NASA TECHNICAL NOTE

NASA TN D-6950

NASA TN D-6950

SONIC-BOOM GROUND-PRESSURE MEASUREMENTS FROM APOLLO 15

by

David A. Hilton, Herbert R. Henderson,
Langley Research Center

and

Royce McKinney
Manned Spacecraft Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • SEPTEMBER 1972

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TN D-6950		

4. Title and Subtitle	5. Report Date
SONIC-BOOM GROUND-PRESSURE MEASUREMENTS FROM APOLLO 15	September 1972
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
David A. Hilton, Herbert R. Henderson, Langley Research Center; and Royce McKinney, Manned Spacecraft Center	L-8445
	10. Work Unit No. 909-72-47-01
9. Performing Organization Name and Address	11. Contract or Grant No.
NASA Langley Research Center Hampton, Va. 23365	
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Note
National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This paper presents sonic-boom pressure signatures recorded during the launch and reentry phases of the Apollo 15 mission. The measurements were obtained along the vehicle ground track at 87 km (47 n. mi.) and 970 km (523 n. mi.) downrange from the launch site during ascent; and at 500 km (270 n. mi.), 55.6 km (30 n. mi.), and 12.9 km (7.0 n. mi.) from the splashdown point during reentry. Tracings of the measured signatures are included along with values of the overpressure, impulse, time duration, and rise times. Also included are brief descriptions of the launch and recovery test areas in which the measurements were obtained, the sonic-boom instrumentation deployment, flight profiles and operating conditions for the launch vehicle and spacecraft, surface weather information at the measuring sites, and high-altitude weather information for the general measurement areas.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Sonic boom Spacecraft Atmospherics	Unclassified – Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	35	$3.00

*For sale by the National Technical Information Service, Springfield, Virginia 22151

SONIC-BOOM GROUND-PRESSURE MEASUREMENTS FROM APOLLO 15

By David A. Hilton, Herbert R. Henderson,
Langley Research Center

and Royce McKinney
Manned Spacecraft Center

SUMMARY

This paper presents sonic-boom pressure signatures recorded during the launch and reentry phase of Apollo 15. The measurements were obtained along the vehicle ground track at 87 km (47 n. mi.) and 970 km (523 n. mi.) downrange from the launch site during ascent; and at 500 km (270 n. mi.), 55.6 km (30 n. mi.), and 12.9 km (7.0 n. mi.) from the splashdown point during reentry. Tracings of the measured signatures are included along with values of the overpressure, impulse, duration, and rise times. Also included are brief descriptions of the launch and recovery test areas in which the measurements were obtained, the sonic-boom instrumentation deployment, flight profiles and operating conditions for the launch vehicle and spacecraft, surface weather information at the measuring sites, and high-altitude weather information for the general measurement areas.

Sonic-boom pressure signatures similar in nature to those associated with aircraft were observed during the ascent and reentry of Apollo 15. Overpressure values of about 50 N/m^2 (1.04 psf) and less than 10 N/m^2 (0.209 psf) were observed during the ascent phase for altitudes of about 63 000 m (206 703 ft) and 179 000 m (587 299 ft), respectively; values of about 9 N/m^2 (0.188 psf), 20 N/m^2 (0.418 psf), and 38 N/m^2 (0.793 psf) were observed during the reentry phase for altitudes of about 52 000 m (170 612 ft), 33 000 m (108 000 ft), and 25 000 m (82 025 ft), respectively. The signatures were not simple N-wave shapes but contained a number of intermediate shocks. Predicted values of the maximum sonic-boom overpressure and wave period made by utilizing available semi-empirical calculation techniques correlated well with the measurements for the reentry conditions. Predictions for the ascent phase were made on the basis of the vehicles only, as it was not clear how to account for the effect of the rocket-motor exhaust plume on the sonic-boom overpressures. The measured arrival times of the boom at each of the five ground recording stations correlated well with predicted values. All signatures exhibited rapid rise times which are of the order of those observed from aircraft. Very long wave periods were observed from the measurements made during the ascent, and these are attributed to the effects of the rocket-engine exhaust plume.

INTRODUCTION

In recent years a large amount of experimental information relating to sonic-boom pressure signatures from various aircraft flight studies has been accumulated. This information includes measurements for small and large aircraft in the weight range 4535 kg (10 000 lb) to 181 437 kg (400 068 lb) operating at altitudes from 15 m (49 ft) to above 22 000 m (72 182 ft) and at Mach numbers up to 3.0. It has been shown that available prediction techniques provide good correlation with the measurements over the range of altitude, Mach number, and aircraft weight. The various aspects of the effects of different parameters may be seen in references 1 to 10.

The Apollo 15 operation provided an excellent opportunity to obtain sonic-boom information at Mach numbers and altitudes well beyond those associated with current aircraft. Also, vehicle configuration and attitude are different from present aircraft. Such information should provide an indication of the applicability of the current theory to predict sonic-boom pressure signatures at very high Mach numbers and altitudes. An experimental program was implemented to obtain sonic-boom data during the ascent and reentry phases of the Apollo 15 mission. Measurements were obtained during ascent at approximately 87 km (47 n. mi.) and 970 km (523 n. mi.) from the launch site and along the ground track of the launch vehicle. During reentry, measurements were obtained at approximately 500 km (270 n. mi.), 56 km (30 n. mi.), and 12.9 (7.0 n. mi.) from splashdown along the reentry ground track.

The purpose of this paper is to present the results of this measurement program. Included are tracings of the sonic-boom signatures along with tabulated values of overpressure, impulse, wave period, and shock rise times. Also included are brief descriptions of the launch and recovery test areas in which the measurements were obtained, the sonic-boom instrumentation deployment, vehicle and spacecraft flight profiles and operating conditions, surface weather information at the measuring sites, and high-altitude weather information for the general measurement areas.

SYMBOLS

Values are given both in the SI Units and the U.S. Customary Units. The measurements and calculations were made in the U.S. Customary Units.

I_o impulse of positive phase of sonic-boom ground-pressure signature, newton-seconds/meter^2 (lb-sec/ft^2)

Δp maximum pressure rise across bow shock wave measured at ground level, newtons/meter^2 (lb/ft^2)

Δt_o time duration of positive phase of sonic-boom ground-pressure signature, seconds

ΔT total time duration of sonic-boom ground-pressure signature, seconds

τ rise time of sonic-boom pressure signature (defined as time from onset of bow shock wave to its maximum positive value of overpressure), seconds

ABBREVIATIONS

S-IC Saturn first stage

S-II Saturn second stage

CM command module

APPARATUS AND METHODS

Test Vehicle

A schematic diagram of the Apollo 15/Saturn V configuration is shown in figure 1. The S-IC stage flight configuration (which includes the total flight vehicle) had an overall length of 110.65 m (363.04 ft) and a gross weight of 2 984 007 kg (6 579 735 lb), with a dry weight of 209 654 kg (462 287 lb), and developed a total thrust of 34 MN (7 643 503 lb), at lift-off. The S-II stage flight configuration had a length of 59.67 m (195.8 ft) with a diameter of 10.06 m (33.01 ft) and developed a total thrust of 5.2 MN (1 169 000 lb). The S-IV stage flight configuration had a length of 31.83 m (104.4 ft) with a diameter of 6.6 m (21.7 ft) and developed a total thrust of 0.9 MN (202 328 lb). The Apollo 15 command module (reentry configuration) had an overall length of 2.6 m (8.5 ft), a maximum diameter of 3.9 m (12.8 ft), and a gross weight at reentry of 5806 kg (12 802 lb).

