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ACOUSTIC ATTENUATION DETERMINED EXPERIMENTALLY DURING ENGINE GROUND TESTS OF THE XB-70 AIRPLANE AND COMPARISON WITH PREDICTIONS

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16. Abstract

Acoustic data obtained during ground runs of the XB-70 airplane enabled the attenuation of sound to be determined for ground-to-ground propagation over distances of 500 feet (152 meters) and 1000 feet (305 meters) for one set of atmospheric conditions. The considerable scatter in the experimentally determined attenuations seemed to be associated with variations in the wind parameters. For downwind propagation, reducing the predicted acoustic-attenuation values obtained from the Society of Automotive Engineers, Inc., ARP 866 by 50 percent for octave bands above 1000 hertz resulted in good agreement between the present experimentally determined and predicted values. Previous investigators recommended the modification to the predicted attenuation values and obtained similar results. Some unexplained differences remain between the experimentally determined and modified predicted attenuation values, indicating that additional research is required.

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INTRODUCTION

One problem in predicting the noise environment in communities adjacent to airports is the variation in acoustic attenuation for different weather conditions. Previous investigators (refs. 1 and 2) theoretically predicted and experimentally determined the acoustic attenuation for some atmospheric conditions. Suggested acoustic-attenuation values for the wide range of atmospheric temperature and relative humidities presented in reference 3 were based upon previous theoretical predictions and experimental investigations. However, these suggested values have not always agreed with results obtained from field measurements (ref. 4).

The XB-70 program provided an opportunity to investigate acoustic attenuation by utilizing acoustic data obtained at three different distances from the airplane during engine tests on the ground. The variations in ambient temperature and humidity during these tests were less than would generally be encountered at an airport over a period of a few hours. Sufficient data were obtained to compute the mean acoustic attenuation for various octave bands and the standard deviation of the attenuations from the mean. This report presents the results of this investigation, which was conducted at Edwards Air Force Base, Calif., in December 1967.

DESCRIPTION OF THE TEST AIRPLANE

The XB-70 airplane (fig. 1) used as the noise source in these tests was a large, multiengine airplane built by North American Aviation, Inc., for the U. S. Air Force. The airplane had six YJ93-GE-3 afterburning turbojet engines installed side by side on approximately 5-foot (1.5-meter) centers in the aft part of the fuselage. The engines were identified as number 1 to number 6, beginning at the outboard engine on the pilot's left. Each engine had an afterburner with a variable exhaust nozzle which allowed the nozzle to be convergent or convergent-divergent. The centerline of the exit nozzle was approximately 11 feet (3.4 meters) above the ground, and the nozzle diameter varied from 2.8 feet (0.8 meter) to 3.3 feet (1.0 meter) during the tests. Military power was the maximum power without afterburner. In the five stages of afterburner, AB-1 was the minimum power setting, and AB-5 was the maximum power setting.

Supersonic flow occurred in the inner nozzle (minimum throat area of the convergent-divergent nozzle) at approximately 93-percent rpm for the ambient conditions at the time of the tests. The ratio of inner nozzle total pressure to ambient pressure at this rpm was calculated to be 1.86.

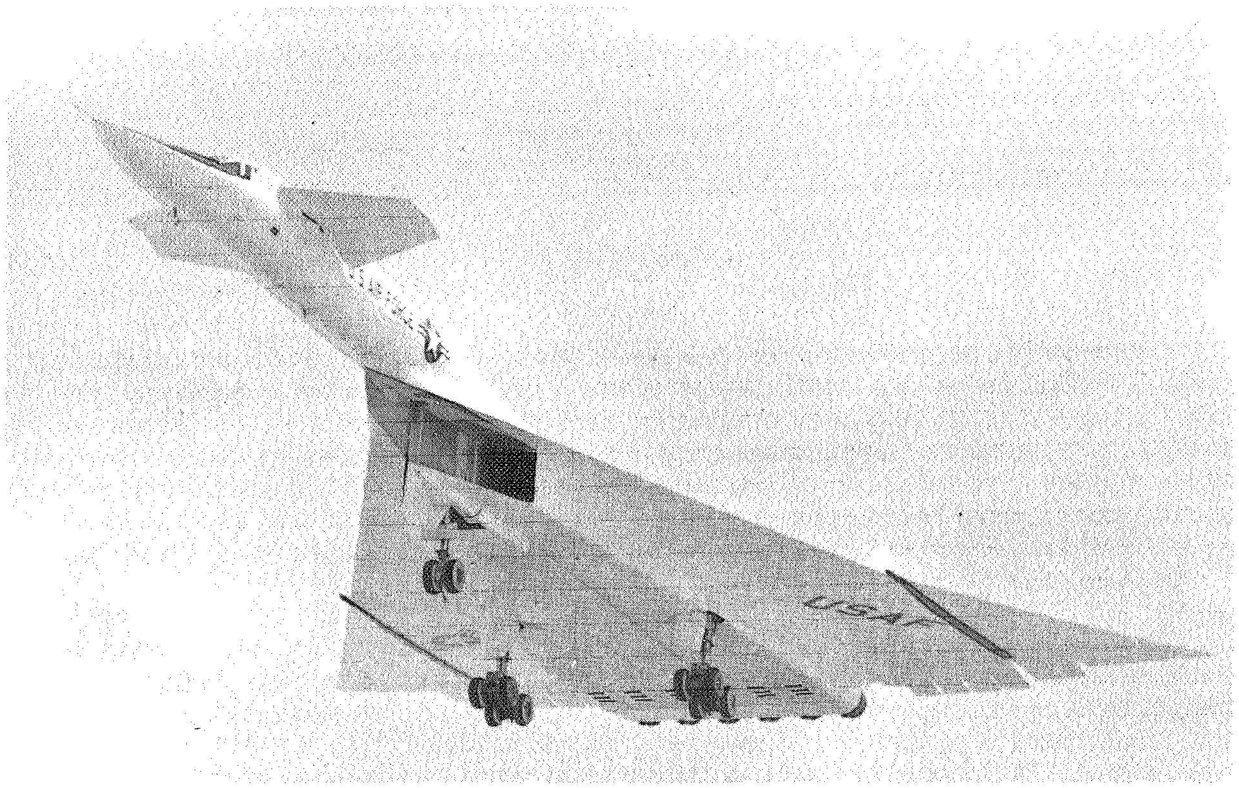


Figure 1. XB-70 airplane.

