2	-63	-35.7	-117
R-050	1.7	9	10	304.1	88	40	197.5	648	277.1	909	378.9	1243	580.0	1903	-11.3	-37	-32.0	-105	-37.5	-123	-8.8	-29
R-050	1.8	8	9	304.1	88	40	215.8	708	278.6	914	376.1	1234	559.6	1836	-25.3	-83	-23.8	-78	-29.6	-97	-52.1	-171

[a] Positive to left of extended runway center line; negative to right of extended runway center line.

TABLE III.- Concluded

(e) $\gamma = -5^{\circ}/-3^{\circ}$; $\delta_f = 30^{\circ}$; F_n/δ = 11 342 N/engine (2550 lbf/engine)

Flight	Run	Meteorological conditions					z at station -								$^a y$ at station -							
		V_C, knots	V_W, knots	T		RH, percent	1		2		3		4		1		2		3		4	
				K	°F		m	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft
R-061	3.4.1	7	6	302.7	85	51	131.4	431	185.0	607	266.1	873	444.4	1458	+11.3	+37	-8.8	-29	-5.7	-19	+17.0	+56
R-061	3.4.2	8	7	302.7	85	51	127.7	419	175.9	577	252.1	827	428.5	1406	+4.2	+14	+10.4	+34	+9.1	+30	+12.2	+40
R-061	3.4.3	7	6	302.7	85	50	127.4	418	172.2	565	245.4	805	434.6	1426	+1.5	+5	+.6	+2	+24.7	+81	+4.8	+16
R-061	3.4.4	8	6	302.7	85	50	128.9	423	179.8	590	252.1	827	432.8	1420	+5.8	+19	+.6	+2	+7.0	+23	+.6	+2
R-061	3.4.5	---	---	302.7	85	50	131.1	430	178.6	586	254.2	834	436.5	1432	+3.7	+12	+14.3	+47	+8.2	+27	+22.3	+73

[a] Positive to left of extended runway center line; negative to right of extended runway center line.

TABLE IV.- SUMMARY LISTING OF $(L_{A,max})_{ref}$ DATA

[Because of instrumentation difficulties, no data are given at station 2 in some cases]

(a) Base-line approach; $\gamma = -3^\circ$; $\delta_f = 40^\circ$;
F_n/δ = 19 793 N/engines (4450 lbf/engine)

Flight	Run	$(L_{A,max})_{ref}$, dB(A), at station -			
		1	2	3	4
R-060	3.1.1	100.1		92.1	88.1
R-060	3.1.2	99.7		91.4	87.3
R-060	3.1.3	99.4		91.6	87.5
R-061	3.1.4	100.3	96.5	91.8	
R-061	3.1.5	99.9	95.9	91.9	86.8
Mean		99.9	96.2	91.7	87.4

(b) $\gamma = -3^\circ$; δ_f □ 30°; F_n/δ □ 17 792 N/engine
(4000 lbf/engine)

Flight	Run	$(L_{A,max})_{ref}$, dB(A), at station -		
		1	3	4
R-060	3.2.1	99.1	90.9	85.5
R-060	3.2.2	98.3	91.1	85.9
R-061	3.2.3	98.5	91.8	86.0
R-060	3.2.4	99.1	89.8	
Mean		98.8	90.9	85.8

TABLE IV.- Continued

(c) $\gamma = -4^{\circ}$; $\delta_f = 30^{\circ}$; F_n/δ = 11 342 N/engine (2550 lbf/engine)

Flight	Run	$(L_{A,max})_{ref}$, dB(A), at station -		
		1	3	4
R-061	3.3.1	94.4	85.1	80.7
R-061	3.3.2	93.2	85.5	79.3
R-061	3.3.3	94.0	84.9	79.4
R-061	3.3.4	93.4	85.2	79.8
R-061	3.3.5	93.9	85.3	78.9
Mean		93.7	85.2	79.6

(d) $\gamma = -5^{\circ}$; $\delta_f = 30^{\circ}$; F_n/δ = 11 342 N/engine (2550 lbf/engine)

Flight	Run	$(L_{A,max})_{ref}$, dB(A), at station -		
		1	3	4
R-050	1.1	89.4	83.4	75.7
R-050	1.2	88.7	81.4	76.7
R-050	1.3	86.8	79.9	76.8
R-050	1.4	87.2	81.6	75.9
R-050	1.5	89.0	82.2	78.9
R-050	1.6	89.2		77.1
R-050	1.7	88.3	82.1	78.3
R-050	1.8	88.3	80.9	78.1
Mean . . .		88.4	81.6	77.2

TABLE IV.- Concluded

(e) $\gamma = -5^{\circ}/-3^{\circ}$; $\delta_f = 30^{\circ}$; F_n/δ = 11 342 N/engine (2550 lbf/engine)

Flight	Run	$(L_{A,max})_{ref}$, dB(A), at station -			
		1	2	3	4
R-061	3.4.1	97.3	91.8	87.2	79.4
R-061	3.4.2	97.3	92.8	86.5	
R-061	3.4.3	96.9	92.5	87.6	81.0
R-061	3.4.4	96.9	92.2	87.8	80.4
R-061	3.4.5	97.0	91.9	87.4	78.8
Mean		97.1	92.2	87.3	79.9

TABLE V.- CONFIDENCE INTERVALS FOR $(L_{A,max})_{ref}$

(a) Base-line approach; $\gamma = -3^{\circ}$; $\delta_f = 40^{\circ}$; F_n/δ = 19 793 N/engine (4450 lbf/engine)

Station	Sample size	Measured mean (table IV)	Sample standard deviation, dB(A)	90-percent confidence interval, dB(A)
1	5	99.9	±0.35	±0.33
2	2	96.2	±.42	±1.9
3	5	91.7	±.27	±.26
4	4	87.4	±.54	±.63

(b) $\gamma = -3^{\circ}$; $\delta_f = 30^{\circ}$; F_n/δ = 17 792 N/engine (4000 lbf/engine)

Station	Sample size	Measured mean (table IV)	Sample standard deviation, dB(A)	90-percent confidence interval, dB(A)
1	4	98.8	±0.41	±0.49
3	4	90.9	±.83	±.97
4	3	85.8	±.26	±.45

(c) $\gamma = -4^{\circ}$; $\delta_f = 30^{\circ}$; F_n/δ = 11 342 N/engine (2550 lbf/engine)

Station	Sample size	Measured mean (table IV)	Sample standard deviation, dB(A)	90-percent confidence interval, dB(A)
1	5	93.7	±0.50	±0.50
3	5	85.2	±.22	±.21
4	5	79.6	±.68	±.65