Test Area and Arrangement

In figure 2 are shown the general test areas associated with the launch and recovery operations of Apollo 15. Sonic-boom measurements in the Atlantic were made onboard two ships (see schematic diagram in fig. 3) positioned along the ground track of the spacecraft: the U.S.S. Salinan at approximately 87 km (47 n. mi.) from the launch site and the U.S.S. Austin approximately 970 km (523 n. mi.) from the launch site, a position where the exhaust plume of the Saturn V would be fully developed.

Measurements in the Pacific were obtained onboard three ships positioned along the ground track of the spacecraft: the U.S.S. Genesee at approximately 500 km (270 n. mi.)

from splashdown, the U.S.S. Kawishiwi at approximately 55.6 km (30 n. mi.) from splashdown, and the U.S.S. Okinawa at approximately 12.9 km (7.0 n. mi.) from splashdown.

Figure 4 is a map of the Atlantic test area in which are shown the actual positions of the two ships along with the spacecraft ground track. Figure 5 is a map of the general splashdown area in the Pacific showing the positions of the three ships along with an indication of the spacecraft ground track. The exact positions of the five ships at the time of boom arrival are given in table I along with the spacecraft altitude and velocity at the overhead position for each ship. Also noted in table I are the exact arrival times of the boom at each ship.

Measurement Platforms

Photographs of the various ships on which boom measurements were obtained are shown in figure 6. The U.S.S. Salinan and the U.S.S. Austin, shown on the left-hand side of the figure, were positioned in the Atlantic Ocean and the U.S.S. Okinawa, the U.S.S. Kawishiwi, and the U.S.S. Genesee were positioned in the Pacific. The U.S.S. Salinan, an Apache class salvage ship is 61.9 m (203.1 ft) long with a 11.7-m (38.4-ft) beam; the U.S.S. Austin, an Austin class LPD is 173.7 m (570 ft) long with a 25.6-m (84-ft) beam; the U.S.S. Okinawa, an Iwo Jima class LPH, is 180.4 m (592 ft) long with a 25.6-m (84-ft) beam; the U.S.S. Kawishiwi, a Neosho class AO, is 199.6 m (654.9 ft) long with a 26.2-m (86-ft) beam; and the U.S.S. Genesee, a Patapsco class AOG, is 94.7 m (310.7 ft) long with a 14.8-m (48.6-ft) beam.

Also indicated in the photographs are the general areas in which the sonic-boom measurement systems were located on each of the five ships. During the ascent and reentry boom measurements, the ships traveled in the direction of flight along the ground track at slow speed utilizing only enough power to maintain steerage and thus keep ship noise at a minimum.

In table II are indicated the ship speeds, surface weather, and sea conditions existing during the measurement portion of the tests. Sea conditions in both the Atlantic and Pacific Oceans were essentially calm.

Spacecraft Positioning

The Apollo 15 space vehicle was launched at the Kennedy Space Center, Florida. Launch azimuth was 80° from true north. Boost to orbit consisted of a full burn of the S-IC and S-II stages and a partial burn of the S-IVB stage of the Saturn V launch vehicle. The mission had a duration of 12 days, and the command module reentered the earth's atmosphere over the mid-Pacific Ocean near Hawaii. The command module landed approximately 2207 km (1191 n. mi.) downrange of the reentry interface, which occurred at an altitude of 121 920 m (400 000 ft).

Figures 7(a) and 7(b) present some of the more pertinent operational data associated with the launch and reentry of the spacecraft, respectively. Altitude in meters is plotted as a function of time. These data were from AS-510 Postflight Trajectory Data supplied by The Boeing Company Space Division, Huntsville, Alabama, and from AS 510/CSM 112/LM-10 Apollo Flight Data from the NASA Manned Spacecraft Center. Indicated in the figures are velocities (in meters/second), the overhead times at each ship, and the time that the boom was recorded at each ship. The total space vehicle (S-IC flight vehicle) passed overhead of the U.S.S. Salinan, but only the S-II flight stage passed over the U.S.S. Austin. At the top of the figures are indicated the events associated with the operation of the launch system, such as maximum dynamic pressure and main engine cutoff.

Pressure-Measurement Instrumentation

The instrumentation employed for the Apollo 15 sonic-boom pressure measurements is similar to that used in references 1 to 10 for measurements of aircraft sonic-boom pressures. The main components of the sonic-boom measuring systems were specially modified condenser-type microphones (see ref. 10), a tuning unit, a dc amplifier, an FM tape recorder, and a recording oscillograph. A block diagram of a typical data acquisition system which was placed aboard each ship is shown in figure 8. Although estimates were made of the expected levels using existing theory (ref. 6), three microphones were used on each ship for purposes of redundancy. The output of each microphone was routed to two separate amplifiers. This technique allowed six separate sensitivity settings to be utilized. Shown in figure 9(a) is a photograph of the signal-conditioning and recording equipment that was mounted in a compartment aboard each ship. Figure 9(b) shows a photograph of the microphone mounting arrangement complete with wind screen (consisting of two layers of cheese cloth).

The microphone sensitivity ranges from about 70 to 150 dB with a frequency response of 0.02 Hz to 10 kHz. The tuning unit consists of a radio-frequency oscillator coupled to a diode detector circuit with a cathode follower output. This unit has a frequency response of 0 to 10 kHz. The dc instrumentation amplifiers are fully transistorized with a dual output capability: a current output for driving high-frequency galvanometers and a voltage output for driving magnetic tape recorders. The frequency response for this dual capability is 0 to 5 kHz $\pm$ 0.2 dB and 0 to 20 kHz $\pm$ 0.2 dB, respectively. The magnetic tape recorders are of the frequency-modulated type operated at 30 ips with a $\pm$40-percent deviation of the carrier having a center frequency of 54 kHz. The frequency response is 0 to 10 kHz $\pm$ 0.5 dB. The recording oscillograph is a direct-writing type which is capable of simultaneously recording up to 24 channels of data. The entire sound-measurement system was calibrated onboard ship by means of discrete-frequency calibrators. These calibrators operated with a fixed frequency of 1 kHz and produced an rms sound pressure level of 130 dB $\pm$ 0.75 dB.

Efforts were made to place the microphones on the deck of each ship in an uncluttered area to minimize the possibility of significant sonic-boom shock-wave reflections. As will be noted from figure 6, two of the ships (the U.S.S. Okinawa and the U.S.S. Austin) were ideally suited for the measurements because large open areas were available. On the other ships, however, the locations were not so desirable. The photographs of figure 10 illustrate the microphone locations aboard the five ships. All three microphones aboard each ship were placed within 0.45 m (1.5 ft) of each other. The combination of flight-path angle and Mach number for the point at which the boom disturbances were generated resulted in sonic-boom disturbance ray paths which were nearly vertical. Therefore, the chances of adjacent surfaces near the microphones causing significant reflected waves would be minimized. The microphones were mounted as close as possible to the deck (0.15 m (6 in.)) so that the incident wave and reflected waves from the deck would be in phase. (See refs. 1 and 2.)

