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VARIABILITY OF MEASURED SONIC BOOM SIGNATURES

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by

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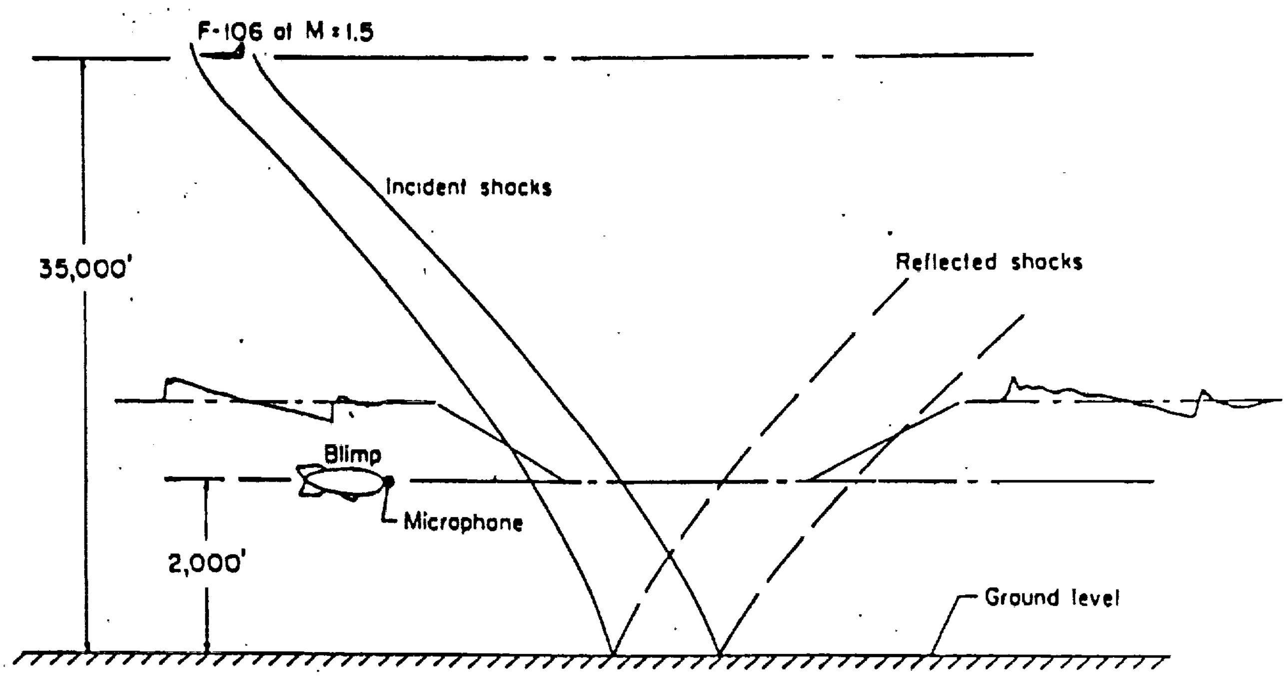
Atmospheric Turbulence

The propagation of sonic booms through the real atmosphere can have a pronounce effect on the signature received on the ground. It has been well established that turbulence in the lower part of the planetary boundary layer known as the mixing layer is a significant contributor to the distortion of sonic booms, as illustrated in this figure. The changes in the atmospheric conditions during a day and from day to day results in a large variation in the sonic boom signature measured on the ground for an aircraft flying at a nominal operating condition at different times of the day. The objective of this study is to evaluate the variability in the loudness of the booms due to these propagation effects.

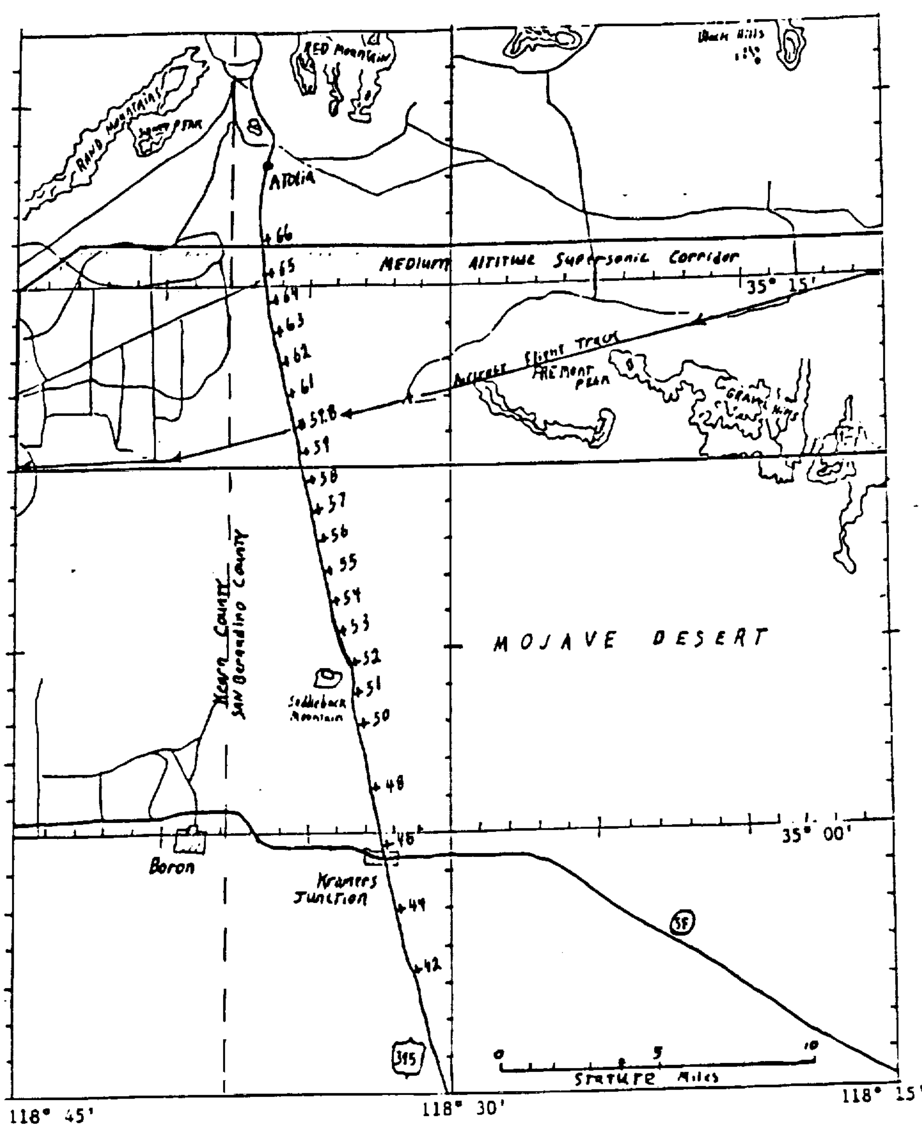
ATMOSPHERIC TURBULENCE EFFECT



BOOMFILE Database Descriptions

The BOOMFILE database contains overpressure distributions for 43 passes of the several types of aircraft previously mentioned. This data was collected using Boom Event Analyzer Recorders (BEAR) and modified Larson Davis LD700 Personal Dosimeters. These devices were arranged in a linear array of 13 microphones located perpendicular to the flight path at sideline distances ranging from 0 miles (i.e., directly under the flight path) to roughly 20 miles as shown in the figure. The aircraft flew across the microphone array with steady flight conditions which were achieved several miles prior to reaching the microphones. BOOMFILE also contains aircraft tracking data which consists of altitude, Mach number, climb angle, acceleration, heading, and lateral and longitudinal position with respect to a reference microphone. This data is provided at one second intervals for most of the aircraft overflights. Limited atmospheric data was also collected during the BOOMFILE tests. This data consisted of ground station wind speed and direction, air pressure, and air temperature measured just prior to each set of flyovers. Upper atmosphere rawinsonde data recorded at nearby weather stations on the test days are also provided. This consists of wind speed and direction, sound speed, relative humidity, dew point, temperature and pressure at 1,000 foot altitude intervals ranging from roughly 2,500 to 100,000 feet above mean sea level (Reference 1).

BOOMFILE MICROPHONE ARRAY



BOOMFILE Flight Conditions

The BOOMFILE flight conditions are listed in this table. The range of conditions is large from Mach 1.0 to 3.0 and altitude 13,000 ft to 70,000 ft with 9 different aircraft. However, repeat runs of the same aircraft at similar flight conditions are limited.

BOOMFILE Flight Conditions Summary

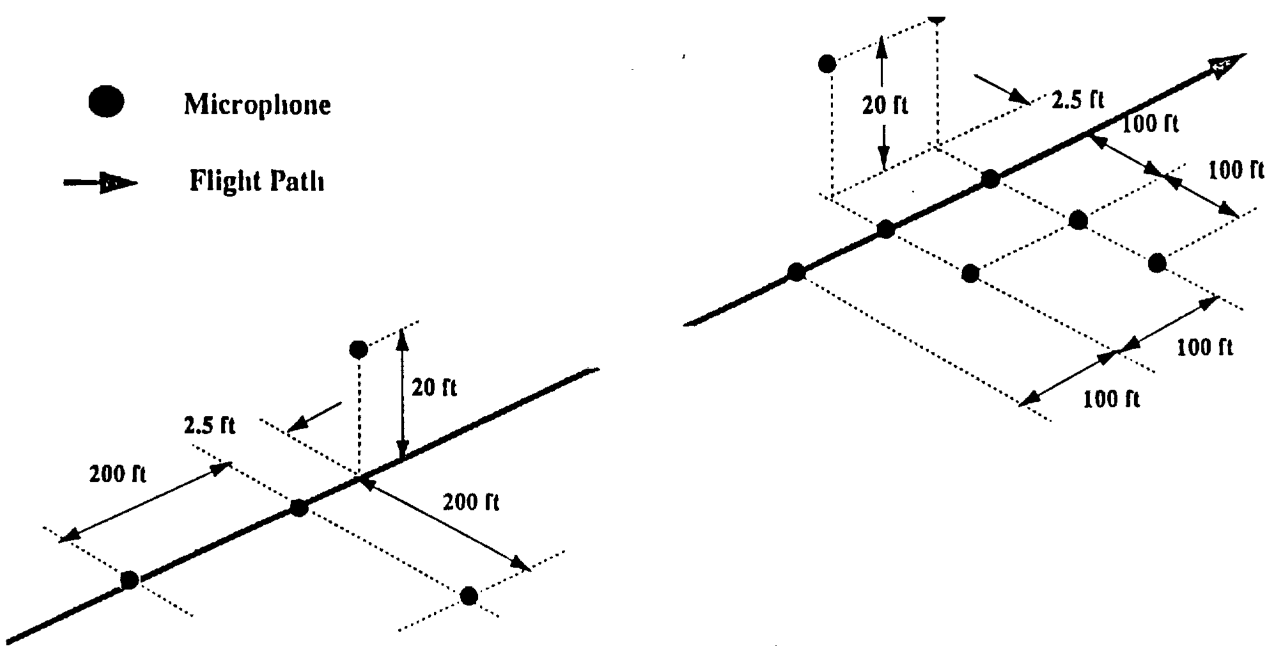
DATE	AIRCRAFT	FLIGHT TRACK INTERSECTION	MACH NUMBER	ALTITUDE (Ft MSL)	BOOM AT SITE 00 (Local Time)
31 JUL 87	F-4 *	57.8	1.20	16000	08:41:20
03 AUG 87	F-4	60.1	1.24	29200	07:48:33
	F-4	60.6	1.29	29300	07:58:33
	F-4	53.6	1.10	13000	08:08:04
	F-4	59.2	1.10	14400	10:29:59
	F-4	61.3	1.37	44400	10:43:22
	T-38	58.6	1.00	13600	10:05:35
	T-38	56.0	1.10	13000	10:12:15
	T-38	59.5	1.11	29600	12:28:18
	T-38	60.5	1.05	21200	12:38:17
04 AUG 87	AT-38	60.0	1.17	41400	07:19:41
	AT-38	60.0	1.12	32300	07:30:09
	AT-38	63.0	1.15	16700	07:36:46
	AT-38	59.6	1.20	30300	09:14:06
	AT-38	59.0	1.10	14000	09:23:15
	F-15	61.5	1.38	41400	07:56:42
	F-15	60.3	1.20	29700	08:04:06
	F-15	60.6	1.10	12500	08:10:13
	F-15	60.0	1.13	15200	10:46:15
	F-15	59.0	1.28	31000	11:02:18
	F-15	64.0	1.42	45000	11:11:28
	F-15	60.0	1.40	45500	11:34:21
05 AUG 87	F-16	57.0	1.25	29500	09:06:05
	F-16	60.0	1.43	46700	09:33:54
	F-16	58.8	1.17	19300	09:44:51
	F-16	59.5	1.13	14400	11:44:24
	F-16	60.6	1.12	13800	11:54:39
	F-16	60.5	1.25	30000	12:04:46
	SR-71	60.8	2.50	64800	09:26:12
	SR-71 *	59.8	3.00	73000	10:55:12
	SR-71	59.4	1.23	32400	11:08:38
	SR-71	62.0	1.70	52000	12:35:51
06 AUG 87	F-18	60.0	1.30	30000	07:44:12
	F-18	59.6	1.40	44700	07:57:05
	F-18	58.0	1.10	14200	08:10:36
	F-18	59.8	1.30	30000	10:22:47
	F-18	59.8	1.43	45000	10:34:14
	F-18 *	59.8	1.10	13000	10:48:38
	F-14	56.2	1.20	31500	08:28:45
	F-14	62.0	1.27	16500	10:43:43
	F-111D	59.8	1.20	14000	11:48:18
	F-111D	59.8	1.40	45000	12:04:44
07 AUG 87	F-111D	58.3	1.25	29900	10:50:26