TABLE V.- Concluded

(d) $\gamma = -5^\circ$; $\delta_f = 30^\circ$; F_n/δ = 11 342 N/engine
(2550 lbf/engine)

Station	Sample size	Measured mean (table IV)	Sample standard deviation, dB(A)	90-percent confidence interval, dB(A)
1	8	88.4	±0.93	±0.62
3	7	81.6	±1.1	±.81
4	8	77.2	±1.2	±.77

(e) $\gamma = -5^\circ/-3^\circ$; $\delta_f = 30^\circ$; F_n/δ = 11 342 N/engine
(2550 lbf/engine)

Station	Sample size	Measured mean (table IV)	Sample standard deviation, dB(A)	90-percent confidence interval, dB(A)
1	5	97.1	±0.20	±0.20
2	5	92.2	±.42	±.40
3	5	87.3	±.50	±.48
4	4	79.9	±.99	±1.2

TABLE VI.- SUMMARY LISTING OF EPNL_{ref} DATA

[Data are referenced to 1.85 km (1 n. mi.) from runway threshold]

(a) Base-line approach; $\gamma = -3^\circ$; $\delta_f = 40^\circ$; $F_n/\delta = 19\ 793$ N/engine (4450 lbf/engine)

Flight	Run	EPNL_{ref}, EPNdB
R-060	3.1.1	109.3
R-060	3.1.2	109.2
R-060	3.1.3	109.6
R-061	3.1.4	109.7
R-061	3.1.5	109.5
Mean		109.5

(b) $\gamma = -3^\circ$; $\delta_f = 30^\circ$; $F_n/\delta = 17\ 792$ N/engine (4000 lbf/engine)

Flight	Run	EPNL_{ref}, EPNdB
R-060	3.2.1	108.4
R-060	3.2.2	108.4
R-061	3.2.3	108.9
R-060	3.2.4	108.3
Mean		108.5

(c) $\gamma = -4^\circ$; $\delta_f = 30^\circ$; $F_n/\delta = 11\ 342$ N/engine (2550 lbf/engine)

Flight	Run	EPNL_{ref}, EPNdB
R-061	3.3.1	105.8
R-061	3.3.2	103.6
R-061	3.3.3	103.7
R-061	3.3.4	103.7
R-061	3.3.5	104.2
Mean		104.2

TABLE VI.- Concluded

(d) $\gamma = -5^\circ$; $\delta_f = 30^\circ$; F_n/δ = 11 342 N/engine
(2550 lbf/engine)

Flight	Run	$EPNL_{ref}$, EPNdB
R-050	1.1	100.9
R-050	1.2	101.8
R-050	1.3	100.1
R-050	1.4	99.8
R-050	1.5	101.1
R-050	1.6	100.9
R-050	1.7	100.2
R-050	1.8	99.8
Mean		100.6

(e) $\gamma = -5^\circ/-3^\circ$; $\delta_f = 30^\circ$; F_n/δ = 11 342 N/engine
(2550 lbf/engine)

Flight	Run	$EPNL_{ref}$, EPNdB
R-061	3.4.1	106.1
R-061	3.4.2	107.6
R-061	3.4.3	107.0
R-061	3.4.4	106.8
R-061	3.4.5	106.5
Mean		106.8

TABLE VII.- CONFIDENCE INTERVALS FOR $EPNL_{ref}$

γ, deg	δ_f, deg	F_n/δ		Mean value of $EPNL_{ref}$, EPNdB	Standard deviation of $EPNL_{ref}$, EPNdB	Sample size	90-percent confidence interval for $EPNL_{ref}$, EPNdB
		N/engine	lbf/engine				
-3	40	19 793	4450	109.5	±0.21	5	±0.20
-3	30	17 792	4000	108.5	±.27	4	±.32
-4	30	11 342	2550	104.2	±.92	5	±.88
-5	30	11 342	2550	100.6	±.71	8	±.48
-5/-3	30	11 342	2550	106.8	±.56	5	±.54

TABLE VIII.- COMPARISON OF NTA VALUES WITH FLIGHT MEASUREMENTS

(a) F_n/δ = 19 793 N/engine (4450 lbf/engine)

z		$(L_{A,max})_{ref}$	
m	ft	Measured	NTA
121.0	397	99.9	99.6
160.0	525	96.2	96.2
226.5	743	91.6	91.6
336.5	1104	87.4	86.2

(b) F_n/δ = 17 792 N/engine (4000 lbf/engine)

z		$(L_{A,max})_{ref}$	
m	ft	Measured	NTA
121.0	397	98.8	98.8
226.5	743	90.9	90.7
336.5	1104	85.8	85.4

(c) F_n/δ = 11 342 N/engine (2550 lbf/engine)

z		$(L_{A,max})_{ref}$	
m	ft	Measured	NTA
121.0	397	97.1	96.5
160.0	525	92.2	93.1
161.5	530	93.7	93.1
202.4	664	88.4	89.6
235.0	771	87.3	87.6
302.1	991	85.2	84.1
378.0	1240	81.6	81.1
418.8	1374	79.9	79.9
448.7	1472	79.6	79.1
561.8	1843	77.2	76.1