Atmospheric Soundings

Rawinsonde observations from Cape Kennedy, Florida, were taken on July 26, 1971, at approximately 15 minutes before liftoff. Measured values of temperature, wind speed and direction, humidity, and sound speed were provided for altitudes from 5 m (16.4 ft) to approximately 34 km (109 913 ft). These various parameters are given in table III.

Rocket sounding data from Barking Sands, Hawaii, were taken on August 7, 1971, approximately 1 hour after splashdown. Measured values of wind direction and speed, temperature, and sound speed were obtained at altitudes from 31 000 m (101 711 ft) to approximately 104 000 m (341 224 ft). The various parameters are listed in table IV. In addition to the weather measurements as described above, local climatological data were obtained from each ship in the test area at the time of the boom arrival and are presented in table II. These data include such characteristics as surface temperatures, surface winds, and sea conditions. At the Atlantic stations, surface temperatures were about 300 K (80.3° F) and surface winds ranged from 4 to 9 knots. At the Pacific station, the temperature ranged around 300 K (80.3° F) and wind velocities were from 4 to 8 knots. As indicated previously, sea conditions were calm in both measurement locations.

RESULTS AND DISCUSSION

Signature Characteristics

Types of experimental data obtained from the measurements of the present studies are illustrated in figure 11, which shows an example Apollo 15 sonic-boom signature measured during reentry. Indicated are the various measured quantities of peak overpressure Δp, wave period ΔT, positive impulse I_o (integrated area of Δp versus time for duration of positive pulse), rise time τ, and the positive duration Δt_o. These

parameters were measured for each of the sonic-boom signatures recorded at each of the five locations and are listed in table V.

Ascent Measurements

Figure 12 presents measured sonic-boom signatures obtained in the Atlantic aboard the U.S.S. Salinan and the U.S.S. Austin which were positioned 87 km (47 n. mi.) and 970 km (523 n. mi.) downrange from the launch site, respectively. Listed in the figure are the velocity and altitude of the launch vehicle at the time it was directly overhead the measurement ship. Also indicated in the figure are the time base for the signatures and the measured overpressure for each signature.

Both signatures exhibit long total duration times having a positive duration in excess of 1.5 seconds. The initial positive impulse is believed to be due to the spacecraft as it neared the overhead position. The positive peak occurring approximately 8 seconds after the initial pressure onset, as measured aboard the U.S.S. Salinan, is believed to be a secondary sonic-boom pressure wave that was generated by the spacecraft farther up the flight track (closer to the launch site) and is due either to the curved flight path of the vehicle or its acceleration rate. (See ref. 2.) The source of the secondary negative pulse that occurs on the signature measured on the U.S.S. Austin approximately 7.5 seconds after the initial positive pulse is not known at this time.

The long duration times are believed to be associated with the effect of the spacecraft rocket-motor plume during ascent. The plume is very large in size and does not have definite length. This lack of finite end dimension is evidenced by the slow negative closure of the shock signature. It is also believed that the overpressures are increased over and above what would be expected for the spacecraft alone because of the presence of the rocket-motor plume, as indicated in recent studies by Raymond M. Hicks and Joel P. Mendoza of the NASA Ames Research Center.

The overpressure signatures as measured during the launch on both ships exhibited very rapid rise times. These rise times were of the same order of magnitude as those previously measured for aircraft sonic-boom signatures. An attempt is made to illustrate these rapid rise times in figure 13. In this figure again the signatures from both ships are presented; however, only a small portion of the positive phase is shown, as the time base has been greatly expanded. As indicated in table V, these rise times are on the order of from 5 to 6 milliseconds. Previous flight studies involving aircraft have indicated that as the altitude increases, the signature rise time also increases. (See fig. 17 of ref. 9.) It is interesting to note, however, that the subjective comments received from the crewmen on the ships, particularly in the Atlantic, indicate that the booms from the spacecraft had a dull sound rather than a sharp sound even though the rise times are equivalent to those of aircraft having a sharp sounding boom. However, in table V it can

be seen that the high-altitude Apollo signatures exhibited rise times that are comparable with signatures measured from low-altitude aircraft, as mentioned before, and do not seem to follow the general trend mentioned above.

Reentry Measurements

The measured sonic-boom signatures obtained onboard the U.S.S. Genesee, the U.S.S. Kawishiwi, and the U.S.S. Okinawa during the descent of the spacecraft are presented in figure 14. An indication of the time base is shown in the figure along with the actual measured overpressure for each signature. For comparative purposes, table VI includes the overpressures that were estimated before the flight from preflight mission data supplied by NASA Manned Spacecraft Center by using the techniques described in references 4 and 6. These preflight estimates were made for the purpose of ranging the instrumentation, and it can be seen that the estimated overpressures and the actual measured overpressure agree well.

However, the signatures exhibit multiple shocks which were not indicated in the tunnel studies of a 0.016-scale model of the Apollo command module by Raymond M. Hicks and Joel P. Mendoza of the NASA Ames Research Center. These shocks are probably due to the spacecraft itself; however, reflections from objects onboard ship cannot be definitely ruled out. As stated before, reasonable care was taken to place the microphones in uncluttered areas. If one inspects the measured signatures closely, there does seem to be a progressive change from a large number of very small multiple shocks, in the case of the measurement aboard the U.S.S. Genesee, to a small number of well-defined shocks, in the case of the measurements taken aboard the U.S.S. Okinawa.

It can be noted that the signatures exhibit rapid rise times as illustrated by the data of figure 15, where again the time base has been expanded in order to illustrate the rapid rise times. As indicated in table V, the measured rise times are on the order of 5 to 10 milliseconds.

Comparison With Other Measured Data

Sonic-boom overpressure measurements have been obtained for other Apollo missions during the launch phase of the flight. (See ref. 11.) These measurements were made in Bermuda by use of a measurement system that had a frequency response of 0.3 Hz to 10 Hz.

Presented in figure 16(a) are the sonic-boom overpressure data measured aboard the U.S.S. Austin by using a system having the frequency response of 0.02 Hz to 10 kHz. In figure 16(b) is the same signature after it has been passed through a system having a response of from 0.3 Hz to 10 Hz. It can be seen that the signature shape is considerably altered and there is some loss in absolute peak overpressure when a measurement system

having a response of 0.3 Hz to 10 Hz is utilized to measure a sonic-boom signature having a fundamental frequency of less than 1 Hz.

Comparison With Calculations

Existing techniques (see refs. 4, 6, and 12) were used to estimate the magnitude of the overpressures and time durations that would be associated with the space vehicle during ascent and reentry, and these comparisons are contained in table VI. On the left side of the table, the measurement positions indicate the flight conditions at overhead. The data for the first two measurement positions relate to ascent conditions, whereas the last three measurement positions relate to descent. The measured values of overpressure and total duration are listed in the table along with estimated values based on the geometry of the vehicle and the nominal flight conditions. Possible effects of the rocket-exhaust plume on ascent and the ionization sheath on descent are ignored. Absolute overpressure estimates were not attempted for the ascent condition since it was not clear how to handle the exhaust plume. Fairly good comparisons were obtained for the measured and calculated overpressures for the descent conditions.