For each of these flights, except where noted by an asterisk, tracking data are provided

XB-70 Database Descriptions

The XB-70 database (Reference 2) consists of frequency spectra and overpressure time histories for 39 flights (51 runs) of the XB-70 aircraft. The data was collected at several ground stations using a microphone, tuning unit, d.c. amplifier, and FM tape recorder setup played back into a recording oscillograph. The oscillograph plots were then digitized using an optical scanning system. In this test program the microphones were arranged in one of two configurations, either three ground and one pole or six ground and two pole microphones all located within a 200 foot by 200 foot grid pattern shown in the figure. The location of the measurement site with respect to the aircraft flight path for different runs ranged from directly overhead to a sideline distance of over 15 miles. Each run is considered as one flight over one cluster of 4 or 8 microphones. Atmospheric data for the XB-70 database consists of digitized trace plots for temperature and wind speed parallel and perpendicular to the flight path for all runs. The National Oceanic and Atmospheric Association provided pressure, temperature, wind, and relative humidity vs altitude profile rawinsonde data at 12:00 and 24:00 hours. They also provided limited test site climatological data consisting of temperature, wind speed and direction, cloud cover description, and dew point within an hour of each run. This database has more repeat runs than BOOMFILE, however, the sideline distance to the microphone cluster varied significantly from run to run (Reference 2).

XB-70 MICROPHONE CLUSTER ARRANGEMENTS



XB-70 Flight Conditions

The flight conditions of the XB-70 database are listed in this table.

XB-70 SONIC BOOM LOG

(for flights of March 4, 1965 through May 27, 1966)

DJM File#	Date	A/C#-Flt #	T/O Time	T/O Gr.Wt.	Flt. Time	Boom Time	Boom Mach	Boom Alt	Boom Gr.Wt.	Land Gr.Wt.
1	3-4-65	1-7	1018	480K	1:37	1114	1.83	50500	337K	297K
2	4-20-65	1-10	1113	510K	1:42	1213	1.80	48000	350K	300K
3	7-1-65	1-14	0650	510K	1:44	0800	2.60	66000	310K	285K
4	7-27-65	1-15	0707	510K	1:43	0732	1.23	32000	423K	300K
5	8-10-65	2-2	0700	470K	1:27	0740	1.38	42300	357K	310K
6	8-18-65	2-3	1220	490K	1:58	1330	1.40	46000	381K	305K
7	8-20-65	2-4	1115	493K	2:04	1159	1.42	42500	387K	295K
8	9-22-65	1-16	1200	510K	1:57	1225	1.50	33800	456K	300K
9	9-29-65	2-6	1147	495K	2:04	1220	1.35	33000	440K	295K
10	10-5-65	2-7	1213	495K	1:40	1243	1.42	31000	438K	295K
11	10-11-65	2-8	1310	515K	1:55	1332	1.51	34000	423K	298K
12	10-14-65	1-17	0906	510K	1:47	0936	1.76	41000	433K	300K
13	10-16-65	2-9	0912	520K	1:43	1027	1.40	50000	313K	295K
14	11-2-65	2-11	1126	520K	1:54	1255	1.80	50500	317K	295K
15	11-4-65	1-18	1019	515K	2:04	1105	1.87	41500	357K	300K
16	11-18-65	1-21	1233	515K	2:02	1338	1.61	41500	348K	300K
17	11-30-65	1-22	0900	515K	1:59	1010	1.82	53000	325K	295K
18	12-1-65	2=13	0902	525K	2:02	1030	2.31	60000	328K	297K
19	12-2-65	1-23	0915	515K	1:59	1040	1.79	54000	317K	300K
20	12-3-65	2-14	0906	520K	1:55	1030	2.48	65500	329K	300K
21	12-10-65	1-25	1230	515K	2:18	1315	1.55	30500	436K	--
			(2nd	run)	----	1400	1.25	38000	371K	295K
22	12-11-65	2-15	0858	520K	2:03	0918	1.50	37000	454K	--
			(2nd	run)	----	1020	2.90	70000	321K	300K
23	12-21-65	2-16	1307	510K	1:49	1427	2.92	70000	321K	300K
24	1-3-66	2-17	0901	520K	1:52	1020	2.91	69800	317K	295K
25	1-11-66	1-31	0702	447K	1:35	0750	1.80	44900	369K	295K
26	1-12-66	2-18	0855	525K	1:48	1018	2.05	66000	297K	290K
27	1-15-66	1-33	1108	450K	1:27	1153	1.78	45100	373K	290K
28	3-4-66	1-36	1055	523K	2:27	1140	1.75	41000	446K	--
	(2nd station-same run)				----	1140	1.82	42000	445K	293K
29	3-7-66	1-37	1402	520K	2:19	1532	1.17	41000	344K	--
	(2nd station-same run)				----	1532	1.17	40000	343K	295K
30	3-15-66	2-24	0909	535K	1:59	1030	2.66	68500	310K	--
	(2nd station-same run)				----	1030	2.66	69300	310K	293K
31	3-17-66	2-25	0847	535K	1:52	1015	2.74	66000	308K	--
	(2nd station-same run)				----	1015	2.74	66000	308K	297K
32	3-19-66	2-26	1040	530K	1:57	1210	2.84	70300	305K	--
	(2nd station-same run)				----	1210	2.84	70300	304K	291K
33	3-28-66	1-40	0950	520K	1:41	1053	1.80	51000	319K	--
	(2nd station-same run)				----	1053	1.80	51000	319K	300K
34	3-29-66	2-29	1027	530K	1:51	1137	1.56	44000	314K	--
	(2nd station-same run)				----	1137	1.56	44000	314K	--
	---------------(2nd run)				----	1152	1.36	36400	304K	--
	(2nd station-2nd run)				----	1152	1.36	36400	304K	300K
35	4-5-66	1-42	1026	520K	2:01	1138	1.55	52000	334K	295K
36	4-21-66	1-45	1539	524K	2:02	1646	2.26	63000	338K	290K
37	4-23-66	2-35	1120	525K	2:01	1140	1.11	32000	468K	--
	(2nd station-same run)				----	1140	1.18	32000	467K	--
	---------------(2nd run)				----	1255	2.20	64000	362K	--
	(2nd station-2nd run)				----	1255	2.20	64000	362K	310K
38	5-16-66	2-38	0900	520K	2:09	1040	1.30	44300	321K	300K
39	5-27-66	2-42	1100	520K	2:08	1240	1.24	39800	310K	300K

Total number of sonic boom flights = 39

Total number of sonic boom runs = 51

Analysis Progression

This figure shows the organization for the remainder of the presentation, beginning with a description of the variables calculated in what will be referred to as the extended database. The analysis of these calculated parameters with respect to the aircraft flight conditions and flight times is reviewed. The analysis then is focused on time of day variations. This is followed by further analysis in terms of lateral cutoff and morning vs afternoon comparisons.

OUTLINE

- EXTENDED DATABASE
- VARIABILITY IN OVERPRESSURE, RISE TIME, AND LOUDNESS WITH FLIGHT CONDITIONS
- SONIC BOOM VARIABILITY IN REPEAT FLIGHTS
- VARIABILITY WITH TIME OF DAY
- VARIABILITY IN BOOM SYMMETRY
- STATISTICAL DISTRIBUTION BY LATERAL DISTANCE
- STATISTICAL DISTRIBUTION BY TIME OF DAY

Extended Database

Several noise metrics and various categories of rise time were determined for each point in the BOOMFILE and XB-70 databases. These quantities, listed in the figure, are available in tabular and digital format. An example of this extended database is shown.

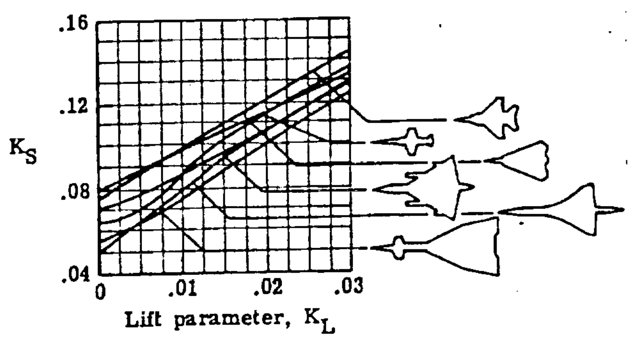
ANALYSIS PARAMETERS

- MAXIMUM OVERPRESSURE, P_{max}
- STEVENS MARK VII PERCEIVED NOISE LEVEL, PLdB
- A-WEIGHTED SOUND EXPOSURE LEVEL, ASEL
- C-WEIGHTED SOUND EXPOSURE LEVEL, CSEL
- RISE TIME FROM 10% TO 90% P_{max}
- RISE TIME TO 50% P_{max}
- RISE TIME TO 75% P_{max}
- RISE TIME TO 100% P_{max}

Prediction Method

The noise metrics for the measured boom signatures were compared to metrics for signatures predicted using Carlson's simplified method (Reference 3) option of the sonic boom analysis program MDBOOM (Reference 4). In this technique, a simple F-function input is scaled to the local conditions. The scaling factors used are the lift parameter, K_L determined from the aircraft Mach number, weight, length, and local pressure, and the shape parameter, K_S determined from the aircraft type and K_L as shown in the figure. K_S is then used to scale the simple F-function of the figure by the factor shown. The signature is then evolved to the microphone (far field), resulting in a change of amplitude. An aging or steepening calculation is then performed to arrive at the signature propagated through a non-turbulent atmosphere (ideal N-wave).

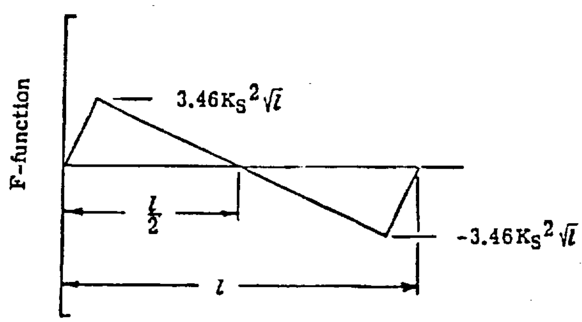
SIMPLIFIED SONIC BOOM PREDICTION PROCEDURE



Enter lift parameter K_L

$$K_L = \frac{\sqrt{M^2 - 1}\; W}{1.4 p_v M^2 l^2}$$

Select shape factor K_S



Flight Condition Groups

For sonic boom variability analysis the BOOMFILE and XB70 data were each divided into four groups based on aircraft altitude and Mach number values. The range of flight conditions for these groups are shown in the figure.