INSTRUMENTATION

Data Acquisition

Microphones of the condenser type were used for all acoustic measurements during the tests. The electrically conditioned microphone signal was transmitted by land lines to recording stations where it was recorded on magnetic-tape recorders of the instrumentation type. The microphones were positioned along circular arcs at radial distances of 500 feet (152 meters), 1000 feet (305 meters), and 1500 feet (457 meters) from the intersection of the airplane centerline and the plane of the exhaust nozzles (fig. 2). Microphones were positioned at 10° intervals in directions of 90° to 140° from the airplane heading on the 500-foot (152-meter) and the 1000-foot (305-meter) radius arcs, and at 120°, 130°, and 140° directions on the 1500-foot (457-meter) radius arc. All microphones were 54 inches (1.35 meters) above the ground. Because the terrain sloped slightly away from the test stand, the centerline of the XB-70 engines was 12.5 feet (3.76 meters) above the microphones, resulting in an angle of propagation of approximately 2° below the horizon for the microphones nearest the airplane. The data-acquisition system is described in detail in reference 5.

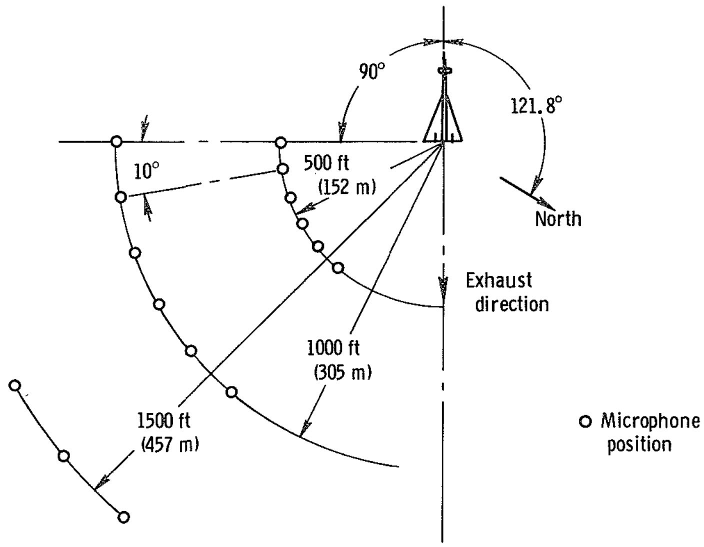


Figure 2. Microphone positions for XB-70 noise tests.

Weather data were obtained at two different locations during these tests. Relative humidity, temperature, and ambient-pressure measurements were obtained from the U.S. Air Force weather station located approximately 1 mile (1600 meters) from the test site. Measured at the test site were wind velocity, direction, and temperature at heights of 6 feet (1.8 meters) and 50 feet (15.2 meters) above the ground.

Data Reduction

The data from the magnetic tape were analyzed by using preferred octave-band filters. The octave-band sound-pressure level was determined for each octave band and each microphone during each test run. An averaging time of 10 seconds was used for all data reduction. All data were corrected for data-acquisition and data-reduction system frequency response and for background noise. Data are considered to be accurate to ±1 decibel. A more complete description of the electronic data-reduction system and the accuracy is included in reference 5.

TEST CONDITIONS

Atmospheric conditions varied slightly during the tests, as shown in the time histories of the measured atmospheric parameters (fig. 3). A time history of the temperature at the test site at a height of 50 feet (15.2 meters) above the ground is not presented because it was within 1° F (0.6° C) of the temperature measured at the test site at a height of 6 feet (1.8 meters) above the ground. The airplane heading was 238.2° (fig. 3), and the surface winds, coming primarily from the northwest, tended to carry the engine noise to the microphones. The relative humidity decreased approximately 10 percent during the tests, primarily because of the increase in temperature of 4° F (2.2° C) so that the amount of water vapor in the air was nearly constant.