The estimates of overall duration are generally low for the ascent conditions and high for the descent conditions. The discrepancies for the ascent flight conditions are again believed to be due to the rocket-exhaust plumes which are not properly accounted for in the estimate. However, if semiempirical techniques are used for the reentry condition (as in the wind-tunnel studies of Raymond M. Hicks and Joel P. Mendoza of the NASA Ames Research Center and Frank Garcia, Jr., of the NASA Manned Spacecraft Center), the agreement between the computed period and the measured period is very good.

CONCLUDING REMARKS

This paper presents sonic-boom pressure signatures recorded during the launch and reentry phases of Apollo 15. Sonic-boom pressure signatures similar in nature to those associated with aircraft were observed during the ascent and reentry. Overpressure values of about 50 N/m^2 (1.04 psf) and 10 N/m^2 (0.209 psf) were observed during the ascent phase for altitudes of 63 000 m (206 703 ft) and 179 000 m (587 299 ft), respectively. The overpressures observed during reentry were about 9 N/m^2 (0.188 psf), 20 N/m^2 (0.418 psf), and 38 N/m^2 (0.793 psf) for altitudes of about 52 000 m (170 612 ft), 33 000 m (108 000 ft), and 25 000 m (82 025 ft), respectively. The signatures were not simple N-wave shapes but contained a number of intermediate shocks. Predicted values of the maximum sonic-boom overpressures and wave period made by utilizing available semiempirical techniques correlated well with the measurements for the reentry condition. All signatures exhibited rapid rise times, which are of the order of those observed

from aircraft. Very long wave periods were observed from the measurements made during the ascent phase, and these are attributed to the effect of the rocket-engine exhaust plume. The rocket-engine exhaust plume has a decided effect on signature duration and closure.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., August 14, 1972.

REFERENCES

1. Maglieri, Domenic J.; Huckel, Vera; and Parrott, Tony L.: Ground Measurements of Shock-Wave Pressure for Fighter Airplanes Flying at Very Low Altitudes and Comments on Associated Response Phenomena. NASA TN D-3443, 1966. (Supersedes NASA TM X-611.)

2. Hubbard, Harvey H.; Maglieri, Domenic J.; Huckel, Vera; and Hilton, David A. (With appendix by Harry W. Carlson): Ground Measurements of Sonic-Boom Pressures for the Altitude Range of 10,000 to 75,000 Feet. NASA TR R-198, 1964. (Supersedes NASA TM X-633.)

3. Schwartz, Ira R., ed.: Second Conference on Sonic Boom Research. NASA SP-180, 1968.

4. Carlson, Harry W.: Correlation of Sonic-Boom Theory With Wind-Tunnel and Flight Measurements. NASA TR R-213, 1964.

5. Seebass, R.: Sonic Boom Theory. J. Aircraft, vol. 6, no. 3, May-June 1969, pp. 177-184.

6. Carlson, H. W.; and Maglieri, D. J.: Review of Sonic-Boom Generation Theory and Prediction Methods. J. Acoust. Soc. Amer., vol. 51, no. 2, pt. 3, Feb. 1972, pp. 675-685.

7. Hayes, Wallace D.; Haefeli, Rudolph C.; and Kulsrud, H. E.: Sonic-Boom Propagation in a Stratified Atmosphere, With Computer Program. NASA CR-1299, 1969.

8. Seebass, A. R., ed.: Sonic Boom Research. NASA SP-147, 1967.

9. Maglieri, Domenic J.; Parrott, Tony L.; Hilton, David A.; and Copeland, William L.: Lateral-Spread Sonic-Boom Ground-Pressure Measurements From Airplanes at Altitudes to 75,000 Feet and at Mach Numbers to 2.0. NASA TN D-2021, 1963.

10. Anon.: Proceedings of the Sonic Boom Symposium. J. Acoust. Soc. Amer., vol. 39, no. 5, pt. 2, May 1966, pp. S1-S80.

11. Cotten, Donald; and Donn, William L.: Sound from Apollo Rockets in Space. Science, vol. 171, no. 3971, Feb. 12, 1971, pp. 565-567.

12. Maglieri, Domenic J.; Hubbard, Harvey H.; and Lansing, Donald L.: Ground Measurements of the Shock-Wave Noise From Airplanes in Level Flight at Mach Numbers to 1.4 and at Altitudes to 45,000 Feet. NASA TN D-48, 1959.

TABLE I.- SHIP POSITION AT WHICH MEASUREMENTS WERE OBTAINED, ALONG WITH LAUNCH VEHICLE AND SPACECRAFT ALTITUDE AND VELOCITY AT OVERHEAD

Date	Measurement location	Ship	Boom arrival time, GMT	Ship position at time of boom arrival, deg	Spacecraft overhead time, GMT	Spacecraft altitude at overhead time		Spacecraft velocity at overhead time	
						meters	feet	m/sec	ft/sec
7-26-71	Atlantic	U.S.S. Salinan	1339:39:7	79.8002 W 28.6501 N	1336:34	63 462	208 219	2210	7 251
7-26-71	Atlantic	U.S.S. Austin	1348:33:22	71.000 W 29.916 N	1341:06	178 778	586 571	4762	15 623
8- 7-71	Pacific	U.S.S. Okinawa	2040:56:00	158.266 W 26.213 N	2039:14:09	25 150	82 517	617	2 024
8- 7-71	Pacific	U.S.S. Kawishiwi	2040:32:00	158.516 W 25.900 N	2038:42:09	33 147	108 759	1367	4 485
8- 7-71	Pacific	U.S.S. Genesee	2039:10:00	162.223 W 23.683 N	2036:20:09	52 485	172 203	5134	16 844

TABLE II.- SUMMARY OF SHIP SPEED, SURFACE WEATHER DATA, AND SEA CONDITIONS AT TIME OF BOOM MEASUREMENTS

Date	Measurement location	Ship	Ship speed, knots	Surface temperature		Relative humidity, percent	Surface wind, knots	Wind direction,[a] deg	Sea condition
				K	^{o}F				
7-26-71	Atlantic	U.S.S. Salinan	2	301	82.13	74	6	215	0.8-meter swell
7-26-71	Atlantic	U.S.S. Austin	2	301	82.13	78	4	145	1.0-meter swell
8- 7-71	Pacific	U.S.S. Okinawa	3	300	80.3	76	8	070	1.2-meter swell
8- 7-71	Pacific	U.S.S. Kawishiwi	5	301	82.13	78	7	130	1.0-meter swell
8- 7-71	Pacific	U.S.S. Genesee	4	300	80.3	76	4	090	1.0-meter swell

[a] Direction from which the wind is blowing from true north.