FLIGHT CONDITIONS
BOOMFILE DATABASE

RANGE	GROUP 1	GROUP 2	GROUP 3	GROUP 4
Altitude (feet)	10,000 - 20,000	25,000 - 35,000	40,000 - 50,000	50,100 - 80,000
Mach number	1.05 - 1.30	1.10 - 1.40	1.10 - 1.50	1.50 - 3.50
Sideline Distance (feet)	0 - 45,000	0 - 55,000	0 - 80,000	0 - 60,000

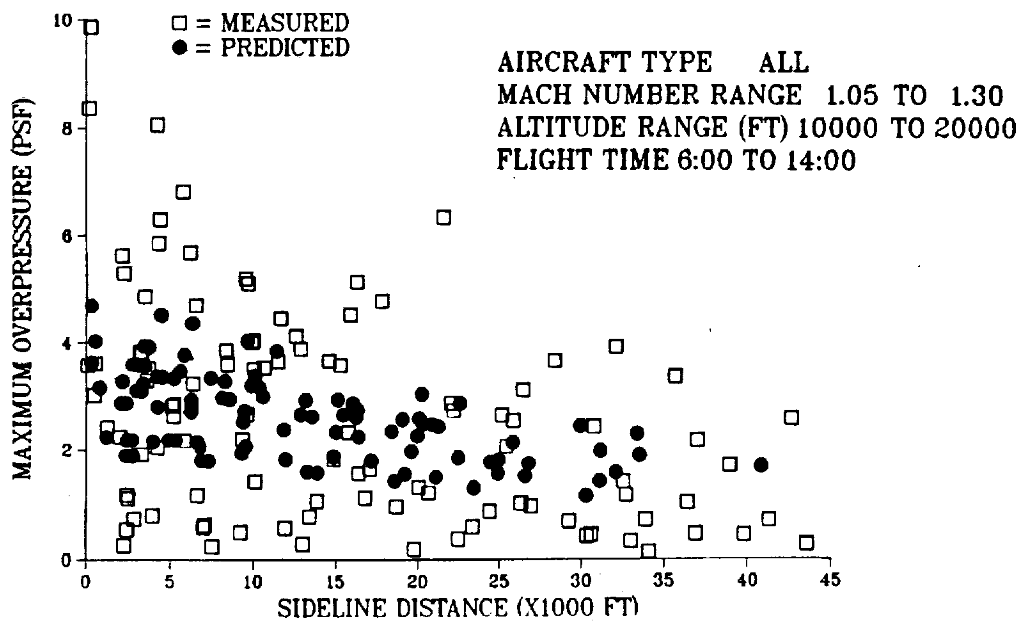
XB70 DATABASE

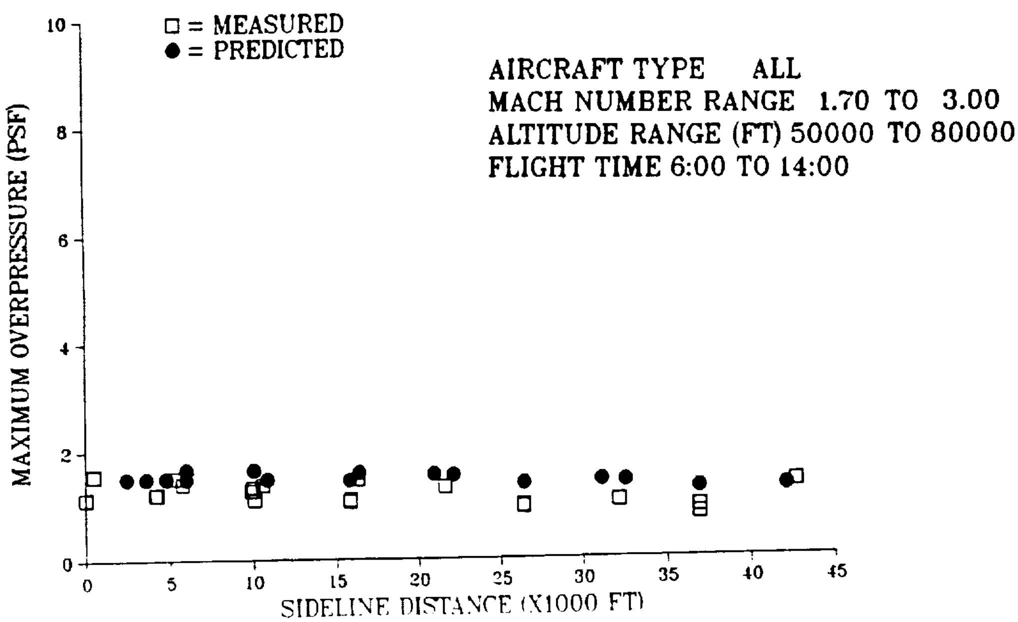
RANGE	GROUP 1	GROUP 2	GROUP 3	GROUP 4
Altitude (feet)	30,000 - 40,000	40,100 - 50,000	50,100 - 60,000	60,100 - 72,000
Mach number	1.17 - 1.55	1.17 - 1.87	1.55 - 2.31	2.05 - 2.92
Sideline Distance (feet)	0 - 50,000	0 - 80,000	0 - 70,000	0 - 80,000

Overpressure Variability Dependence on Flight Conditions

Comparisons between measured and calculated data were made for the various metrics and rise times as they varied with sideline distance. The high altitude / high Mach number group, bottom figure, shows very good agreement between measured maximum overpressures and predicted maximum overpressures (assuming uniform non-turbulent atmosphere). For the low altitude / Mach number group, upper figure, the comparison is relatively poor. While the measurements in both groups include the effects of propagation through the lower layer of turbulent atmosphere, the high altitude / high Mach number group represents flights where measurements are well within the lateral cutoff, where the boom has already propagated an adequate distance so that the shock is in an equilibrium state prior to entering the lowest 5,000 feet of the atmosphere, and where the propagation through the atmosphere is more vertical than the low altitude / low Mach number flights. These can be expected to reduce variability in measurements and improve theory - data agreement. These plots include morning as well as afternoon flights.

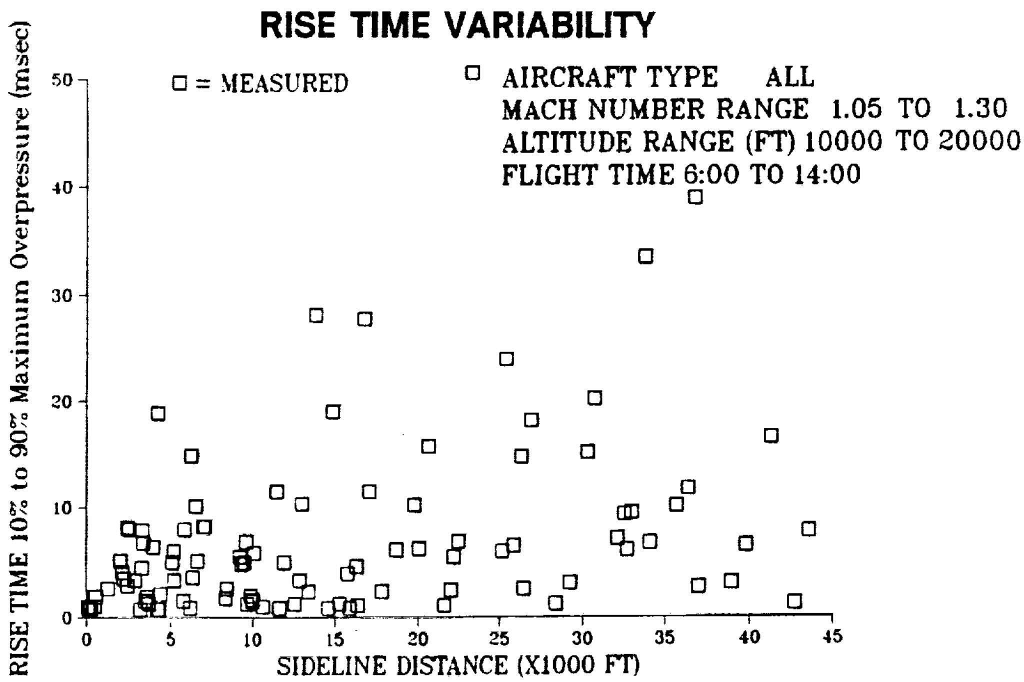
OVERPRESSURE VARIABILITY

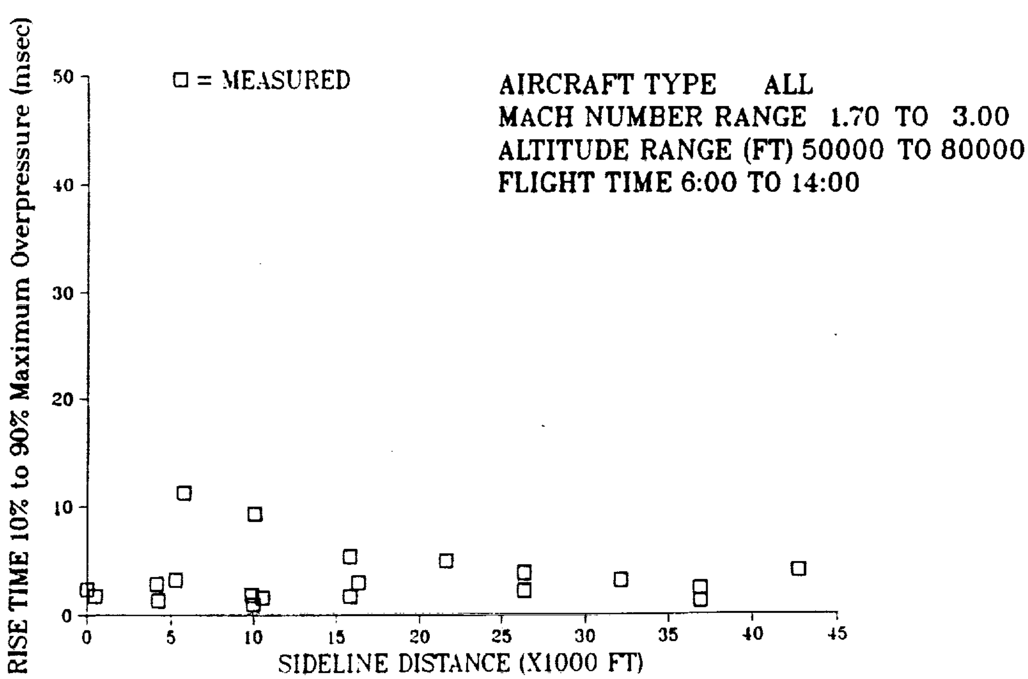




Rise Time Variability Dependence on Flight Conditions

The variability in the rise times (measured from 10% to 90% P_{max}) for two groups of measurements is plotted in these figures. Again, the low altitude / low Mach number group (top figure) shows a wider range of values (up to 50.3 msec) compared to the smaller variation (up to 11.8 sec) for the high altitude / high Mach number group (bottom figure).