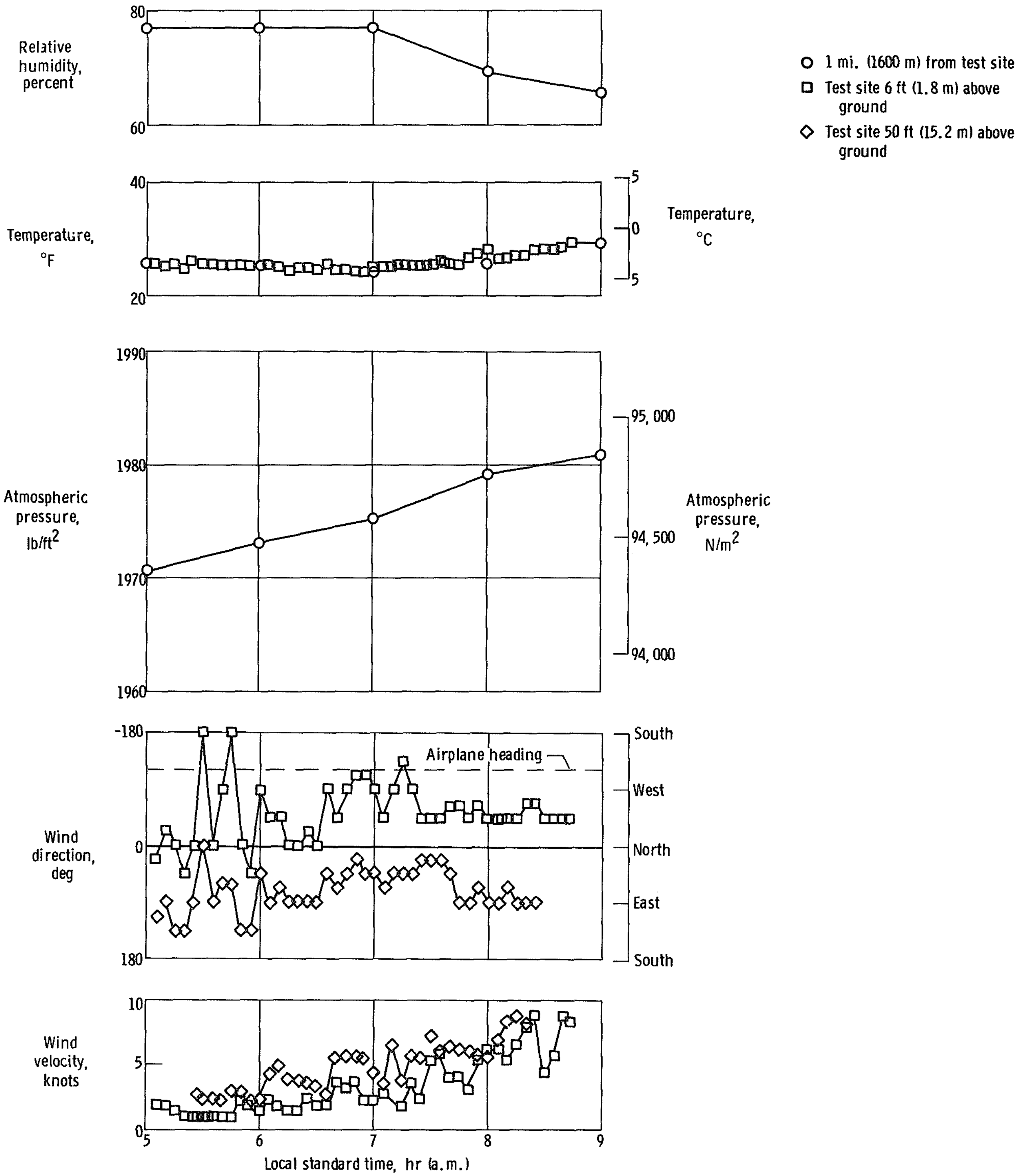


Figure 3. Atmospheric conditions during tests.

The local time of day for each test run, the engine(s) operating, and the engine operating condition are presented in table 1. The table shows the intermixing of engine operating conditions, wide range of thrust, engine spacing, and number of engines operating. The runs were consecutive, with the time between runs just that needed to set the proper engine operating conditions for the next run.

TABLE 1. ENGINE OPERATING CONDITIONS FOR EACH TEST RUN

Run no.	Local time of day, a. m.	Specific engine(s) in operation	Engine operating conditions	Total thrust, lb	Total thrust, N
1	5:08	1	Idle	1,100	4,893
2	5:12	1	97 percent rpm	15,790	70,237
3	5:14	1	Military	19,620	87,741
4	5:16	1	AB-4	24,635	109,582
5	5:17	1	AB-5	26,785	119,146
6	5:18	1	AB-2	22,785	101,353
7	5:20	1	100 percent rpm	18,745	83,382
8	5:22	1	90 percent rpm	10,215	45,439
9	5:25	1	80 percent rpm	4,920	21,885
10	5:26	1	75 percent rpm	3,340	14,857
11	5:33	1,6	Idle	2,230	9,920
12	5:36	1,6	80 percent rpm	9,795	43,570
13	5:39	1,6	90 percent rpm	21,110	93,902
14	5:41	1,6	97 percent rpm	32,690	145,412
15	5:44	1,6	Military	40,200	178,818
16	5:46	1,6	AB-1	44,110	196,211
17	5:47	1,6	AB-5	55,110	245,141
18	5:53	1,4	Idle	1,930	8,585
19	5:56	1,4	80 percent rpm	9,630	42,836
20	5:58	1,4	90 percent rpm	20,365	90,588
21	6:01	1,4	97 percent rpm	31,130	138,473
22	6:03	1,4	Military	39,065	173,770
23	6:05	1,4	AB-1	43,425	193,164
24	6:06	1,4	AB-5	55,000	244,652
25	6:27	1,2,3,4,5,6	Idle	7,188	31,974
26	6:30	1,2,3,4,5,6	70 percent rpm	13,681	60,856
27	6:34	1,2,3,4,5,6	80 percent rpm	27,874	123,980
28	6:37	1,2,3,4,5,6	85 percent rpm	39,520	175,794
29	6:39	1,2,3,4,5,6	90 percent rpm	55,432	246,574
30	6:42	1,2,3,4,5,6	97 percent rpm	81,524	362,637
31	6:45	1,2,3,4,5,6	Military	101,371	450,921
32	6:46	1,2,3,4,5,6	AB-1	113,124	503,200
33	6:48	1,2,3,4,5,6	AB-2	118,329	526,353
34	6:50	1,2,3,4,5,6	AB-3	122,840	546,419
35	6:52	1,2,3,4,5,6	AB-4	129,640	576,667
36	6:53	1,2,3,4,5,6	AB-5	138,720	617,057
37	7:00	1,2,3	Idle	3,375	15,013
38	7:02	1,2,3	80 percent rpm	13,320	59,250
39	7:05	1,2,3	90 percent rpm	26,840	119,390
40	7:07	1,2,3	97 percent rpm	38,305	170,039
41	7:09	1,2,3	Military	50,460	224,457
42	7:11	1,2,3	AB-1	63,820	283,885
43	7:13	1,2,3	AB-5	70,825	315,045
44	7:22	1,2	Idle	2,255	10,031
45	7:27	1,2	80 percent rpm	9,025	40,145
46	7:29	1,2	90 percent rpm	18,695	83,159
47	7:32	1,2	97 percent rpm	28,670	127,530
48	7:34	1,2	Military	37,375	166,252
49	7:36	1,2	AB-1	41,165	183,111
50	7:37	1,2	AB-5	51,710	230,017
51	7:50	1,2,5,6	Idle	4,560	20,284
52	7:53	1,2,5,6	80 percent rpm	18,615	82,804
53	7:55	1,2,5,6	90 percent rpm	39,100	173,925
54	7:58	1,2,5,6	97 percent rpm	58,540	260,399
55	8:00	1,2,5,6	Military	75,855	337,420
56	8:03	1,2,5,6	AB-1	84,170	374,407
57	8:05	1,2,5,6	AB-5	105,025	467,174
58	8:14	2	Military	17,965	79,912
59	8:19	2	AB-5	27,825	123,772
60	8:20	2	AB-3	24,335	108,247
61	8:21	2	Military	19,920	88,609
62	8:24	2	Idle	1,135	5,049
63	8:34	1,2	Military	36,925	164,251
64	8:36	1,2	AB-1	41,045	182,577
65	8:37	1,2	AB-2	42,640	189,672
66	8:38	1,2	AB-3	44,050	195,944
67	8:40	1,2	AB-4	46,795	208,154
68	8:42	1,2	AB-5	51,660	229,795

RESULTS AND DISCUSSION

Problems in Determining Attenuation

Measurements made in the field include attenuation due to spherical spreading, ground attenuation, effect of wind on the propagation of sound, and atmospheric attenuation. Attenuation data obtained in the field generally have considerable scatter, as was shown in reference 4.