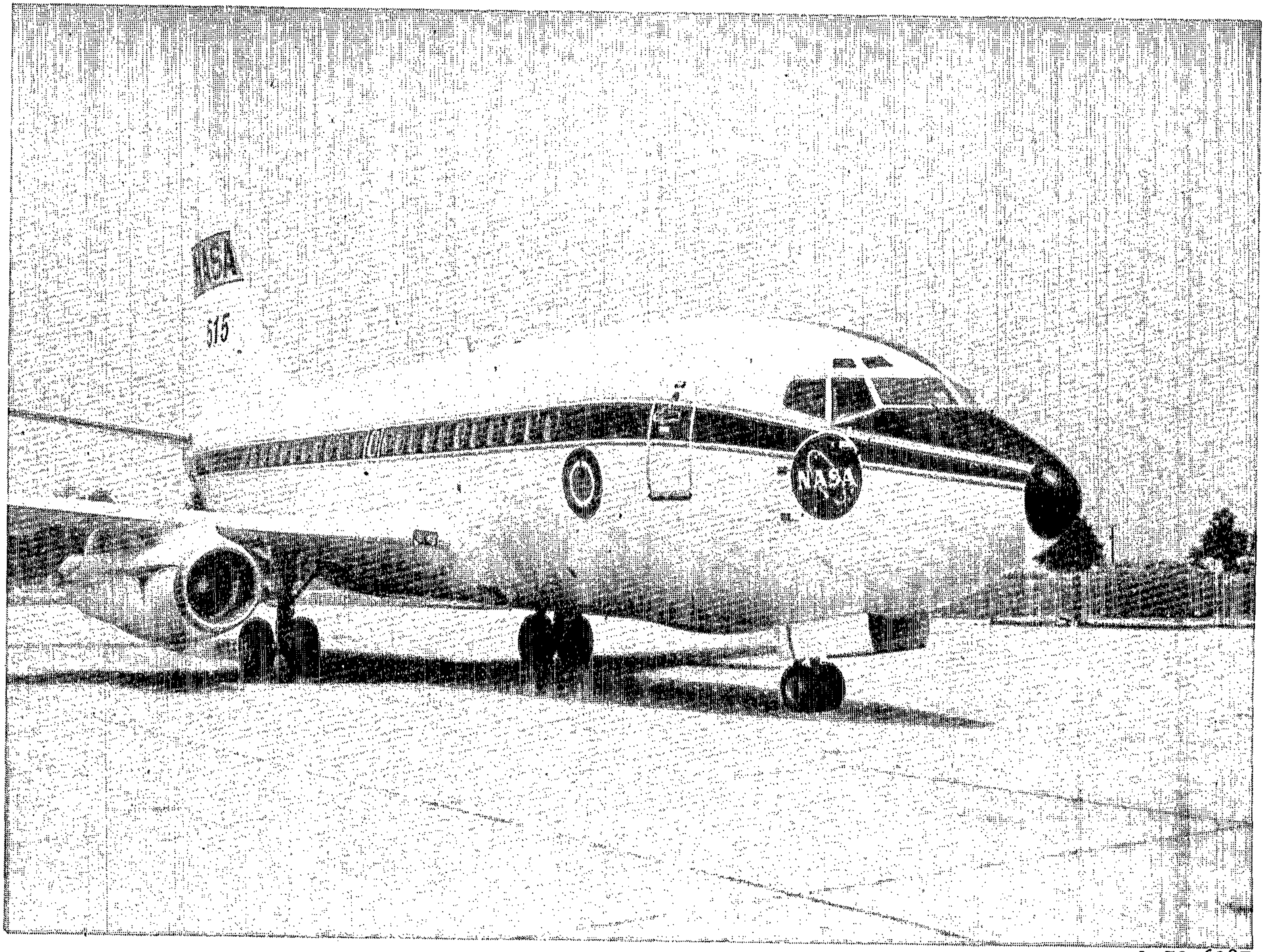

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Figure 1.- Photograph of test aircraft.

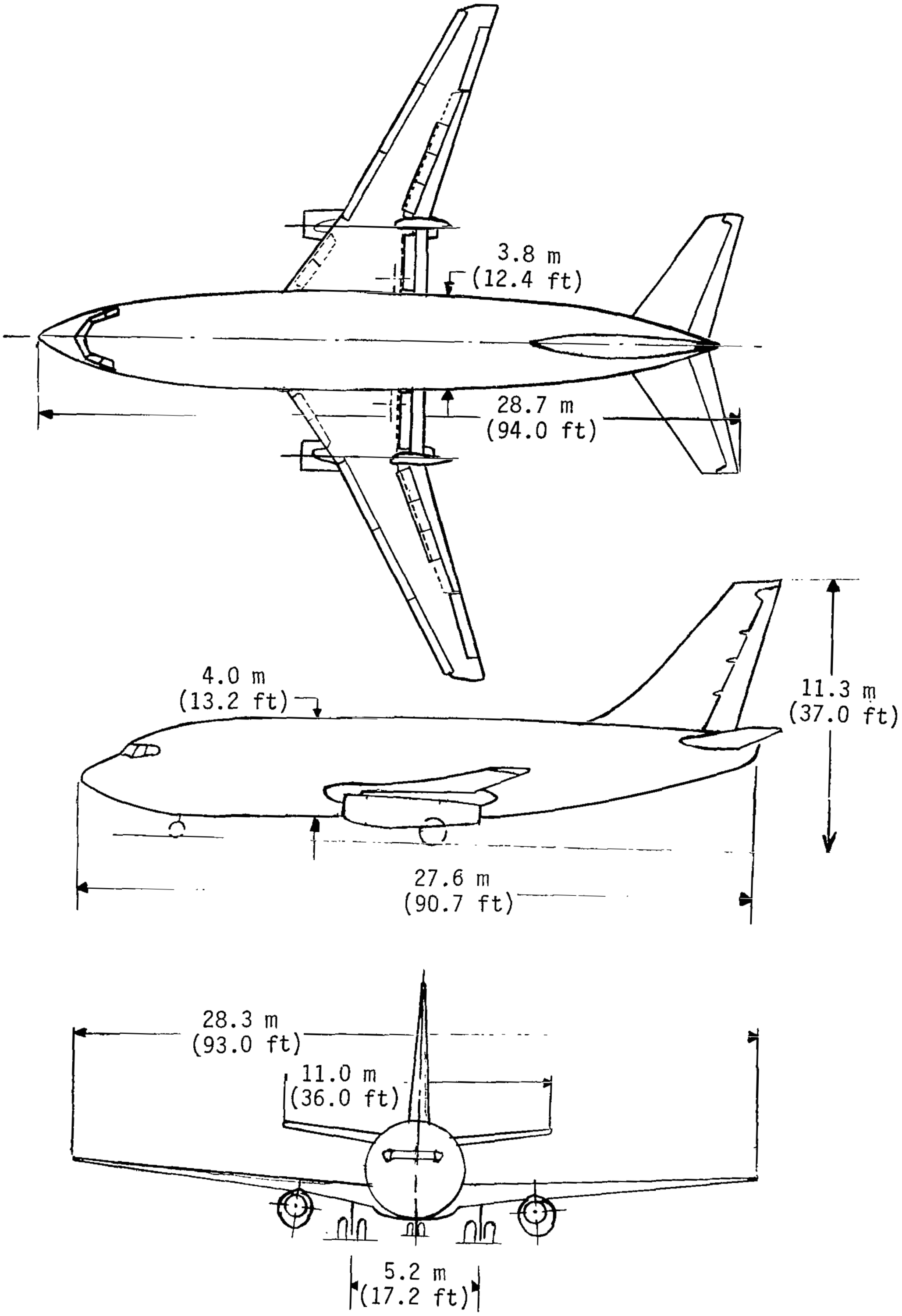


Figure 2.- Dimensions of test aircraft.