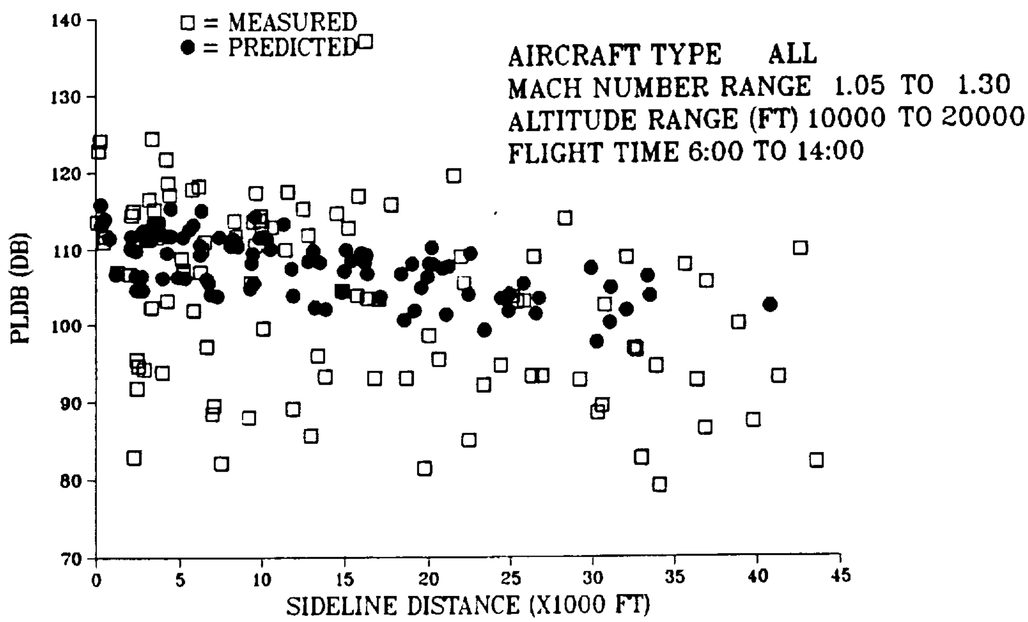


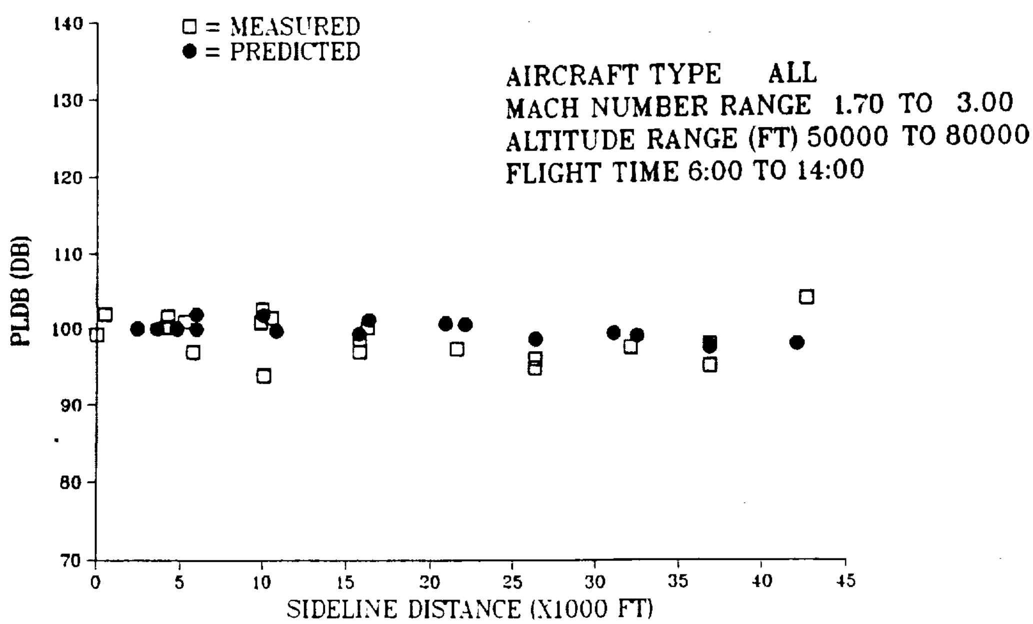


Loudness Variability Dependence on Flight Conditions

These figures illustrate that, as would be expected based on the observations of previous figures, the loudness of the measured and predicted booms are in good agreement for the high altitude / high Mach number flight groups (bottom figure). For the low altitude / low Mach number altitude group the loudness values of the measured booms are scattered around the predicted boom loudness values (top figure). For the other frequency domain metrics, ASEL and CSEL, similar comparisons were noted.

LOUDNESS VARIABILITY

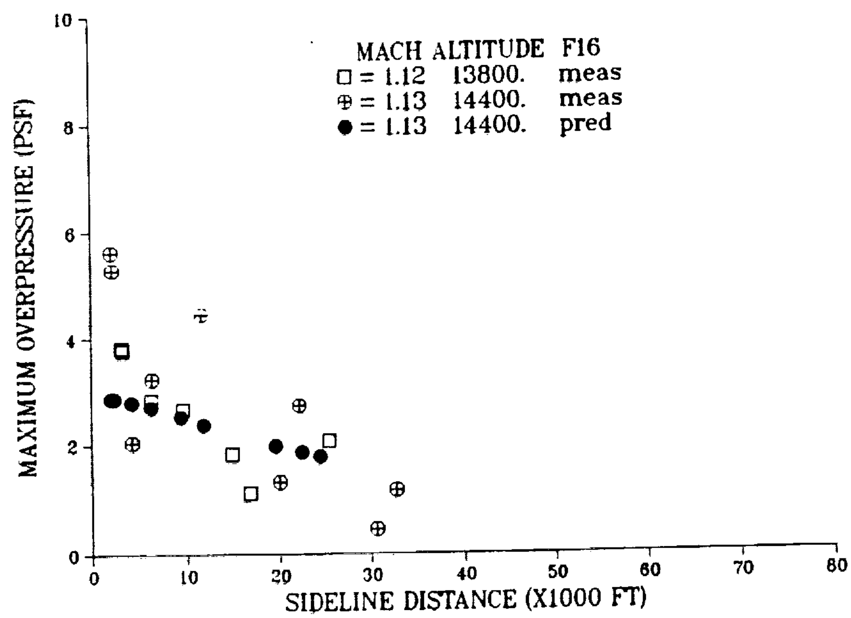


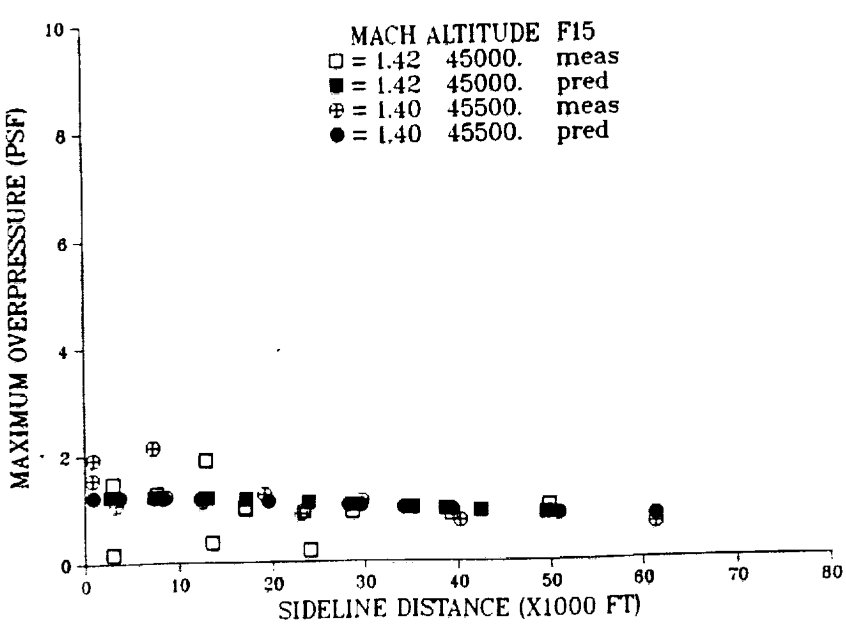


Sonic Boom Variability in Repeat Flights

The BOOMFILE database has a limited number of repeat flights (i.e., same aircraft at nominally the same flight conditions). Analysis of measurements from two such sets are shown. The first set consists of two flights of F16 aircraft at an altitude of 14,000 feet. The second set consists of two flights of F15 aircraft at a higher altitude of 45,000 feet. In each case, the repeat flights were made within a few minutes of the first flight. These plots thus provide a real representation of the variability in sonic boom measurements due to propagation effects. It can be noticed that the lower altitude runs (top figure) show a greater variability in sonic boom maximum overpressure compared to the higher altitude runs (bottom figure).

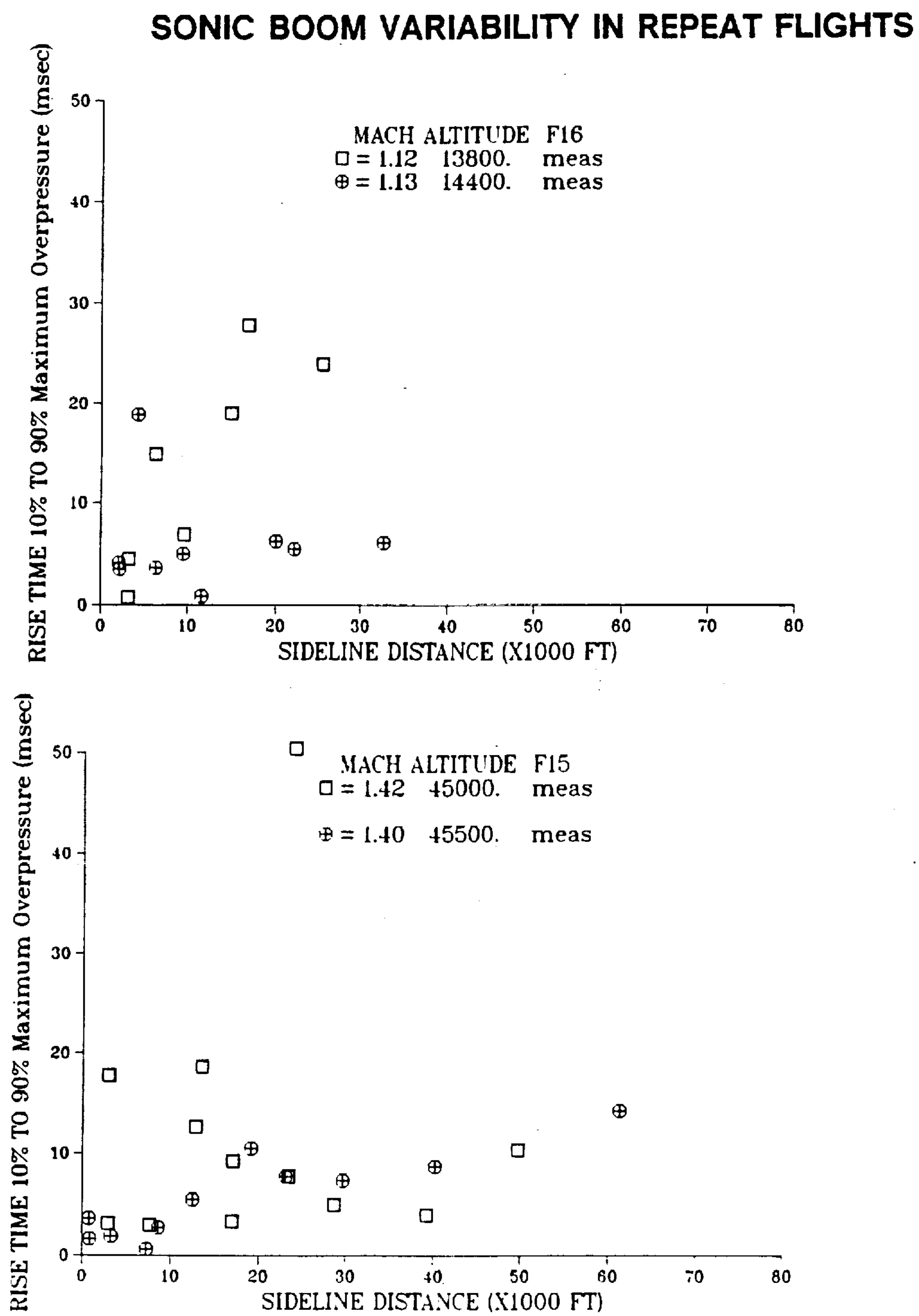
SONIC BOOM VARIABILITY IN REPEAT FLIGHTS