TABLE III.- SUMMARY OF WEATHER DATA OBTAINED BY RAWINSONDE PRIOR TO APOLLO 15 LAUNCH

Altitude, m	Wind direction, deg	Wind speed, knots	Temperature, K	Relative humidity, percent	Absolute humidity, g/m^3	Sound speed, m/sec
5	170	8	301.3	69	19.12	348
305	160	9	298.2	75	17.42	346
610	168	7	297.4	71	15.68	346
914	182	6	295.7	68	13.69	345
1 219	182	7	294.0	64	11.60	344
1 524	185	7	292.4	61	10.17	343
1 829	188	7	290.8	57	7.51	342
2 134	182	5	289.0	49	6.68	341
2 438	161	5	286.7	55	6.41	340
2 743	165	6	285.4	45	4.84	338
3 048	174	7	283.2	55	5.12	337
3 353	185	6	281.6	42	3.58	336
3 658	187	6	280.6	23	1.85	336
3 962	175	5	278.2	28	1.91	336
4 267	152	3	276.6	25	1.52	334
4 572	187	3	275.0	23	1.29	333
4 377	246	5	273.8	20	1.03	332
5 182	254	6	271.6	19	.82	332
5 486	241	6	269.4	20	.75	330
5 791	238	8	266.8	22	.68	329
6 096	239	9	264.6	21	.56	327
6 401	234	8	262.6	20	.44	326
6 706	213	9	260.0	21	.38	323
7 010	201	9	257.6	23	.35	322
7 315	207	5	254.8	23	.28	320
7 620	196	3	253.0	25	.27	319
7 925	147	2	251.4	29	.27	318
8 230	106	4	249.4	26	.20	316
8 534	104	6	246.8	26	.16	315
8 839	87	5	245.6	23	.13	314
9 144	99	8	244.4	22	.11	313
9 449	101	12	241.0	25	.09	311
9 754	89	13	238.7	26	.08	310
10 058	80	12	236.1	26	.06	308
10 363	87	14	234.2	25	.05	307
10 668	87	21	231.6	27	.04	305
10 973	92	28	229.0	27	.03	303
11 273	93	30	226.8	27	.02	302
11 582	84	28	224.4	27	.02	300
11 887	77	30	222.2	28	.02	299
12 192	70	31	221.2	16	.01	298
12 497	67	31	217.4	29	.01	296
12 802	64	33	215.6	29	.01	294
13 106	63	36	215.6			292
13 411	61	36	212.8			290
13 716	64	34	209.6			287
14 021	71	33	207.2			287
14 326	78	31	205.2			288
14 630	78	23	205.6			288
14 935	61	18	205.6			288
15 240	55	17	206.6			288
15 545	62	17	204.4			287
15 850	72	16	204.2			287
16 154	77	13	206.4			288
16 459	64	14	205.4			287
16 764	53	18	205.4			287

TABLE III. - SUMMARY OF WEATHER DATA OBTAINED BY RAWINSONDE PRIOR TO APOLLO 15 LAUNCH – Concluded

Altitude, m	Wind direction, deg	Wind speed, knots	Temperature, K	Relative humidity, percent	Absolute humidity, g/m^3	Sound speed, m/sec
17 069	56	19	205.4			287
17 374	68	19	206.6			288
17 678	76	19	208.0			289
17 983	84	19	208.8			290
18 288	93	20	210.0			290
18 593	92	22	210.4			291
18 898	92	23	210.6			291
19 202	94	25	209.8			290
19 507	95	27	210.0			291
19 812	92	28	211.2			291
20 117	90	32	214.2			293
20 422	91	34	214.8			294
20 726	91	34	215.4			294
21 031	89	34	216.8			295
21 336	91	35	216.8			295
21 641	101	36	217.8			296
21 946	108	33	218.6			296
22 250	106	35	218.8			296
22 555	106	37	218.6			296
22 860	105	38	218.2			296
23 165	103	38	218.6			296
23 470	98	39	219.2			297
23 774	94	41	220.0			297
24 079	93	44	222.2			299
24 384	93	42	225.2			301
24 689	88	36	227.4			302
24 994	86	33	227.0			302
25 298	92	33	226.4			301
25 603	98	33	226.2			301
25 908	99	34	227.2			302
26 213	97	37	228.2			302
26 518	95	38	228.4			303
26 822	95	39	227.3			302
27 127	94	43	226.4			301
27 432	92	45	226.8			302
27 737	88	46	228.8			303
28 042	85	47	230.0			304
28 346	84	47	230.2			304
28 651	85	48	230.4			304
28 956	87	50	230.6			305
29 261	89	52	229.6			303
29 566	90	54	230.0			304
29 870	89	56	231.4			305
30 175	90	57	231.6			305
30 480	92	55	233.0			306
30 785	93	53	234.6			307
31 090	95	53	235.2			307
31 394	96	53	235.4			308
31 699	97	54	235.6			308
32 004	98	55	236.4			308
32 309	98	55	237.4			309
32 614	102	56	238.0			309
32 918	106	55	238.0			309
33 223	108	55	238.8			310
33 528	---	---	238.2			309

TABLE IV.- SUMMARY OF WEATHER DATA OBTAINED BY ROCKETSONDE AFTER APOLLO 15 SPLASHDOWN

Altitude, m	Wind direction, deg	Wind speed, knots	Temperature, K	Sound speed, m/sec	Altitude, m	Wind direction, deg	Wind speed, knots	Temperature, K	Sound speed, m/sec
31 000	96	62	----	---	68 000	86	45	209.0	290
32 000	95	60	226.0	301	69 000	79	60	209.0	290
33 000	96	56	227.0	302	70 000	79	78	209.0	290
34 000	106	52	231.0	305	71 000	81	91	207.0	289
35 000	101	49	235.0	307	72 000	82	99	217.0	285
36 000	80	49	234.0	307	73 000	82	101	213.0	293
37 000	77	52	241.0	311	74 000	80	97	214.0	293
38 000	79	56	236.0	308	75 000	80	93	213.0	293
39 000	91	64	240.0	311	76 000			209.0	290
40 000	94	78	240.0	311	77 000			207.0	289
41 000	105	72	248.0	316	78 000			207.0	289
42 000	108	76	249.0	316	79 000			205.0	287
43 000	104	70	258.0	322	80 000			202.0	285
44 000	88	68	258.0	322	81 000			200.0	284
45 000	92	76	258.0	322	82 000			200.0	284
46 000	103	74	272.0	331	83 000			200.0	284
47 000	92	85	257.0	322	84 000			200.0	284
48 000	94	101	271.0	330	85 000			200.0	284
49 000	97	68	260.0	323	86 000			201.0	
50 000	85	72	288.3	322	87 000			202.0	
51 000	102	78	253.0	319	88 000			203.0	
52 000	132	89	266.0	327	89 000			204.0	
53 000	140	52	250.0	317	90 000			205.0	
54 000	96	39	255.0	320	91 000			206.0	
55 000	114	70	272.0	331	92 000			206.0	
56 000	128	54	252.0	318	93 000			203.0	
57 000	152	31	255.0	320	94 000			198.0	
58 000	161	33	256.0	321	95 000			194.0	
59 000	182	31	254.0	320	96 000			194.0	
60 000	214	21	251.0	318	97 000			196.0	
61 000	288	6	252.0	318	98 000			197.0	
62 000	27	10	239.0	310	99 000			196.0	
63 000	95	16	229.0	303	100 000			197.0	
64 000	123	35	231.0	305	101 000			200.0	
65 000	125	51	223.0	290	102 000			207.0	
66 000	118	49	212.0	292	103 000			218.0	
67 000	102	41	212.0	292	104 000			228.0	