Location	Distance from threshold, km (n. mi.)
1	2.01 (1.08)
2	2.75 (1.48)
3	4.02 (2.17)
4	6.12 (3.30)

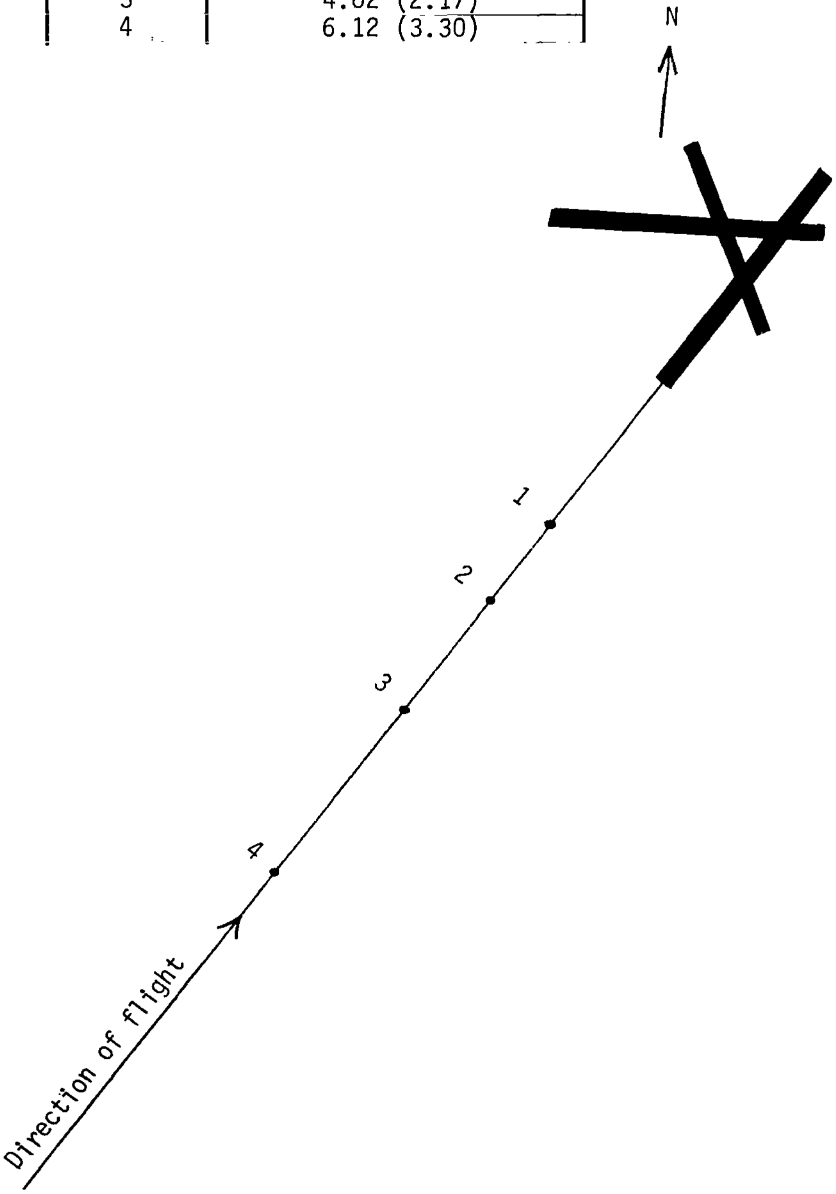


Figure 3.- Microphone locations.

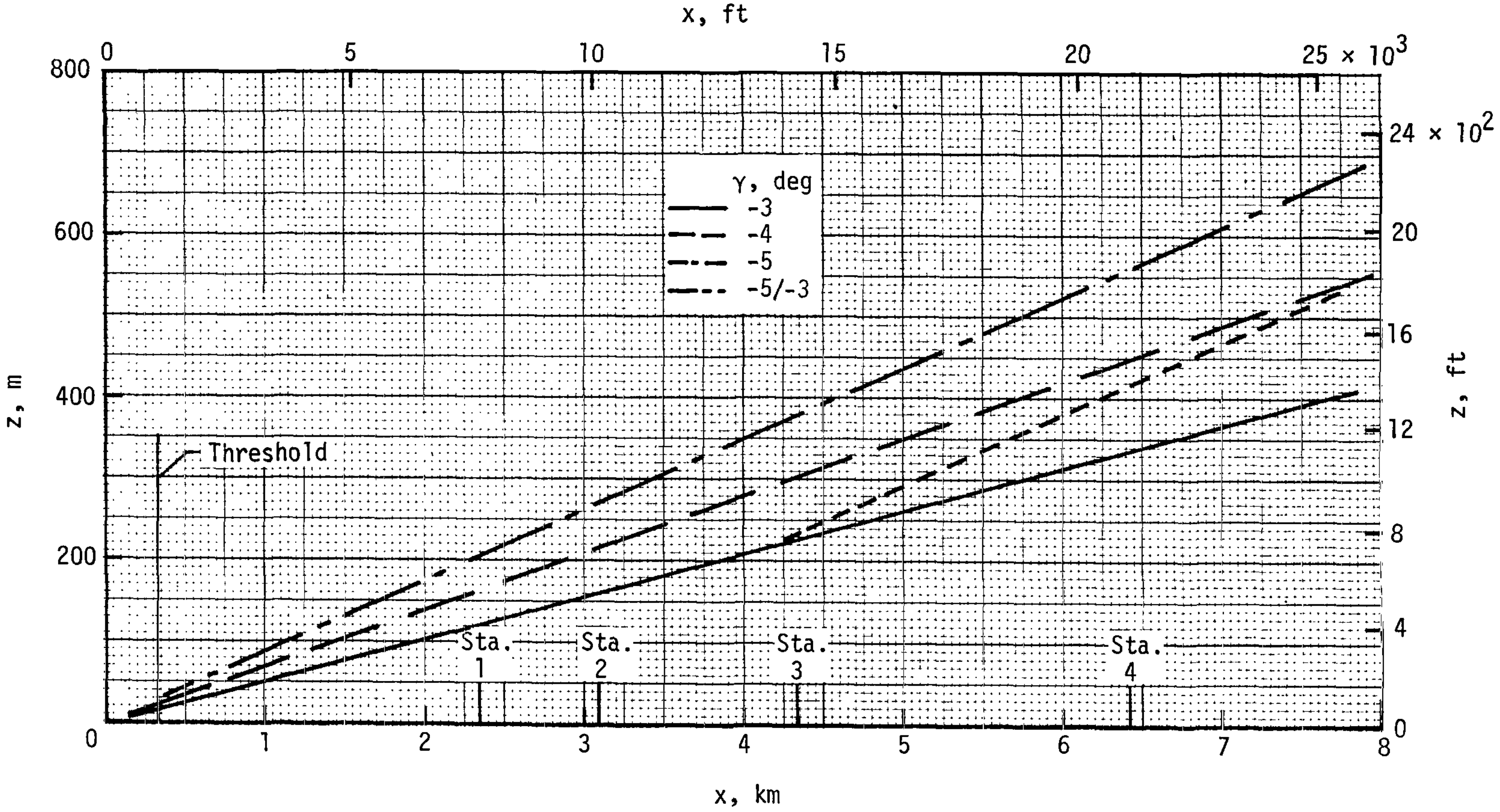


Figure 4.- Flight profiles.