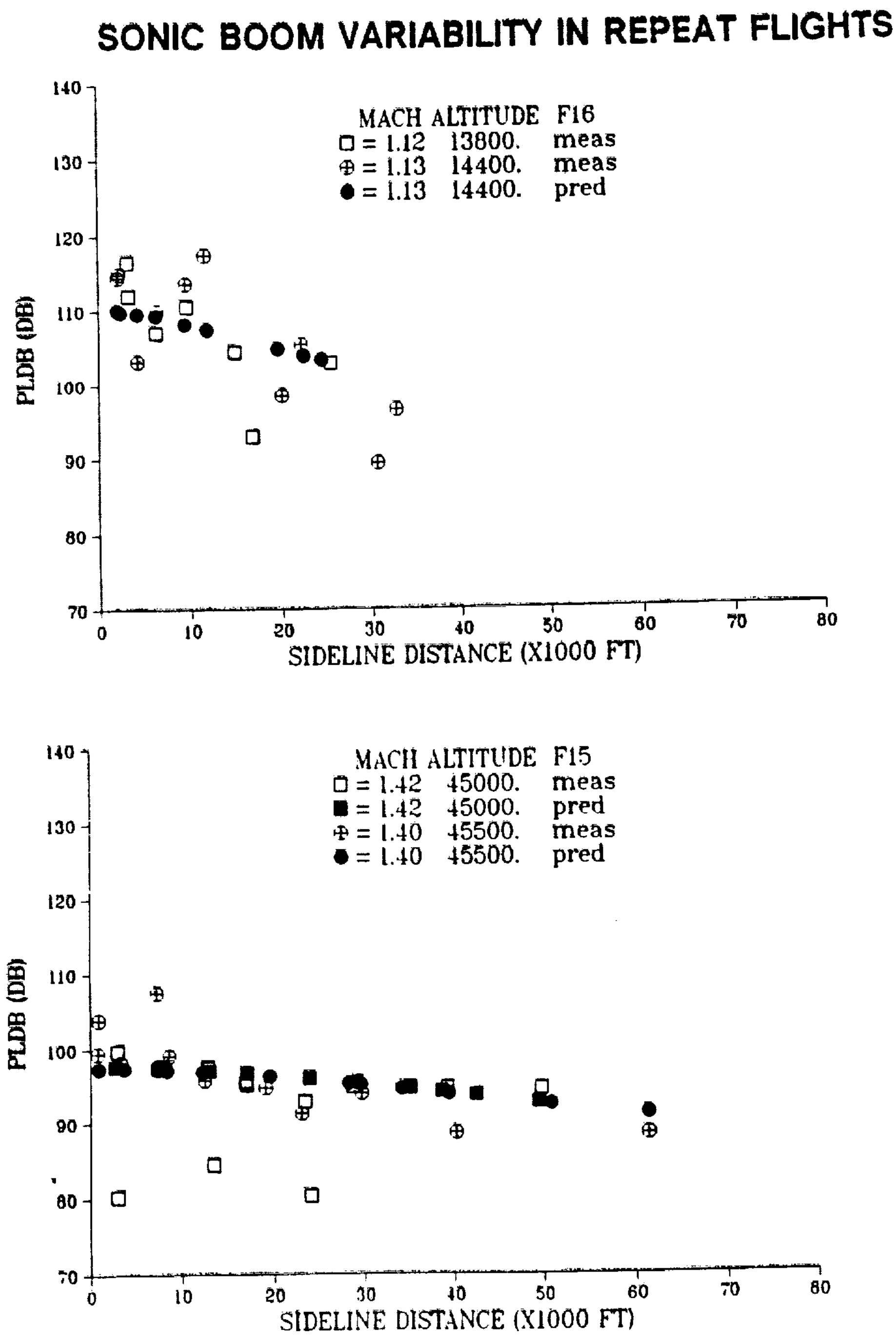
Sonic Boom Variability in Repeat Flights

These plots show that the lower altitude runs (top figure) have greater variability rise time compared to the higher altitude runs (bottom figure).



Sonic Boom Variability in Repeat Flights

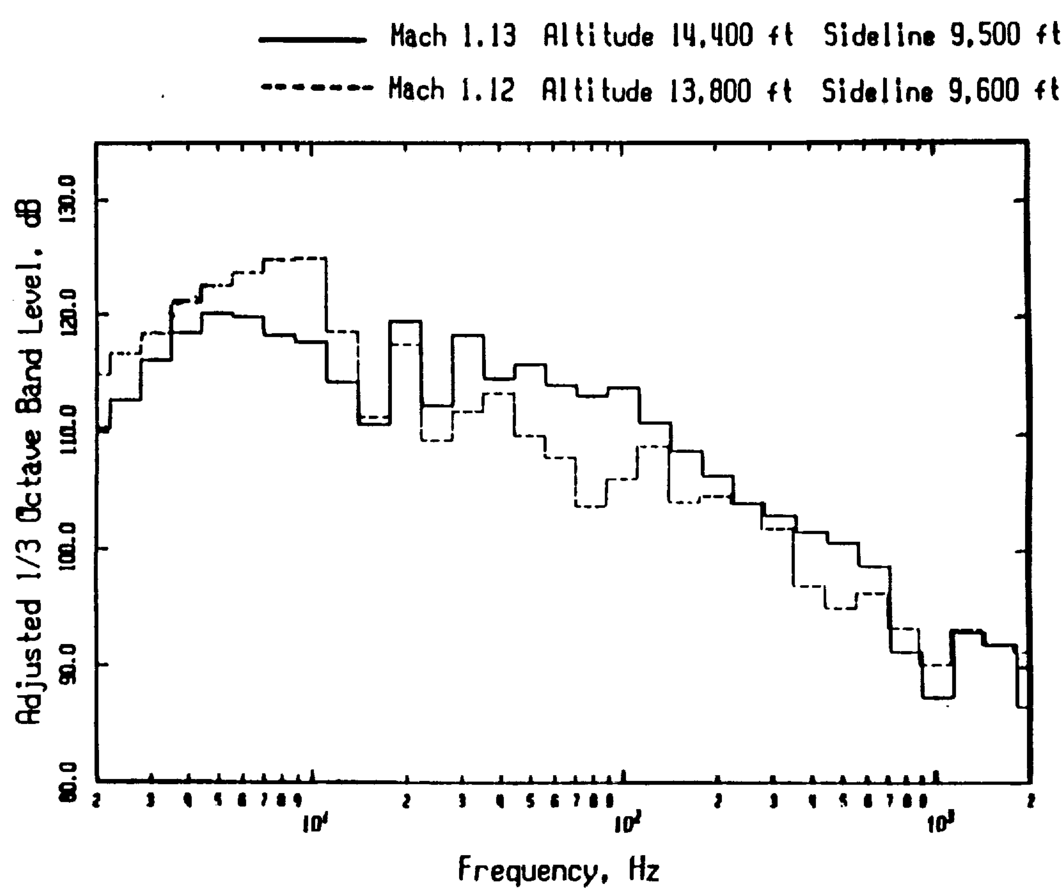
These plots show that the lower altitude runs (top figure) have greater variability in loudness compared to the higher altitude runs (bottom figure).



Sonic Boom Variability in a Repeat Data Point

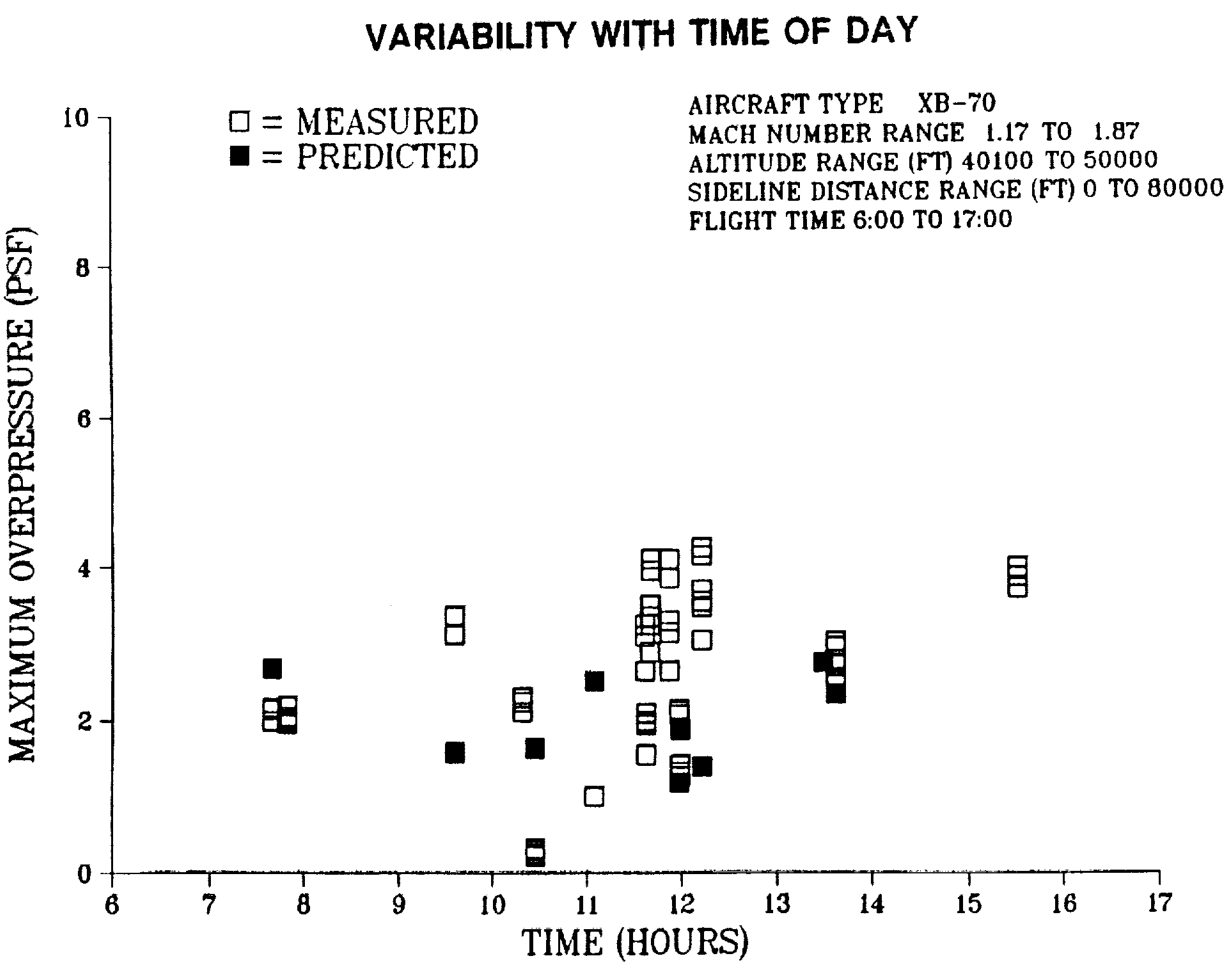
Data from two different flights at similar flight conditions roughly 10 minutes apart show the effect propagation through the atmosphere has on sonic booms. The overpressure plots show that the 11:44 flight resulted maximum overpressure of 5.19 psf and a rise time of 5 ms whereas the 11:54 flight yielded a maximum overpressure of 2.66 psf with a rise time of 6.875 ms. The difference in loudness between these two booms was 3.1 PLdB. The spectra plot shows that the 11:44 flight had less low frequency noise (below 200 Hz) and more high frequency noise (above 200 Hz) than the 11:54 flight.