Attenuation due to spherical spreading does not contribute to the scatter in the data because, by definition, the expansion of the sound energy to cover the spherical surface results in an attenuation of 6 decibels for each doubling of the distance from the source. The ground attenuation was considered to be negligible, because the measurements were made over a hard, flat surface which was free of vegetation.

Although the amount of acoustic attenuation changes with wind velocity and direction, the attenuation variation during these tests was expected to be small. Atmospheric attenuation varies also with temperature and relative humidity and is different for different frequencies of the measured sound. In this report, predicted attenuation is the far-field atmospheric attenuation obtained from reference 3 to which the attenuation due to spherical spreading has been added. The predicted attenuations are limited to the extremes in relative humidity and temperature encountered during the tests.

Because there is usually scatter in acoustic measurements obtained in the field, mean attenuation values and standard deviations are useful in evaluating the data. The mean attenuation values and standard deviations were computed by using the following formulas:

$$\text{Mean attenuation} = \frac{\text{Sum of attenuation}}{\text{Number of samples}}$$

$$\text{Standard deviation squared} = \frac{\text{Sum }\left[(\text{Attenuations} - \text{Mean attenuation})\text{ squared}\right]}{\text{Number of samples minus 1}}$$

Reference 5 shows that the noise level and direction of propagation of the maximum noise level were different for subsonic and supersonic XB-70 engine exhaust flow. The changes in direction of noise propagation and noise levels between subsonic and supersonic flow might cause the microphones closest to the airplane to be in the near field of the sound source for supersonic exhaust flow and in the far field for subsonic flow. Because of the possibility that some of the supersonic data were near-field data, the mean attenuations and standard deviations were determined separately for the subsonic and supersonic exhaust-flow data.

Data Analysis

Typical octave-band sound-pressure levels measured simultaneously at three different distances from the airplane are presented in figure 4. The data are from a propagation direction of 120° from the airplane heading, with engine number 1 operating at maximum afterburner power. The octave-band acoustic attenuations over a distance of 500 feet (152 meters) and 1000 feet (305 meters) were obtained by subtracting the measured octave-band sound-pressure levels at 1000 feet (305 meters) and 1500 feet (457 meters) from the octave-band sound-pressure levels at 500 feet (152 meters).

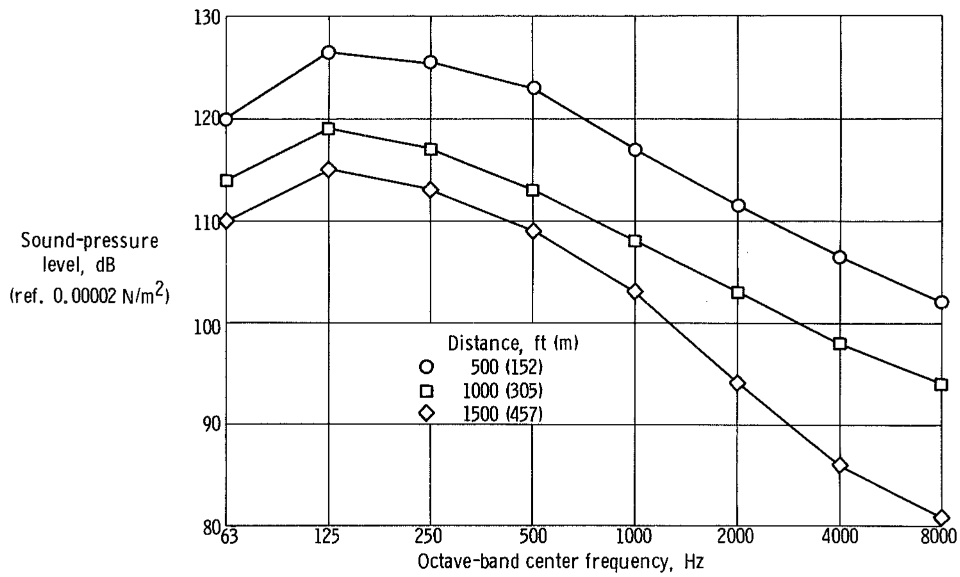
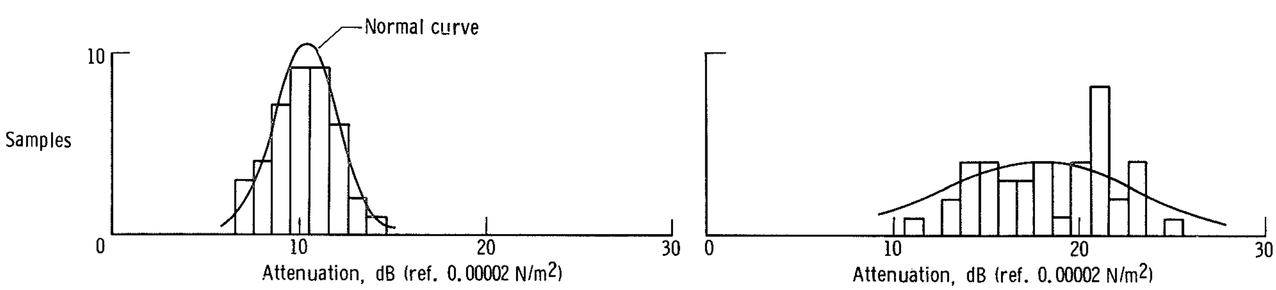


Figure 4. Octave-band sound-pressure levels at three distances from the XB-70 airplane. One engine; maximum afterburner; propagation direction, 120° from the airplane heading.

Typical scatter in the attenuation data for the present tests is shown in figure 5. The data are for a propagation direction of 120° from the aircraft heading over a



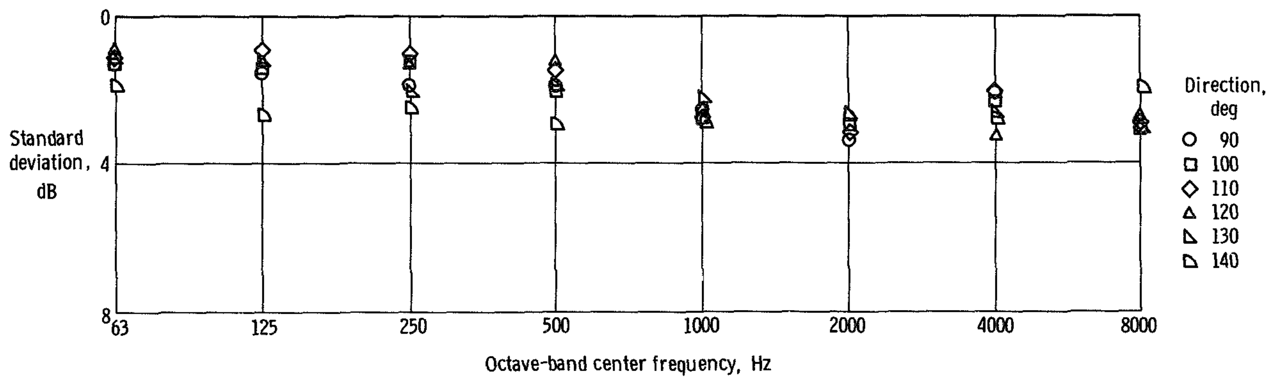
(a) 63-hertz octave-band center frequency. *(b) 8000-hertz octave-band center frequency.*

Figure 5. Illustration of scatter in octave-band sound pressure level attenuation data. Propagation distance, 1000 feet (305 m); supersonic exhaust flow; propagation direction, 120° from the airplane heading; 41 samples, or test runs, in each octave band.