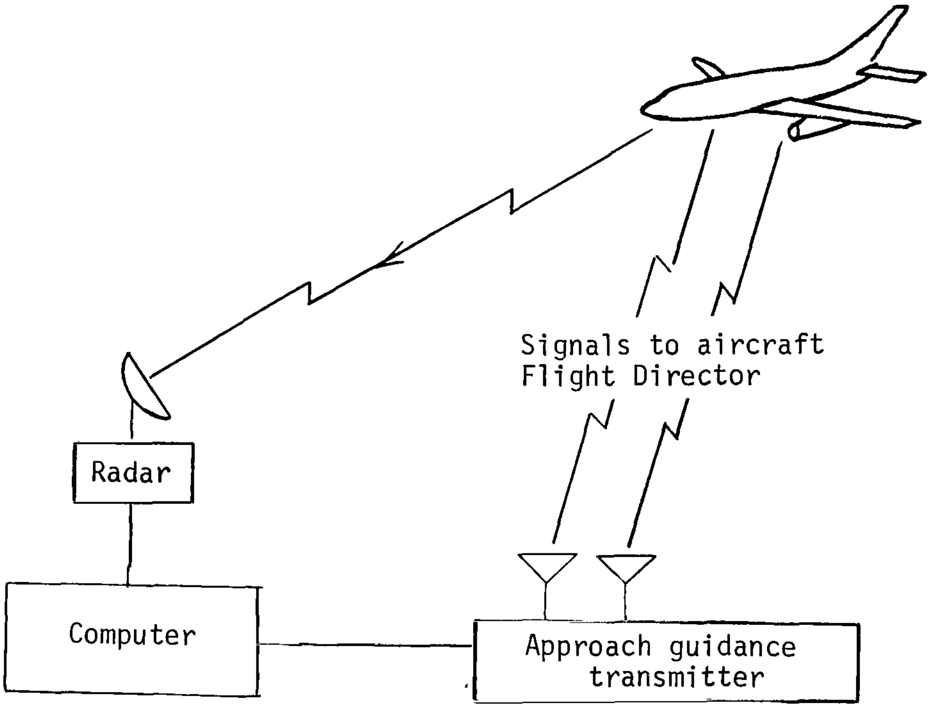


Figure 5.- Approach guidance system.

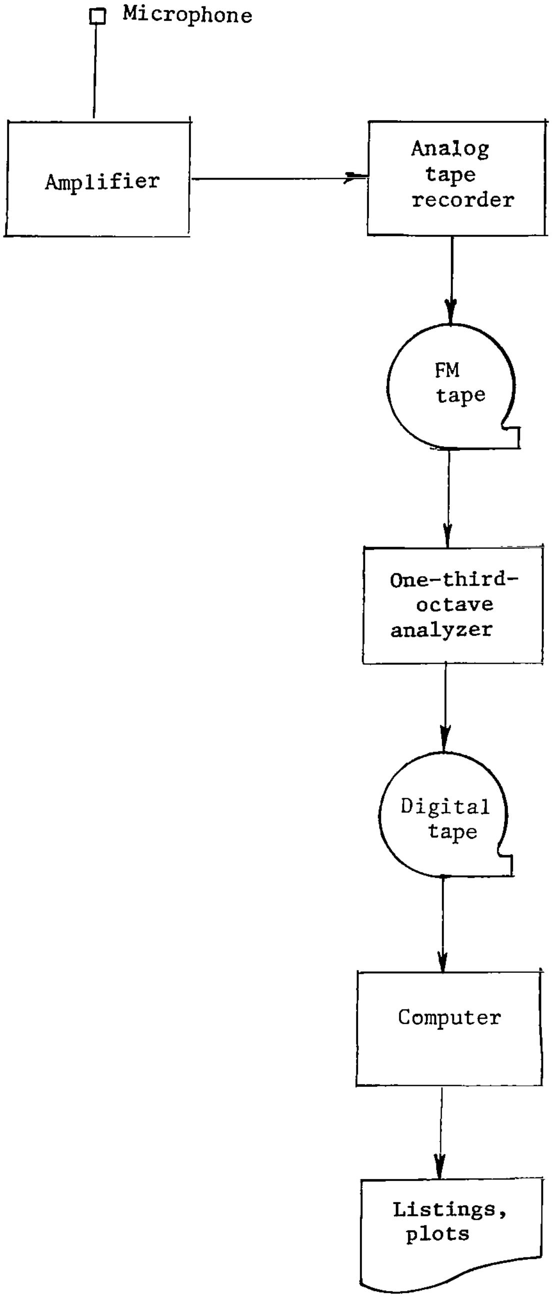
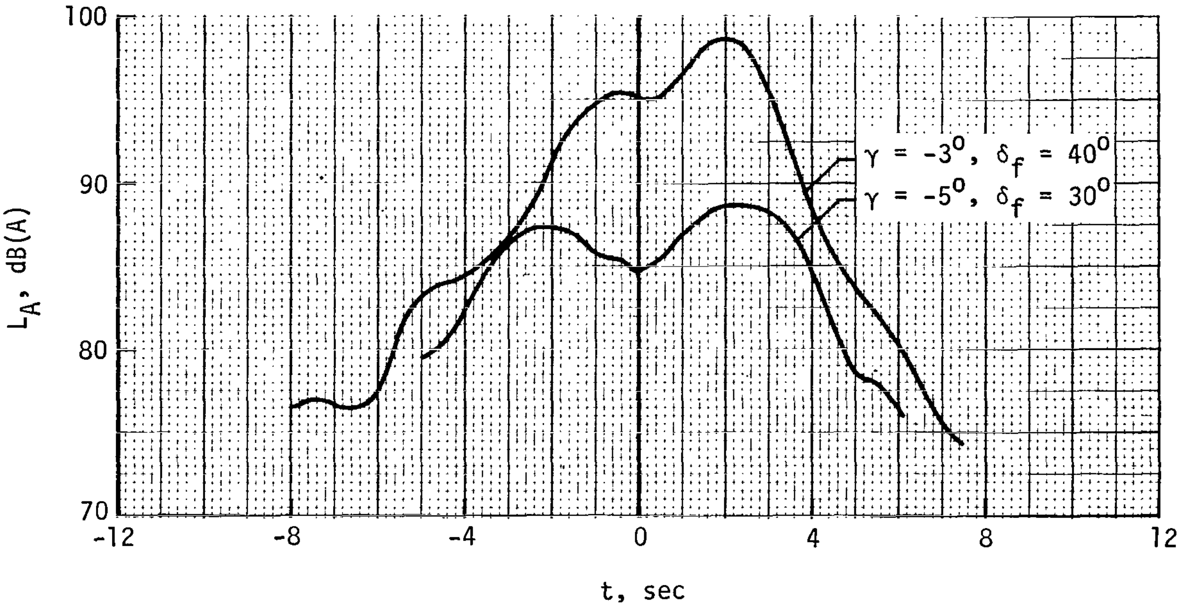
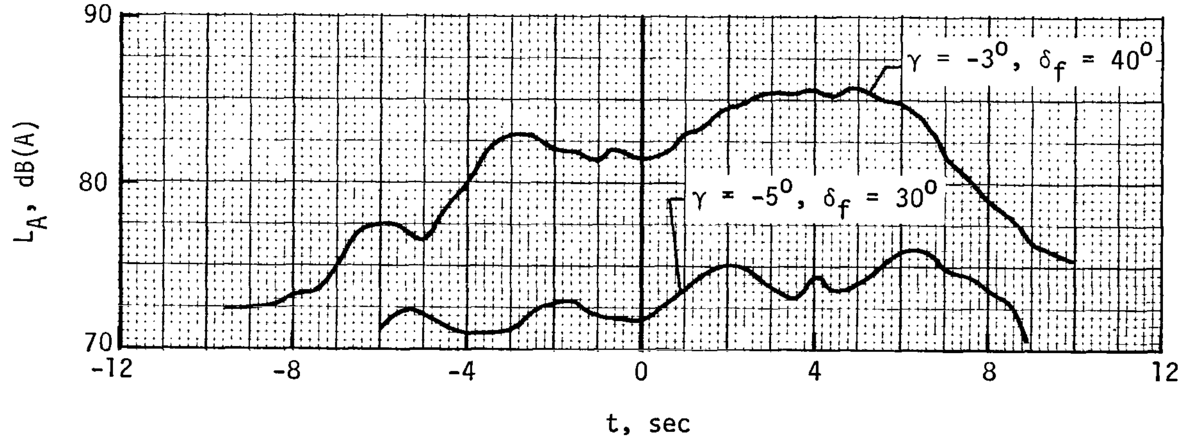