TABLE V.- SUMMARY OF SONIC-BOOM DATA FOR LAUNCH AND REENTRY OF APOLLO 15

Ship	Δp		I_o		τ, sec	Δt_o, sec	ΔT, sec
	N/m^2	lb/ft^2	$N\text{-}sec/m^2$	$lb\text{-}sec/ft^2$			
U.S.S. Salinan	50.27	1.05	43.24	0.903	0.005	1.52	2.30
U.S.S. Austin	9.15	0.191	10.68	0.223	0.006	1.83	3.64
U.S.S. Genesee	9.43	0.197	1.58	0.033	0.0065	0.315	0.505
U.S.S. Kawishiwi	20.97	0.438	1.92	0.040	0.010	0.170	0.250
U.S.S. Okinawa	38.30	0.800	2.25	0.047	0.0055	0.1575	0.230

TABLE VI.- COMPARISON OF MEASURED AND CALCULATED SIGNATURE CHARACTERISTICS

Measurement location	Ship	Space vehicle	Flight condition			Sonic-boom signature characteristics					
			Altitude, m	Altitude, ft	Mach number	Δp, N/m^2		Δp, lb/ft^2		ΔT, sec	
						Measured	Calculated	Measured	Calculated	Measured	Calculated
Atlantic	U.S.S. Salinan	S-IC	63 462	208 218	7.09	50.27	----	1.05	----	2.30	0.576
Atlantic	U.S.S. Austin	S-II	178 778	586 571	6.51	9.15	----	0.191	----	3.64	0.364
Pacific	U.S.S. Genesee	CM	52 485	172 203	16	9.43	11.01	0.197	0.230	0.505	0.644
Pacific	U.S.S. Kawishiwi	CM	33 147	108 755	4.5	20.97	22.98	0.438	0.480	0.250	0.449
Pacific	U.S.S. Okinawa	CM	25 150	82 517	1.7	38.30	36.87	0.800	0.770	0.230	0.317

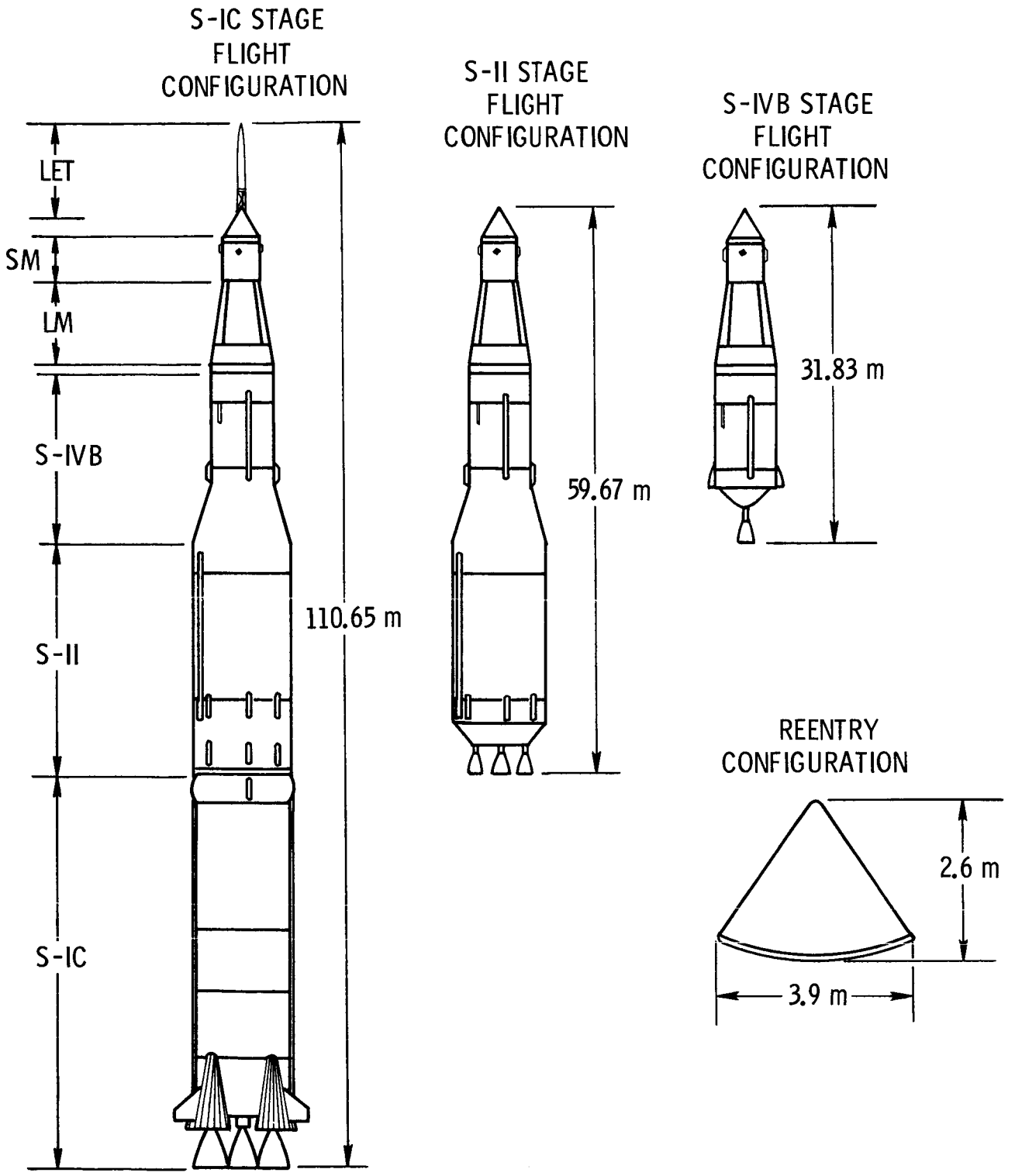


Figure 1.- Schematic diagram of Apollo 15/Saturn V launch vehicle and reentry vehicle configurations.