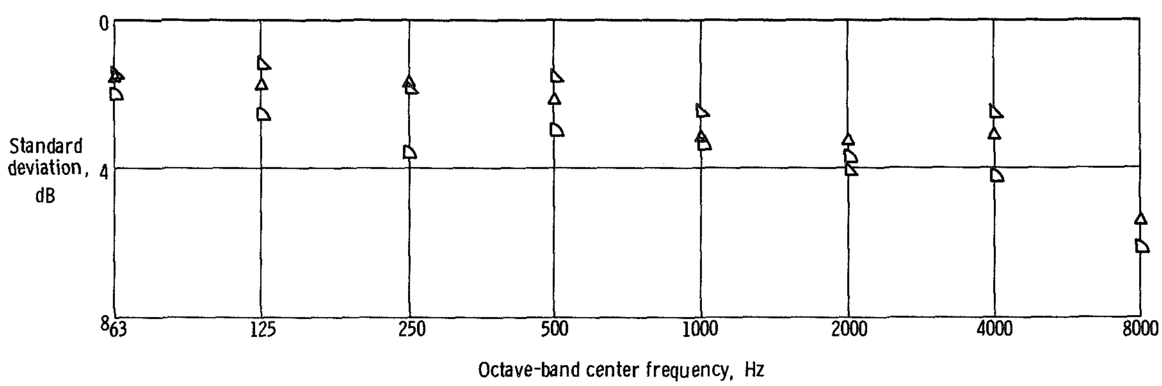
propagation distance of 1000 feet (305 meters). Only the lowest (63 Hz) and highest octave bands (8000 Hz) are shown, to illustrate the minimum and maximum data scatter during these tests. Included are all the test runs (samples) in which the exhaust flow was supersonic. The attenuation data are grouped in 1-decibel increments, according to the number of times (samples) a particular attenuation occurred. The greater scatter in the 8000-hertz octave band than in the 63-hertz octave band indicates the presence of small-scale atmospheric variations between the sound source and the microphones. The scatter shown in this figure is comparable to the scatter shown in reference 4.

Normal distribution curves computed by using the mean attenuation and standard deviation are also shown in figure 5. The normal distribution curves are reasonable representations of the data, which shows that the standard deviation provides an approximate indication of the probable range of attenuation values.

The standard deviations of the data groups used in this report are shown in figures 6(a) to 6(d). The number of samples used to compute these standard deviations are

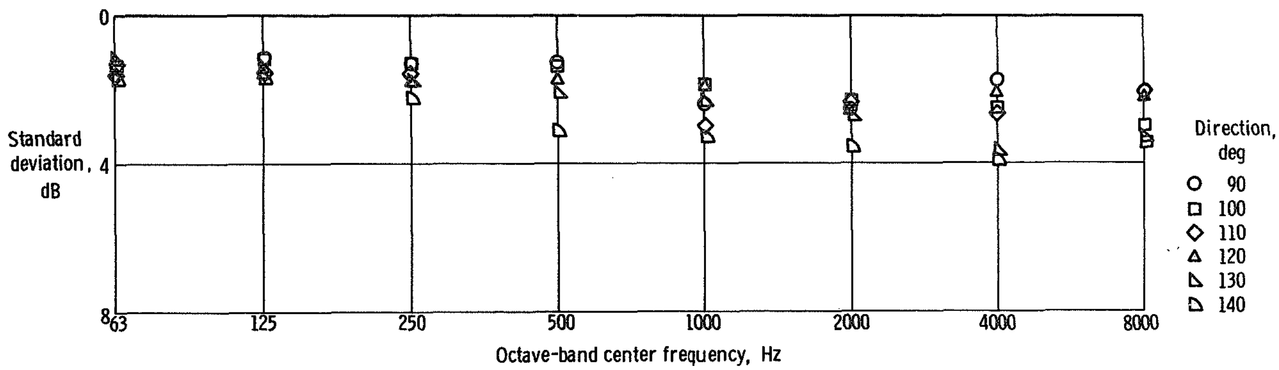


(a) Subsonic exhaust flow, propagation from 500 ft (152 m) to 1000 ft (305 m).

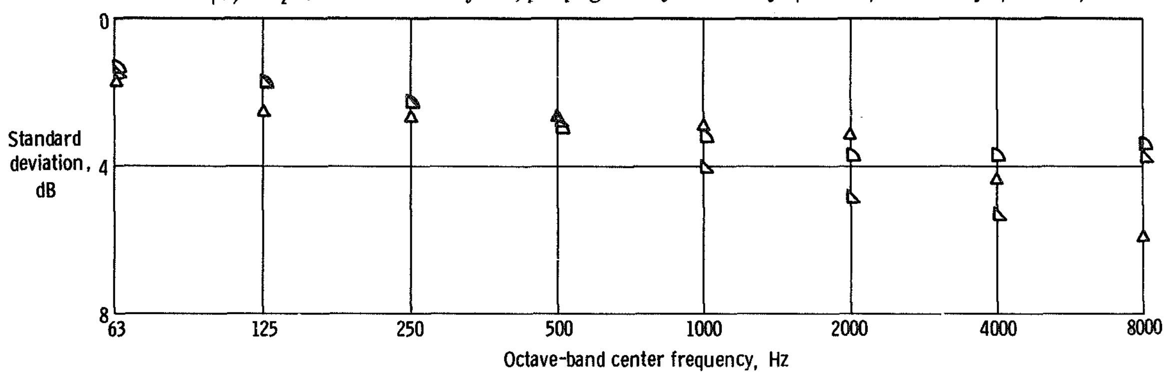


(b) Subsonic exhaust flow, propagation from 500 ft (152 m) to 1500 ft (457 m).