Figure 6.- Data reduction procedure.

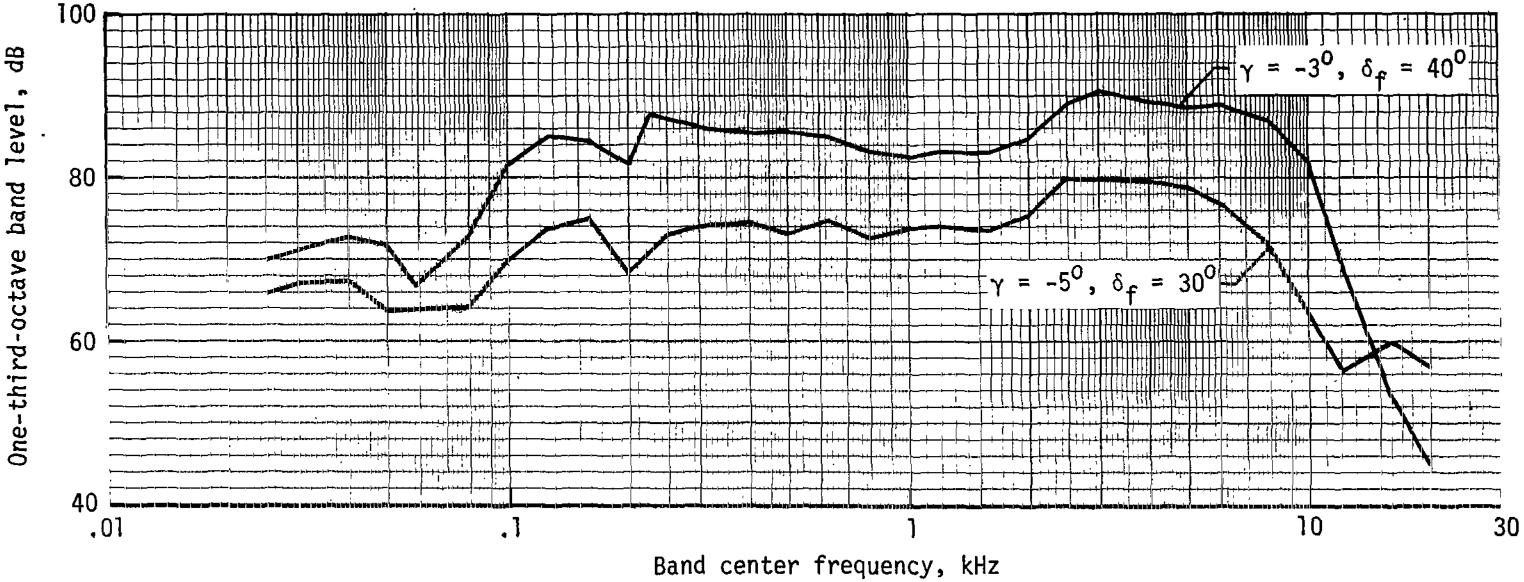


(a) Station 1.