SONIC BOOM VARIABILITY IN A REPEAT DATA POINT



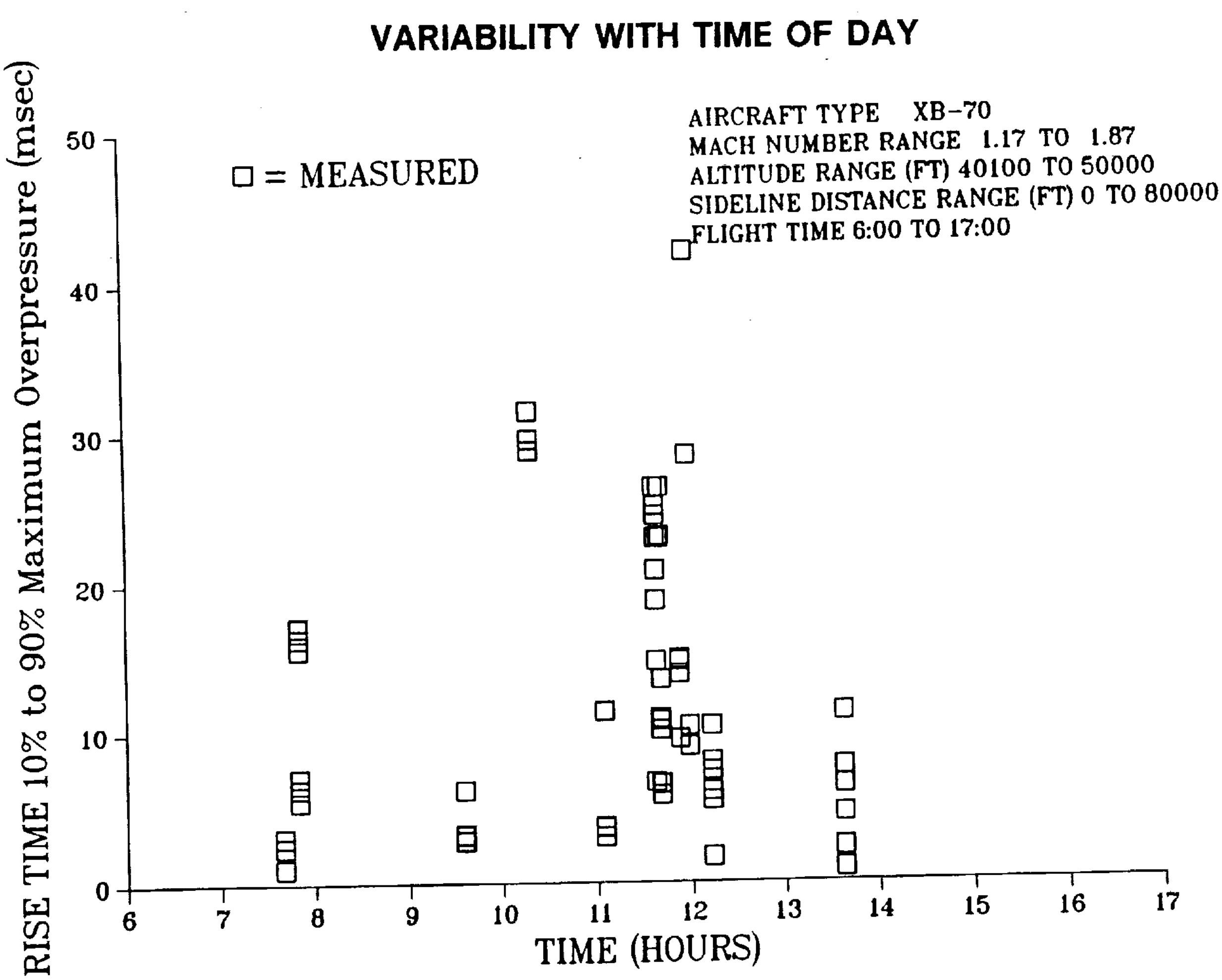
Variability with Time of Day

The measurements set up in the XB-70 database used either a three or six ground microphone cluster in a 200 by 200 foot square. Only minor variations are expected from one microphone to the other in the absence of significant propagation effects. Atmospheric turbulence and thus the propagation are expected to vary with the time of the day. The figure examines the variation in maximum overpressure with time of day. The data points are for flight conditions Mach = 1.17 to 1.87 and altitude = 40,000 ft to 50,000 ft (identified as Group 2 previously). The variation in values from one cluster to another is due to differences in operating conditions and sideline distances but the variations within a cluster are due to propagation differences. It can be noticed in this figure that the variability in maximum overpressure is very small for morning flights (prior to 11AM). Around noon and in the afternoon this variability increases a little.



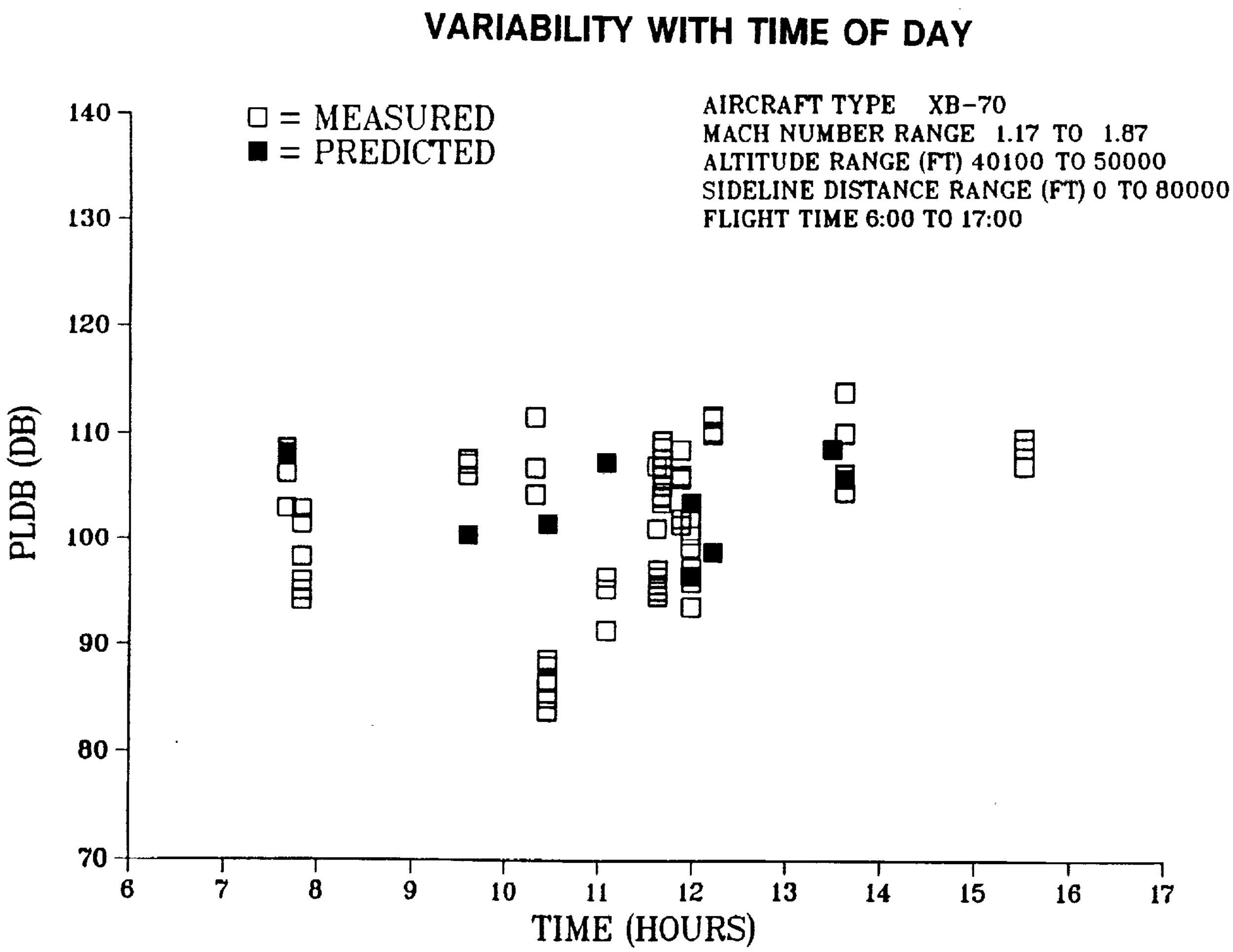
Variability with Time of Day

This figure shows the variation in rise time with time of day. The data points are for flight conditions Mach = 1.17 to 1.87 and altitude = 40,000 ft to 50,000 ft (identified as Group 2 previously). The variation in values from one cluster to another is due to differences in operating conditions and sideline distances but the variations within a cluster are due to propagation differences. The rise time shows a large increase in variability in the afternoon.



Variability with Time of Day

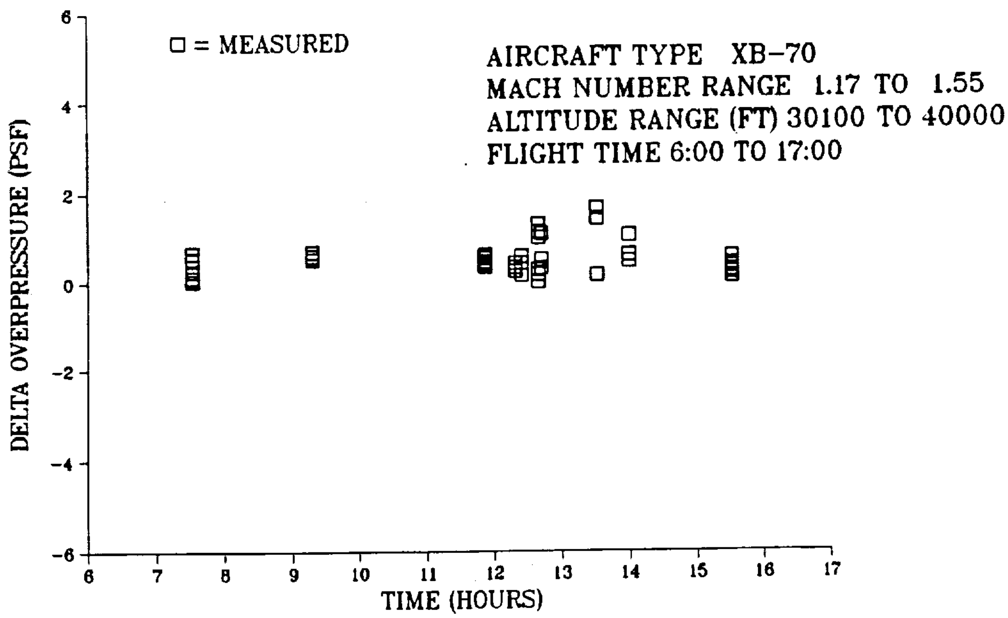
This figure examines the variation in loudness with time of day. The data points are for flight conditions Mach = 1.17 to 1.87 and altitude = 40,000 ft to 50,000 ft (identified as Group 2 previously). The variation in values from one cluster to another is due to differences in operating conditions and sideline distances but the variations within a cluster are due to propagation differences. It can be noticed in this figure that the variability in loudness can be as much as 10 PLdB in the measured data. Similar variability in loudness was noticed in groups 1,3, and 4 of the XB-70 database with the higher altitude runs generally having slightly lower variability.

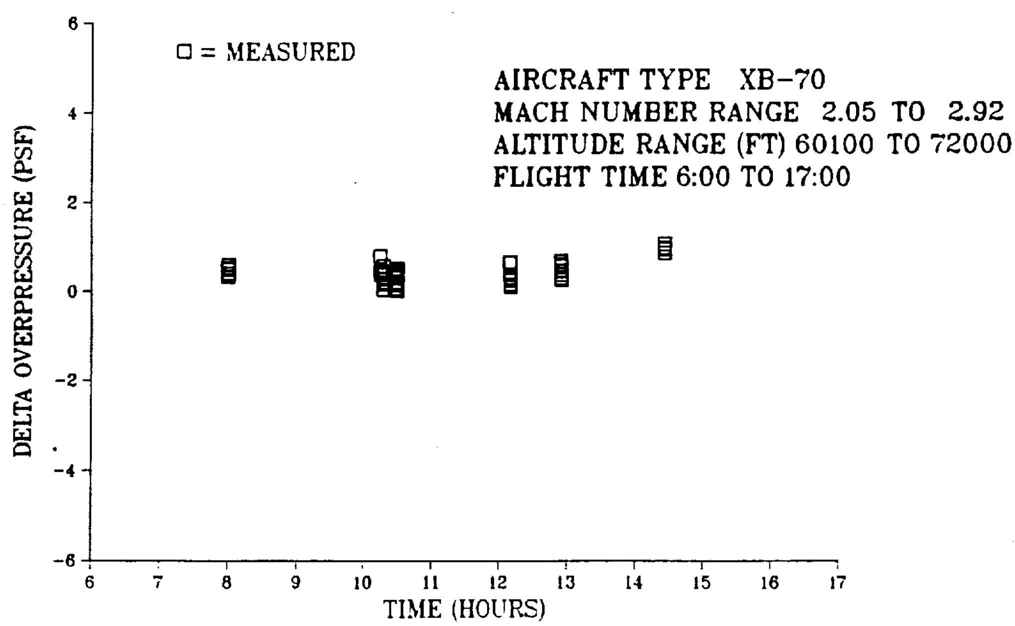


Variability in Boom Symmetry

Sonic boom asymmetry was determined by the difference between overpressure, PLdB, ASEL, or CSEL calculated separately for the compression portion and the expansion portion of the sonic boom signature. The variability in Δ overpressure for the lower altitude / lower Mach number group of flights (top figure) is slightly greater than the high altitude / high Mach number group of flights (bottom figure). The lower values and smaller variability in Δ overpressure (front shock) for the higher altitude / higher Mach number group is consistent with the near N-wave signatures and reduced atmospheric effects associated with these signatures in this altitude group.