Figure 6. Standard deviation of XB-70 octave band sound pressure level data for two distances and various directions from the airplane heading.



(c) Supersonic exhaust flow, propagation from 500 ft (152 m) to 1000 ft (305 m).



(d) Supersonic exhaust flow, propagation from 500 ft (152 m) to 1500 ft (457 m).

Figure 6. Concluded.

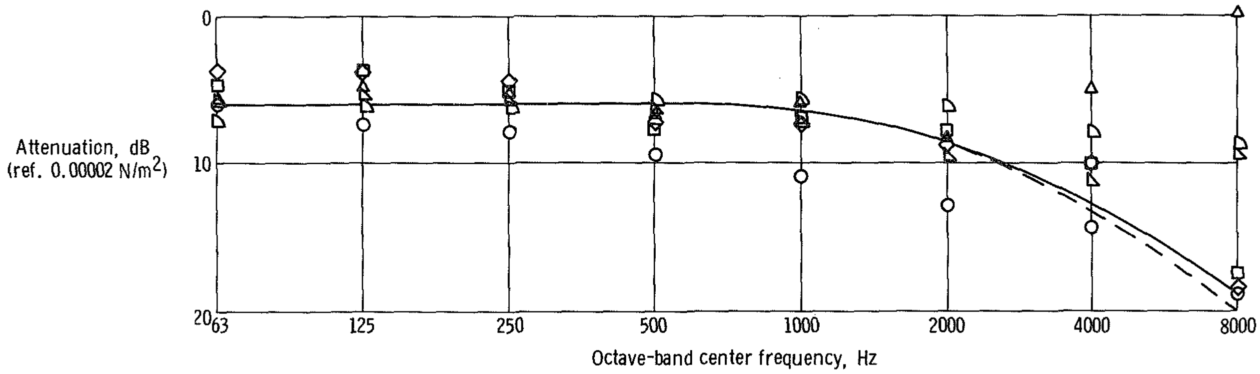
presented in table 2. The standard deviations of the data in the various octave bands are similar enough that comparison of the mean values of attenuation of the data groups is reasonable. Where differences appear to be significant between standard deviations of the attenuation for the various groupings of figure 2 (for example, subsonic flow at two distances at 8000 hertz), the data presented in table 2 indicate that differences are probably due to sample size. The standard deviation of the data generally increases with octave-band frequency.

TABLE 2. NUMBER OF RUNS (SAMPLES) FOR EACH COMPUTATION

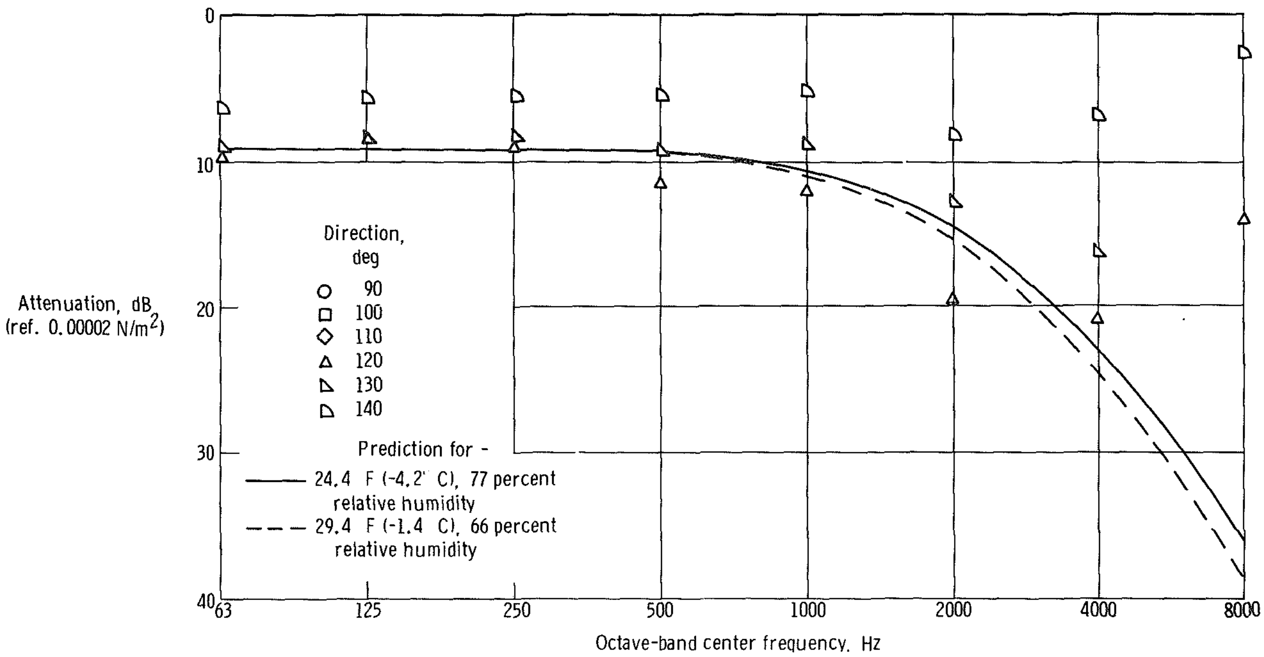
Distance, ft. (m)	Exhaust flow	Direction, deg	Number of runs (samples) for octave-band center frequency of —							
			63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
500 (152) to 1000 (305)	Subsonic	90	24	24	24	24	24	24	24	14
		100	25	25	25	25	25	25	25	21
		110	24	24	24	24	24	24	24	12
		120	24	24	24	24	24	24	23	13
		130	24	24	24	24	24	24	24	9
		140	23	23	23	23	23	23	23	23
	Supersonic	90	41	41	41	41	41	41	41	41
		100	43	43	43	43	43	43	43	43
		110	41	41	41	41	41	41	41	41
		120	41	41	41	41	41	41	41	41
		130	41	41	41	41	41	41	41	41
		140	41	41	41	41	41	41	41	41
500 (152) to 1500 (457)	Subsonic	120	24	24	24	24	24	24	24	9
		130	24	24	24	24	24	24	24	0
		140	15	15	15	15	15	15	15	5
	Supersonic	120	41	41	41	41	41	41	41	41
		130	41	41	41	41	41	41	41	40
		140	41	41	41	41	41	41	41	39

Mean Attenuations

The mean octave-band attenuations for various propagation directions from the airplane heading and for two distances are presented in figures 7(a) to 7(d) to assess the possibility that some of the microphones were in the near field of the sound source. Also shown are the predicted attenuation curves corresponding to maximum and minimum values of temperature and relative humidity which occurred during these tests. The scatter of the attenuation data obscures any consistent trends in the direction of propagation. The low-frequency data cluster around the predicted value, indicating that all the microphones were in the far field of the noise source, because the maximum sound levels occurred in the low-frequency octave bands (fig. 4). Because all microphones were in the far field of the noise source, it is proper to compare the measured and predicted attenuations at all frequencies.