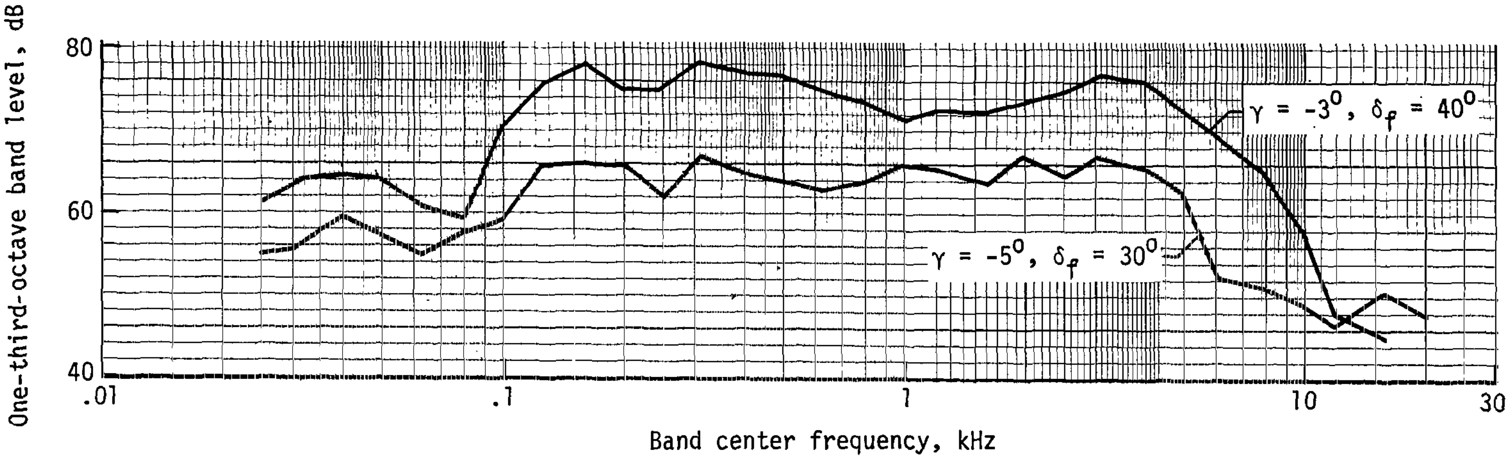


(b) Station 4.

Figure 7.- Typical L_A time histories measured at stations 1 and 4.



(a) Station 1.



(b) Station 4.

Figure 8.- Typical noise spectra measured at stations 1 and 4.

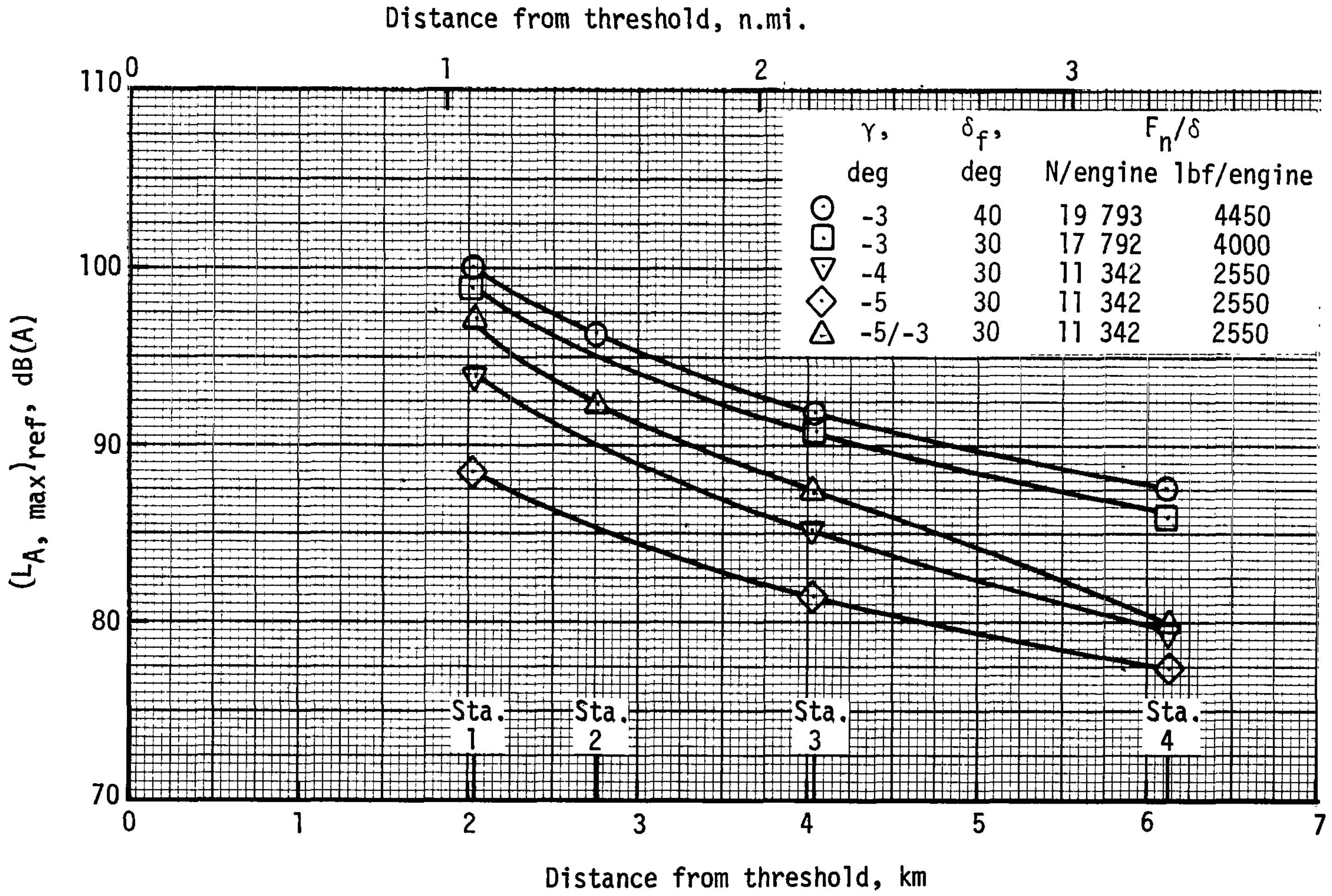


Figure 9.- Maximum noise recorded at stations located various distances from threshold.