VARIABILITY IN BOOM SYMMETRY

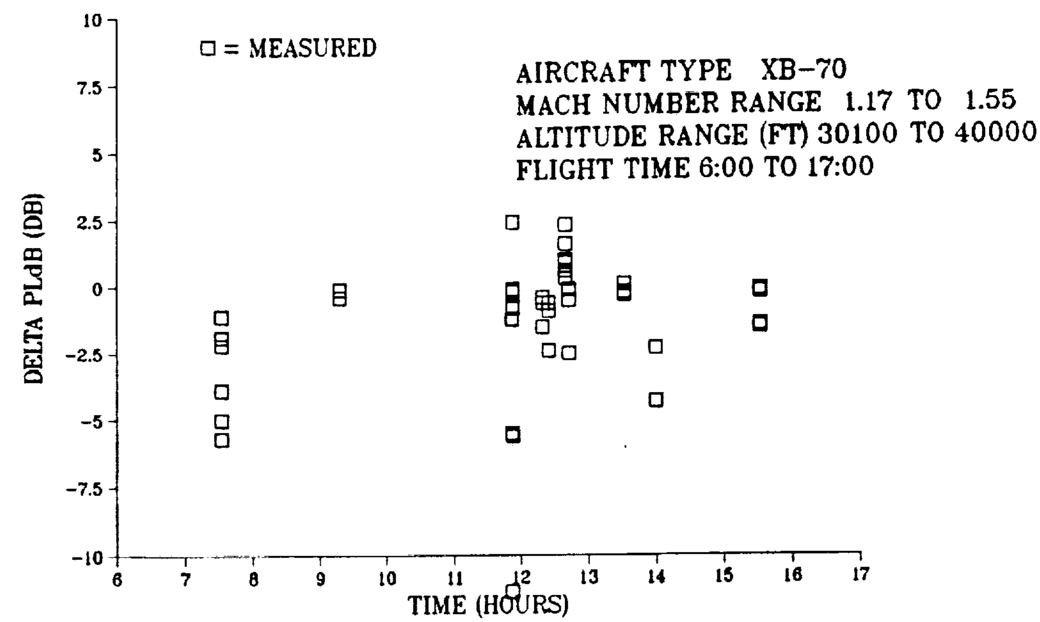


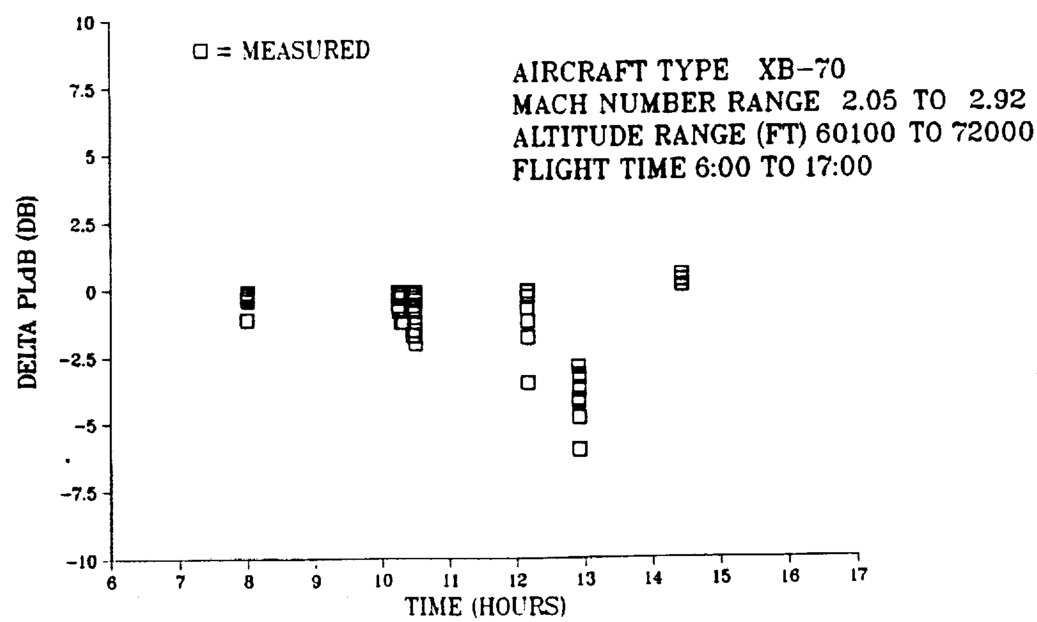


Variability in Boom Symmetry

Sonic boom asymmetry was determined by the difference between overpressure, PLdB, ASEL, or CSEL calculated separately for the compression portion and the expansion portion of the sonic boom signature. The variability in Δ PLdB in the lower altitude / lower Mach number group of flights (top figure) is slightly greater than the high altitude / high Mach number group of flights (bottom figure). In the "afternoon hours", the asymmetry in loudness has a greater variability than the asymmetry in overpressure (previously shown). This is an indication of the larger effect of atmospheric turbulence on rise time.

VARIABILITY IN BOOM SYMMETRY

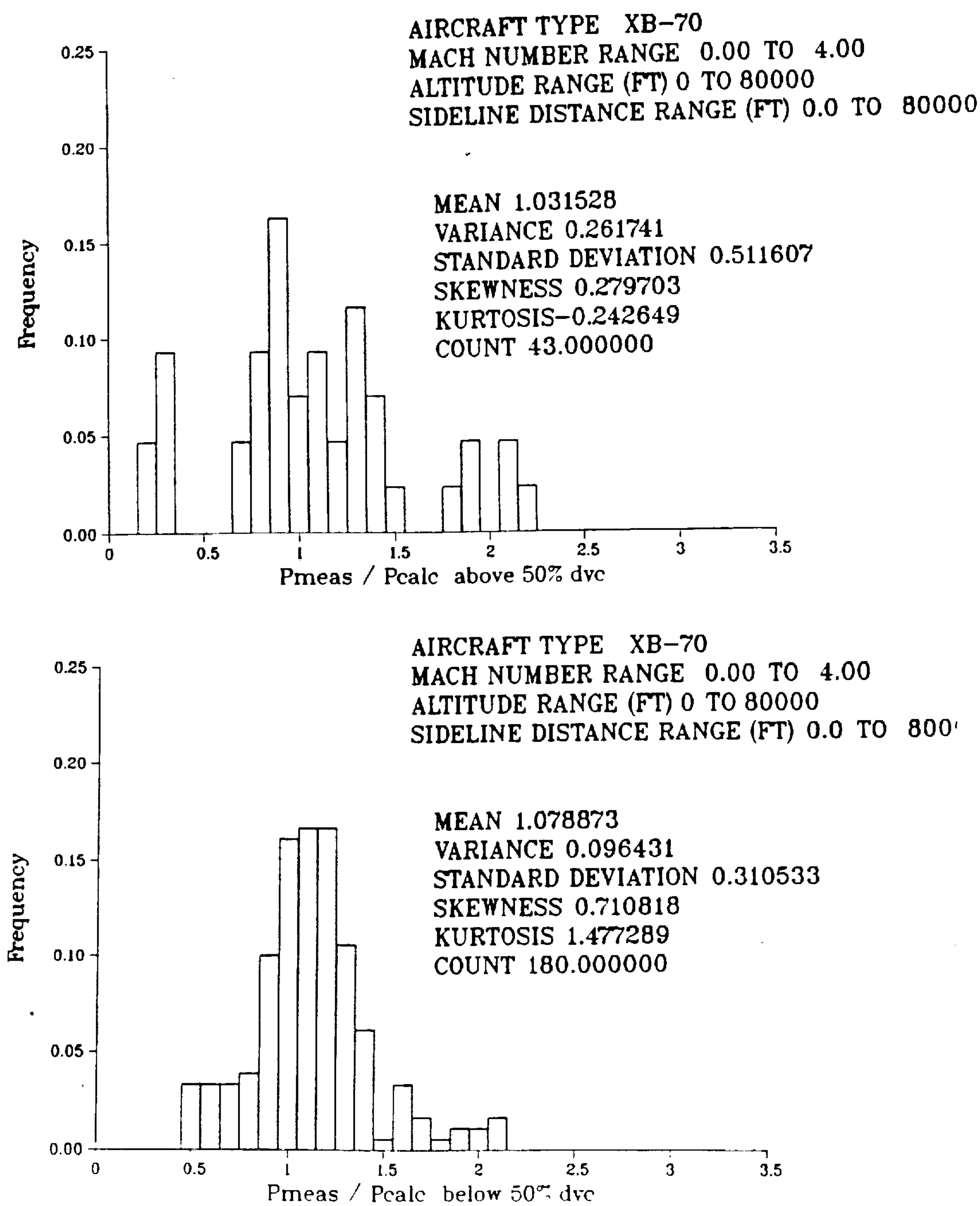




Statistical Distribution

The XB-70 database was divided into two data groups - those within 50 percent of the calculated lateral cutoff distance (dyc) and those outside of this boundary. Such a grouping has been used in Reference 5 in the analysis of BOOMFILE data. The histograms these figures represent the distribution of measured maximum overpressure values (normalized by the corresponding calculated uniform atmospheric maximum overpressure) in the database for these two groups. It can be seen that for the below 50% dyc group (bottom figure) maximum overpressure distribution is nearly symmetric and has approximately a normal distribution shape with shorter skirts (smaller variance) away from the mean value. By comparison, the above 50% dyc group (top figure) shows a large variability in measured maximum overpressure.

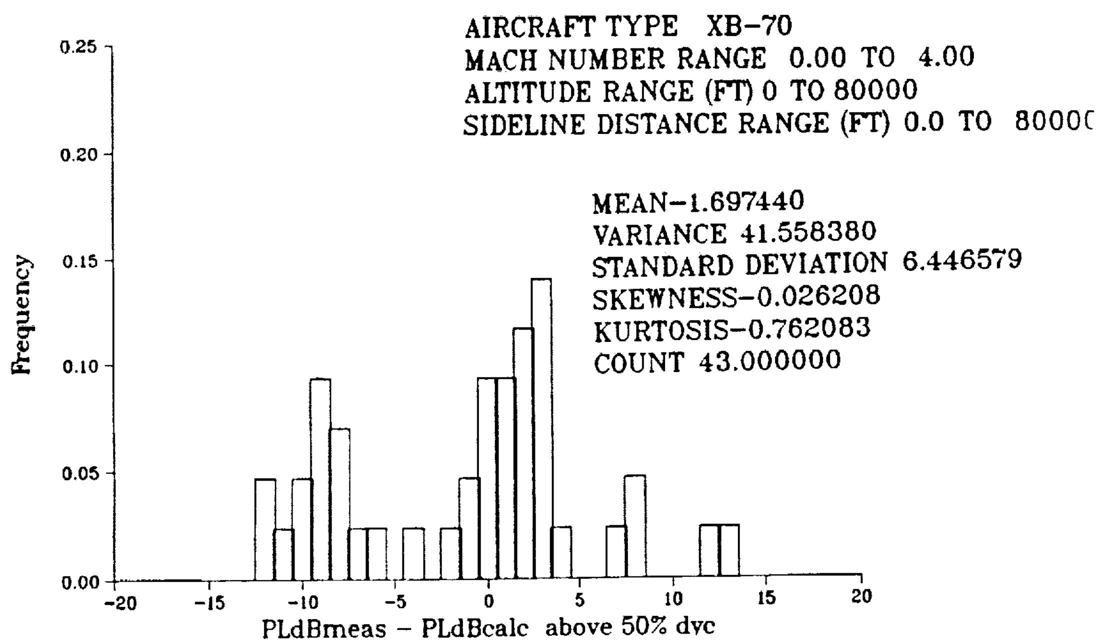
STATISTICAL DISTRIBUTION

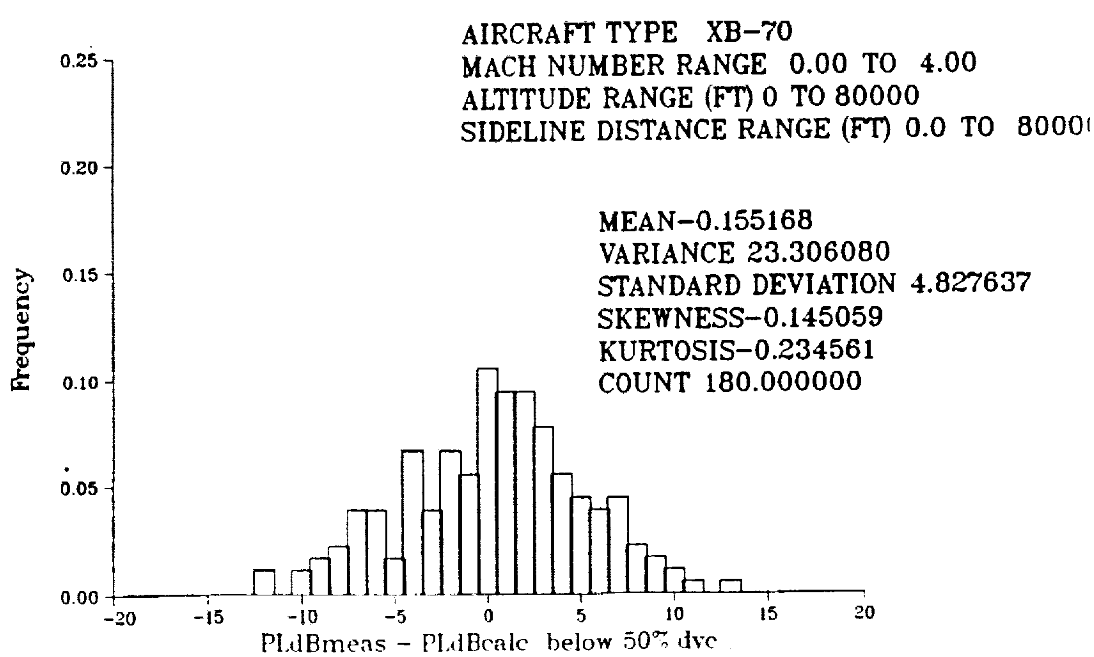


Statistical Distribution

The XB-70 database was divided into two data groups - those within 50 percent of the calculated lateral cutoff distance (dyc) and those outside of this boundary. Such a grouping has been used in Reference 5 in the analysis of BOOMFILE data. The histograms in these figures represent the distribution of the difference between measured and calculated (uniform atmosphere assumed) loudness in the XB-70 database for these two groups. The below 50% dyc group (bottom figure) has a symmetric distribution with a -0.15 dB mean for $PL_{meas} - PL_{calc}$ whereas the above 50% dyc group (top figure) has a bi-modal type distribution with a -1.7 dB mean and larger variance about the mean.