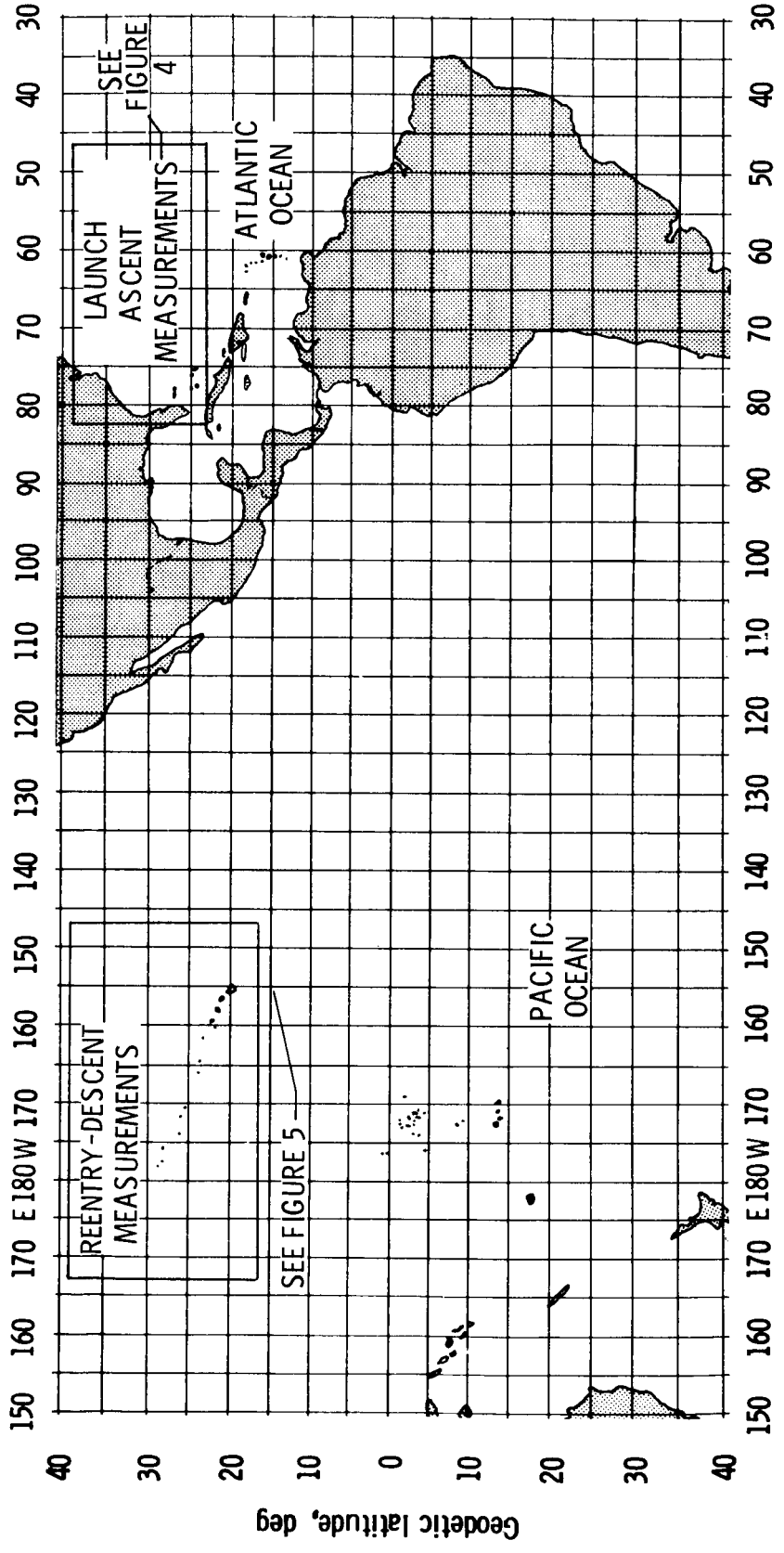


Figure 2.- Map showing general areas in which sonic-boom measurements were obtained.

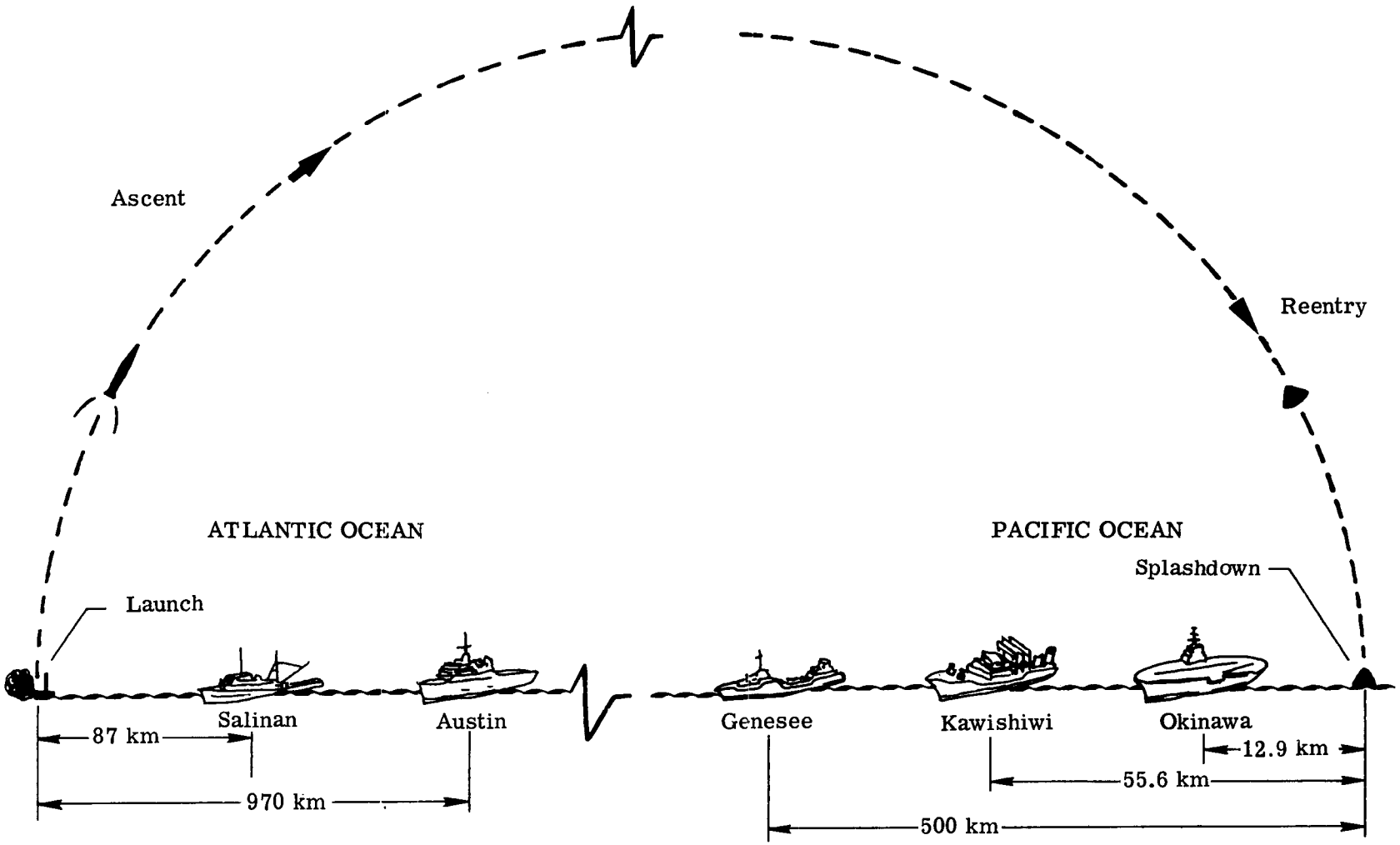


Figure 3.- Schematic showing ship position for data acquisition during launch and reentry.