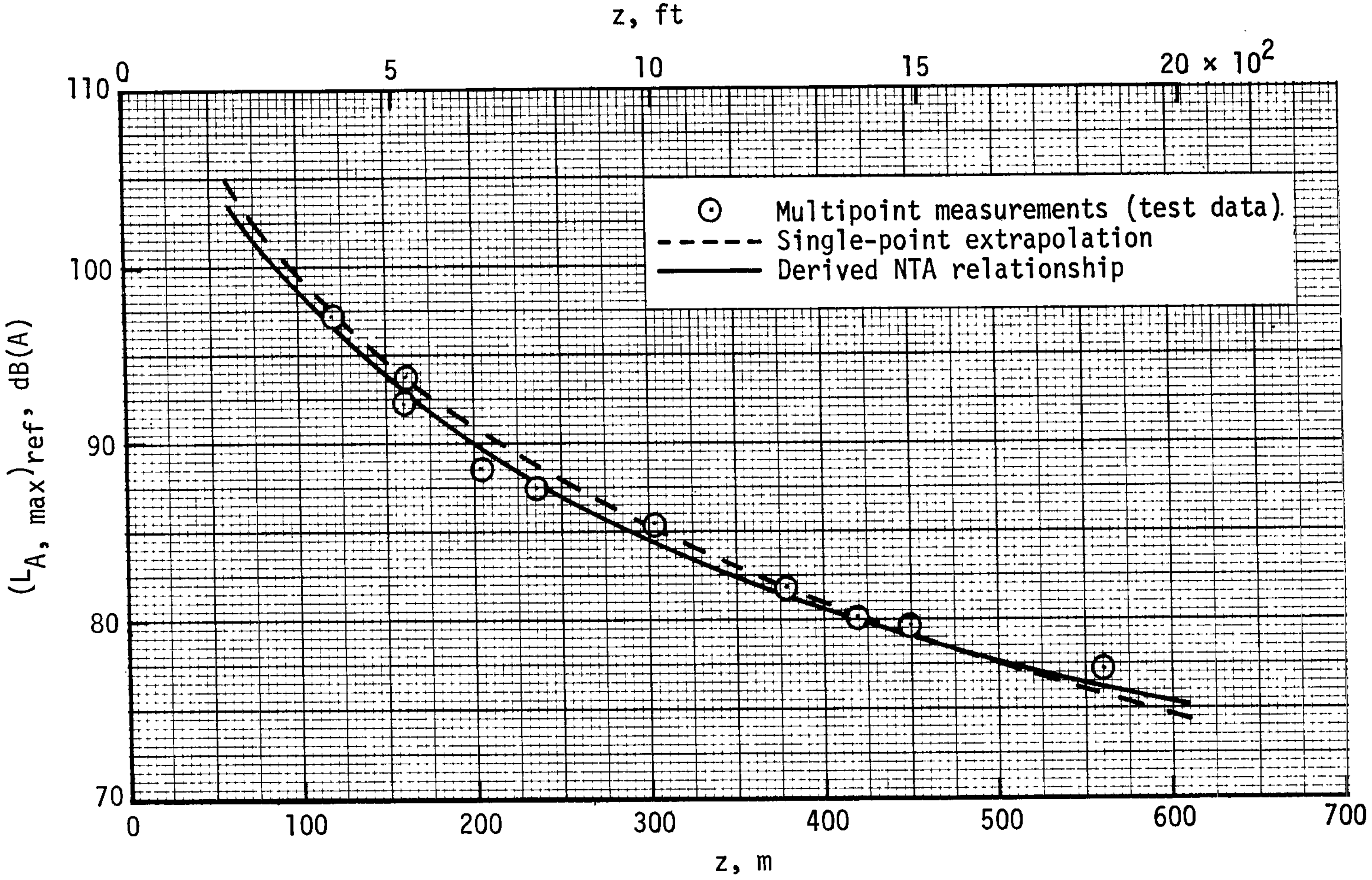


Figure 10.- Variation of $(L_{A,max})_{ref}$ with vertical distance for F_n/δ = 11 342 N/engine (2550 lbf/engine), determined from multipoint measurements and single-point measurement extrapolation.

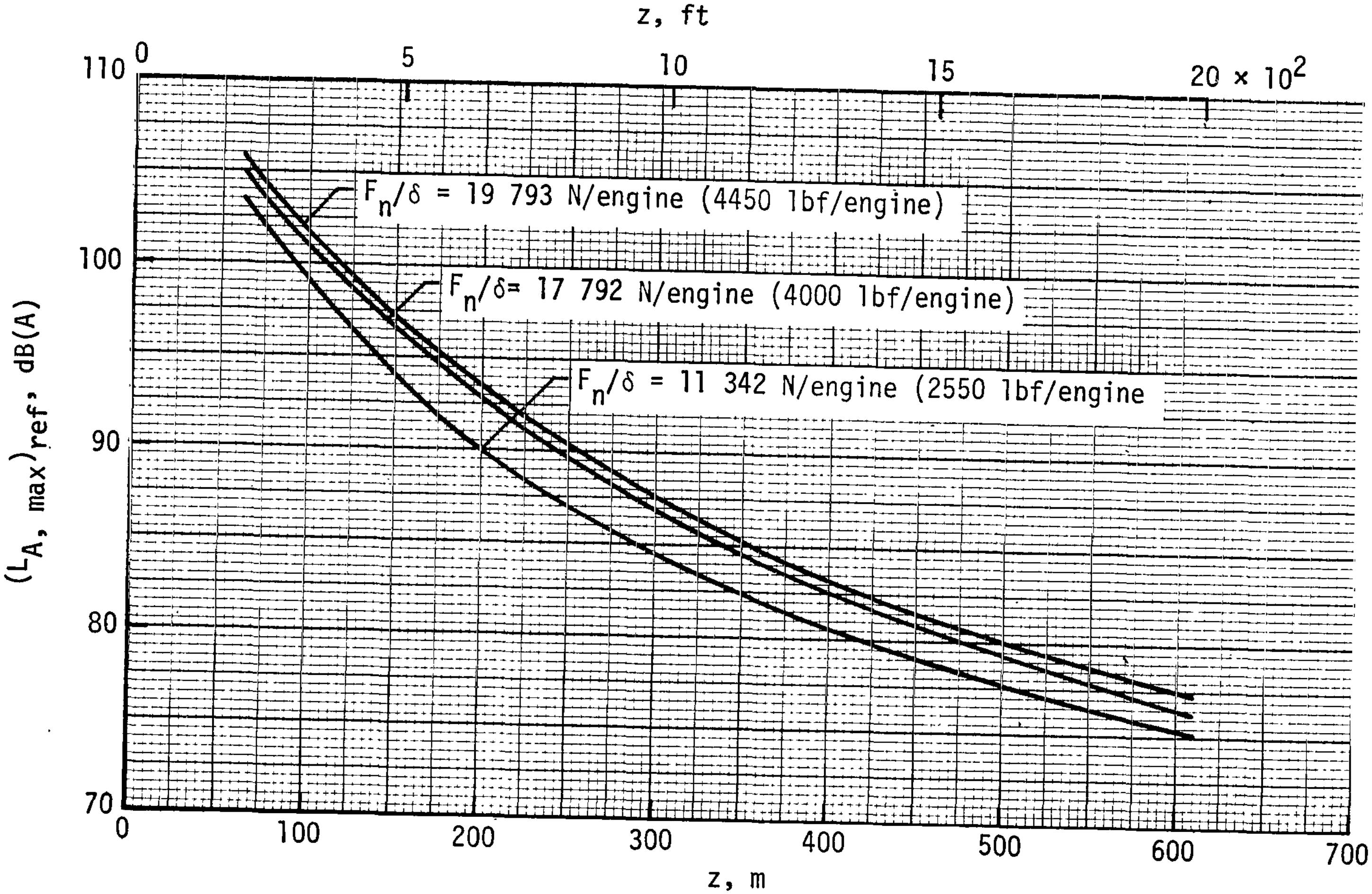


Figure 11.- Variation of $(L_{A,\max})_{\mathrm{ref}}$ with vertical distance for three thrust levels representative of current and advanced approach techniques.

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