STATISTICAL DISTRIBUTION

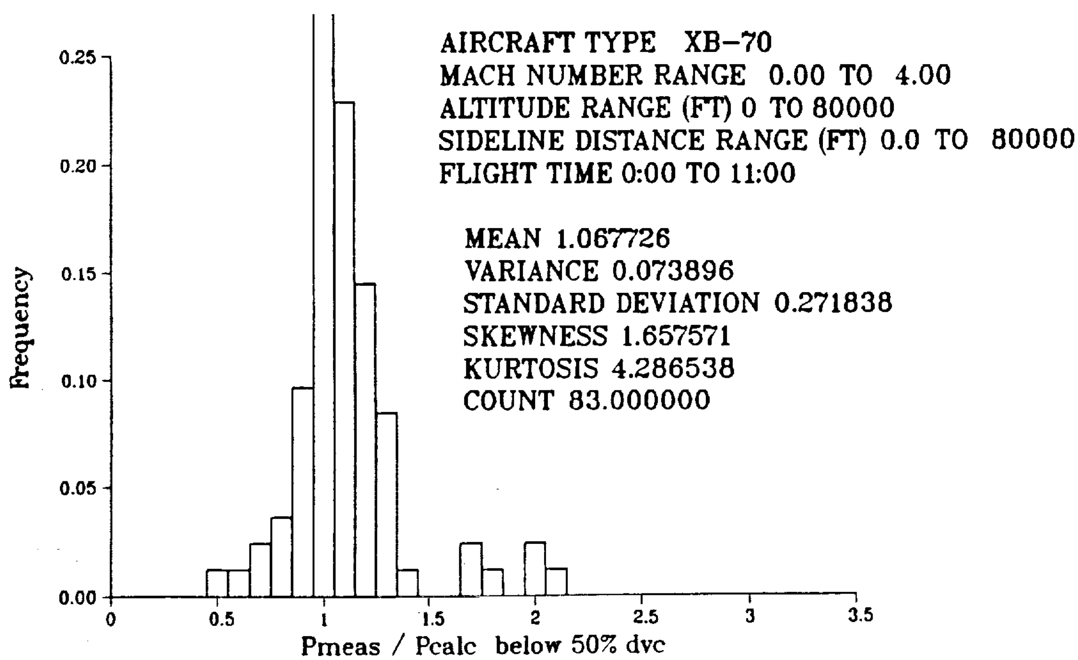


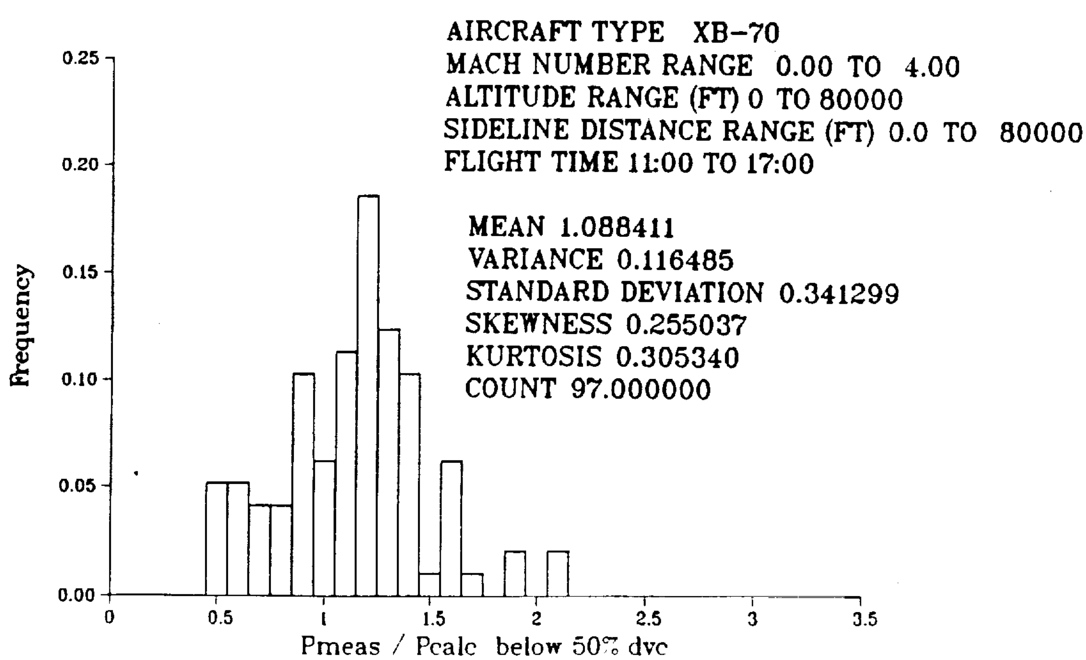


Statistical Distribution by Time of Day

The variability of measured maximum overpressure in the below 50% dye group was further analyzed in terms of the time of day to statistically quantify the turbulence effects. The histogram in top figure shows that the maximum overpressure measurements for the morning (before 11am) flights have a smaller variability than for flights which occur after 11am (bottom figure). While the mean values of maximum overpressure in the two plots are not very different, the mean values occurs more frequently before 11am than after 11am (i.e., the afternoon distribution has a larger variance). This trend was also observed in the sonic boom measurement program at White Sands Missile Range (Reference 6).

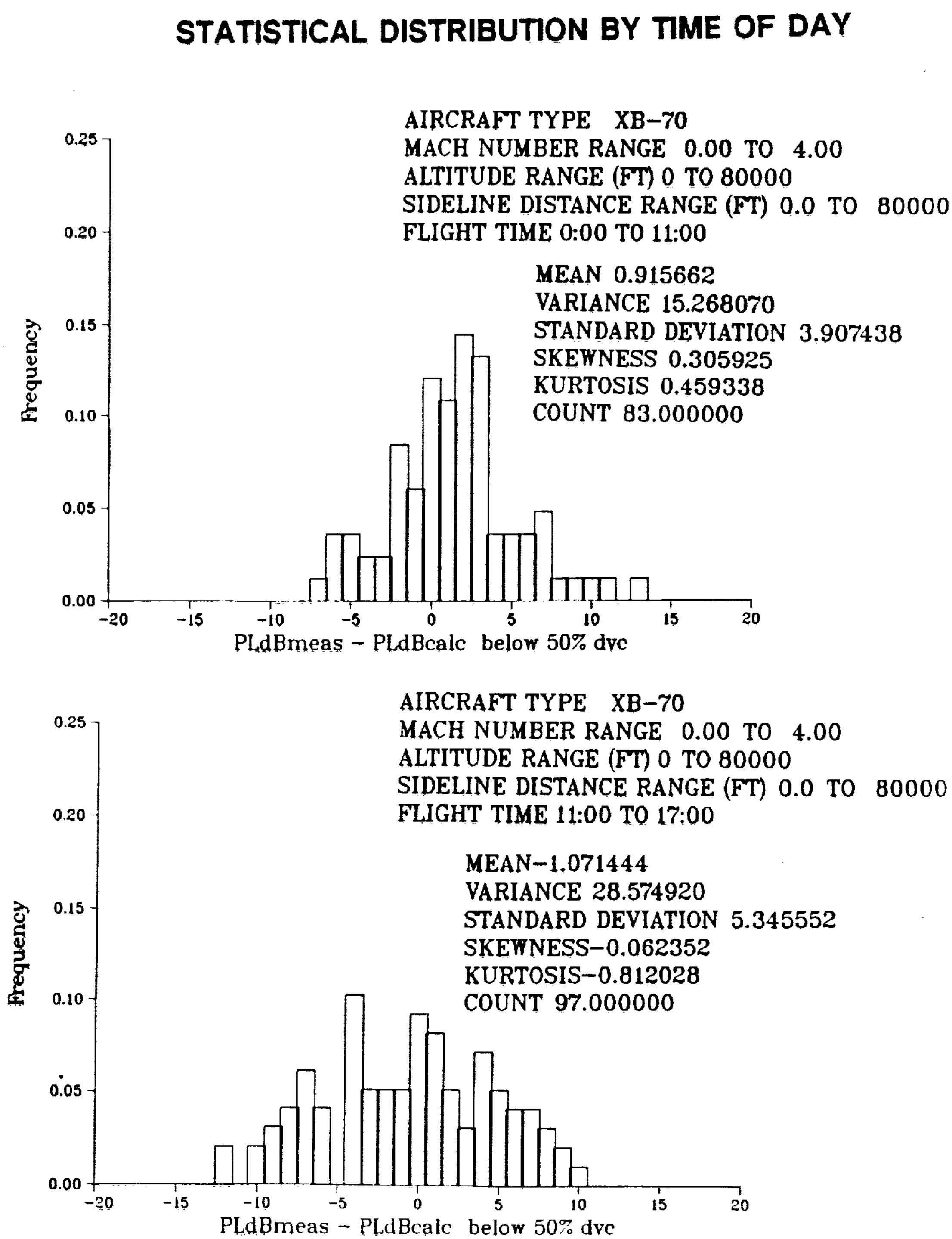
STATISTICAL DISTRIBUTION BY TIME OF DAY





Statistical Distribution by Time of Day

The variability of measured loudness in the below 50% dyc group was further analyzed in terms of the time of day to statistically quantify the turbulence effects. The histogram in top figure shows that the loudness measurements for the morning (before 11am) flights have a smaller variability than for flights which occur after 11am (bottom figure).



Summary

The BOOMFILE and XB70 databases were analyzed in various calculated metrics and rise times which are available in electronic format. The variation in boom loudness was observed to be as much as 10 PLdB with larger variation occurring in the lower altitude / lower Mach number flights, afternoon flights, and outside the carpet semi-span. Analysis of asymmetry showed that differences of up to 12 dB occurred and was greater for lower altitude / lower Mach number flights.

SUMMARY

- **ANALYZED VARIABILITY IN SONIC BOOM SIGNATURE PARAMETERS AND METRICS (DUE TO ATMOSPHERIC PROPAGATION) USING BOOMFILE AND XB-70 DATABASES**
- **10 dB VARIABILITY IN BOOM LOUDNESS POSSIBLE**
- **GREATER VARIABILITY OBSERVED IN**

  LOWER ALTITUDE / LOWER MACH NUMBER FLIGHTS

  AFTER MID-MORNING FLIGHTS

  MEASURMENTS OUTSIDE 50% OF SONIC BOOM CARPET SEMI-SPAN
- **UP TO 12 dB ASYMMETRY OBSERVED**
- **VARIABILITY IN BOOM ASYMMETRY GREATER FOR LOWER ALTITUDE / LOWER MACH NUMBER FLIGHTS**

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2. Maglieri, D. J. et al, Summary of XB-70 Sonic Boom Signature Data for Flights During March 1965 Through May 1966", NASA Contract Report 189630, 1992.

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