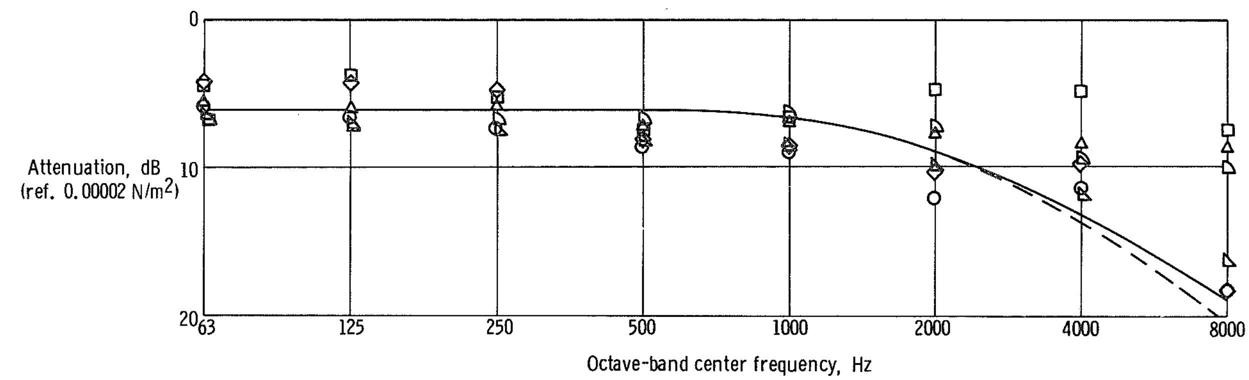


(a) Subsonic exhaust flow, propagation from 500 ft (152 m) to 1000 ft (305 m).

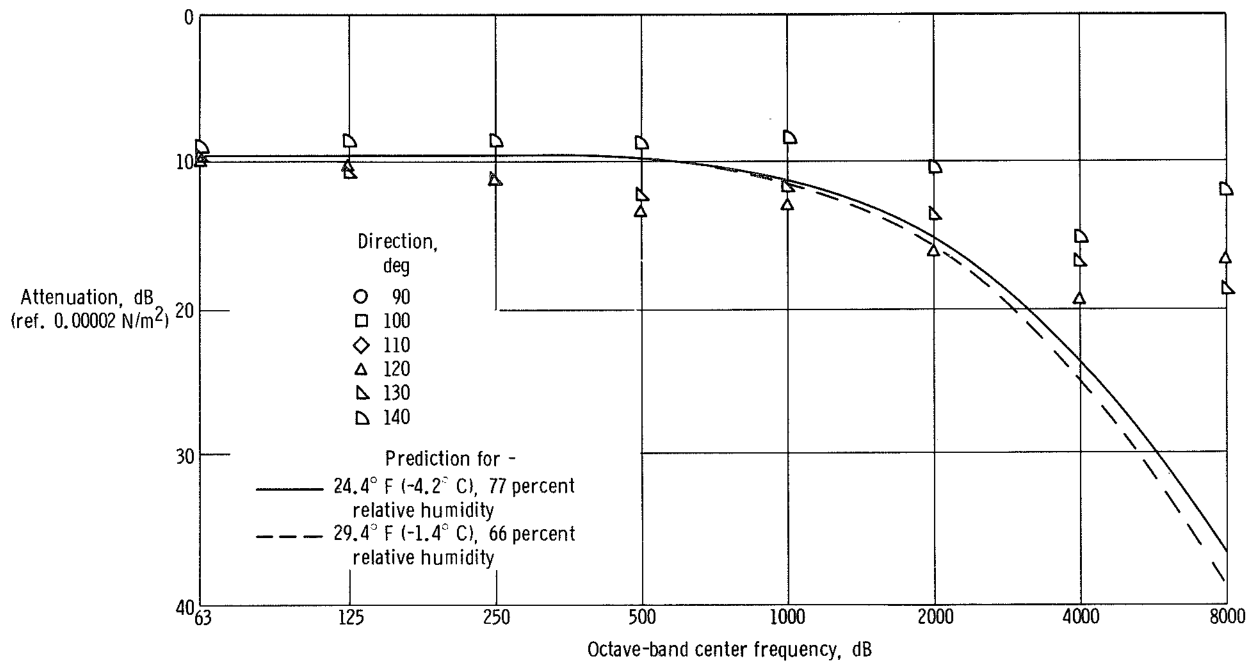


(b) Subsonic exhaust flow, propagation from 500 ft (152 m) to 1500 ft (457 m).

Figure 7. XB-70 mean sound-attenuation data over two distances for various directions from the airplane heading, and atmospheric attenuation for the extremes of atmospheric conditions during the tests (computed from ref. 3).



(c) Supersonic exhaust flow, propagation from 500 ft (152 m) to 1000 ft (305 m).

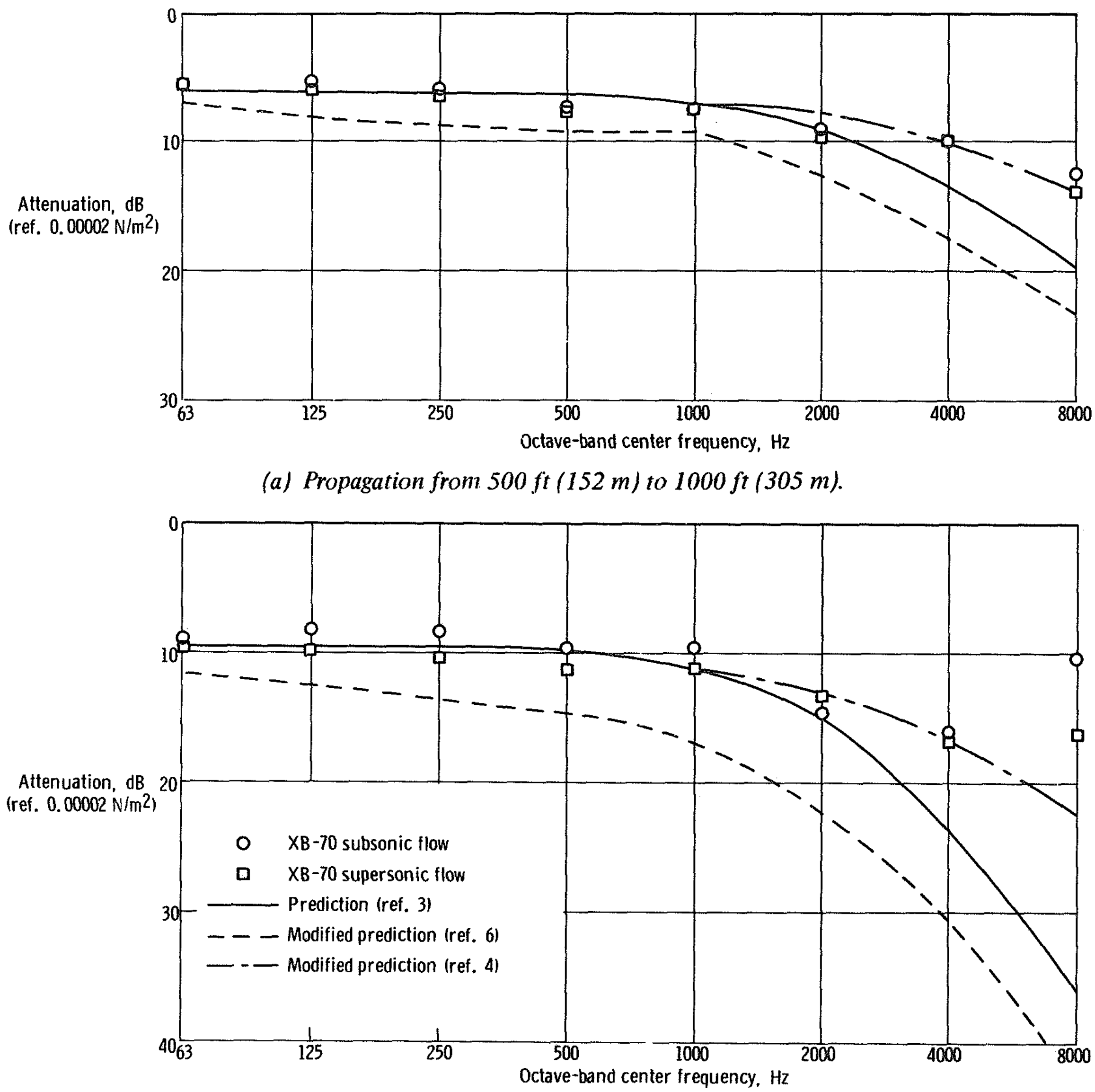


(d) Supersonic exhaust flow, propagation from 500 ft (152 m) to 1500 ft (457 m).

Figure 7. Concluded.

The scatter in the data is greater than would be predicted for the changes in relative humidity and temperature which occurred during these tests and is also larger than had been anticipated for the surface wind velocity (fig. 3). The wind direction was such that the noise was generally propagated downwind, but the time histories of the wind indicate considerable variation in velocity and direction during the tests. The wind variations indicate that the atmosphere was nonhomogeneous with respect to factors which could cause attenuation of sound. A nonhomogeneous atmosphere would cause more scatter of the high-frequency sound than of the low-frequency sound. This trend, which is evident in the data, does not positively establish that the scatter in the data is a function of the variation of the wind parameters; however, it does indicate a reasonable probability that the scatter is directly associated with the wind-parameter variations.

The scatter in the octave-band attenuations precludes determining the adequacy of the predicted attenuations. The mean attenuation was computed for all directions of propagation to obtain one mean attenuation in each octave band for subsonic exhaust flow and one for supersonic exhaust flow. These computed mean attenuations are presented in figures 8(a) and 8(b). Also presented are the predicted attenuations for 24.4° F (-4.2° C) and 77-percent relative humidity (ref. 3), which show agreement with the measured values for octave bands at and below 2000 hertz. The XB-70 8000-hertz octave-band attenuation data for a propagation distance of 1000 feet (305 meters) for subsonic and supersonic exhaust flow do not agree. The reason for this disagreement is unknown, but it may be the smaller sample size of the subsonic data (table 2).



(a) Propagation from 500 ft (152 m) to 1000 ft (305 m).

(b) Propagation from 500 ft (152 m) to 1500 ft (457 m).

Figure 8. Comparison of mean octave-band attenuation of XB-70 data for two distances with attenuations calculated from references 3, 4, and 6.

Wind can cause field-determined attenuation to be greater or less than the predicted attenuation. References 4 and 6 each present a method for predicting acoustic attenuation for downwind propagation of sound. The method of reference 6 is based on data from tests which indicate that additional acoustic attenuation occurs when sound is being propagated downwind because turbulence dissipates the sound. When the predicted levels of reference 3 were modified by using the method presented in reference 6, agreement with the measured data in all octave bands was unsatisfactory (fig. 8).

Reference 4 indicates that the atmospheric attenuations determined from reference 3 should be decreased by 50 percent for octave bands above 1000 hertz. Modifying the predicted attenuations in this manner[1] resulted in good agreement with the measured data (fig. 8) except for the 8000-hertz octave band from a propagation distance of 1000 feet (305 meters). The reason for this disagreement is unknown.

CONCLUDING REMARKS

Attenuation data obtained during ground operation of the XB-70 airplane engines indicated that the attenuation values derived from the Society of Automotive Engineers, Inc., ARP 866 are not directly applicable to all test conditions. For sound propagated downwind, reducing the attenuation values derived from ARP 866 by 50 percent in the 2000-, 4000-, and 8000-hertz octave bands resulted in good agreement between experimentally determined and predicted attenuation values. These modifications of atmospheric attenuation values were suggested by previous investigators who obtained similar results. Although reasonable agreement was obtained between the experimentally determined and modified predicted attenuation, an unexplained difference remained, showing the need for additional research.

The scatter in the attenuation data was greater than anticipated and seemed to be associated with variations in wind velocity and direction. The amount of scatter indicated that a large number of data samples should be obtained during noise measurements to determine the mean attenuation.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., October 9, 1970.

[1] Amount of attenuation due to spherical spreading is not modified.

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