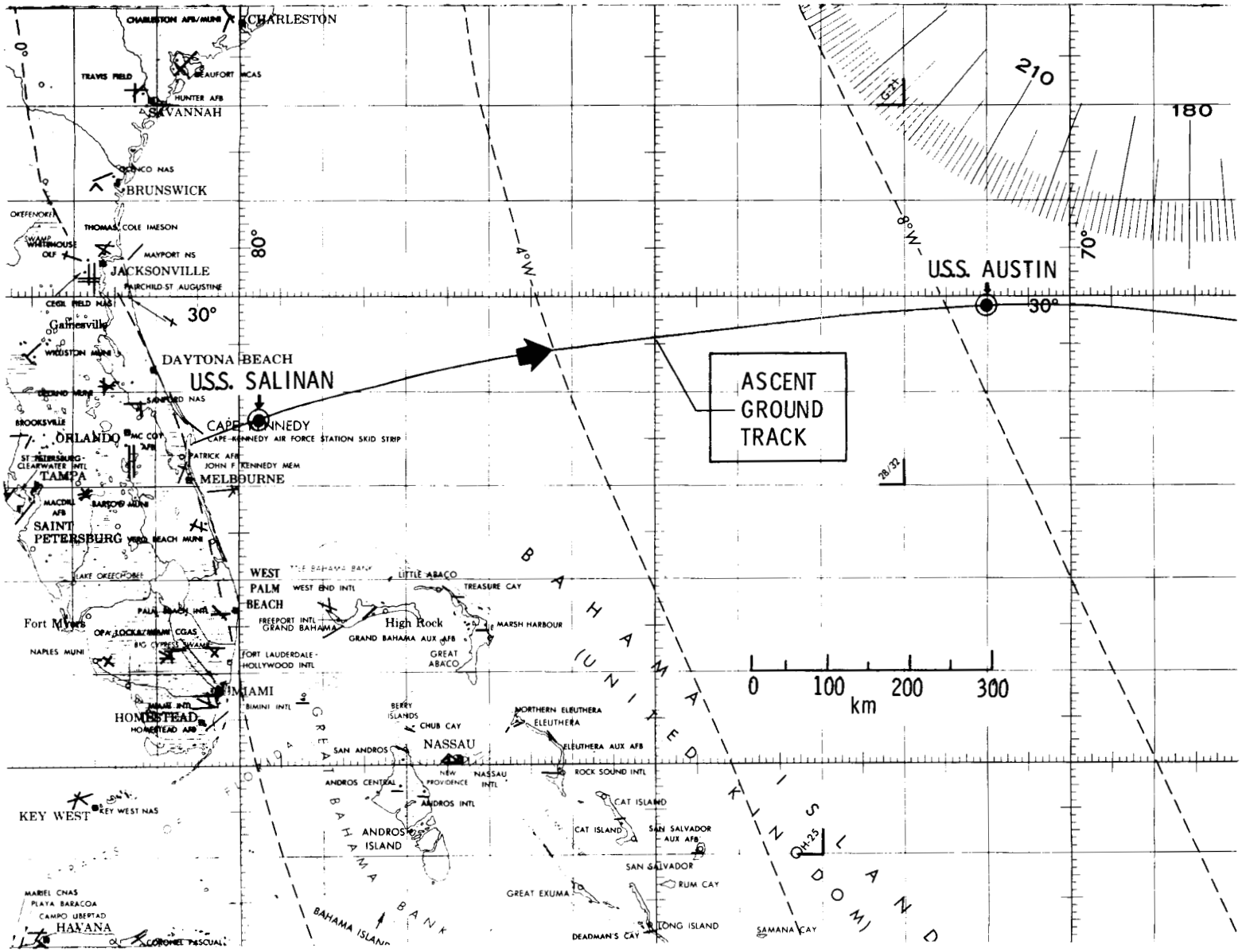


Figure 4.- Map of the North Atlantic showing the positions of the two measurement ships along with the Apollo 15 ground track.

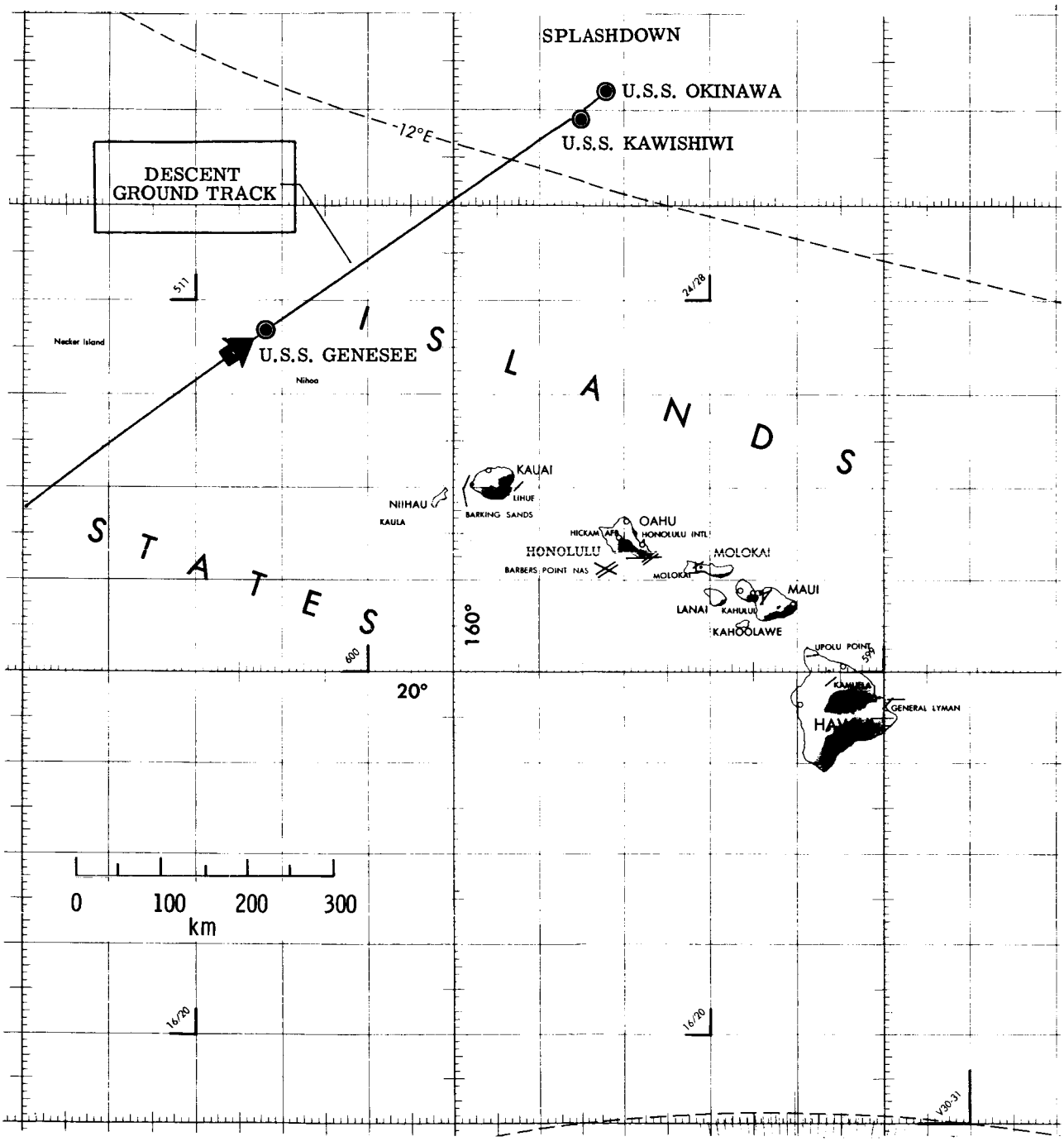
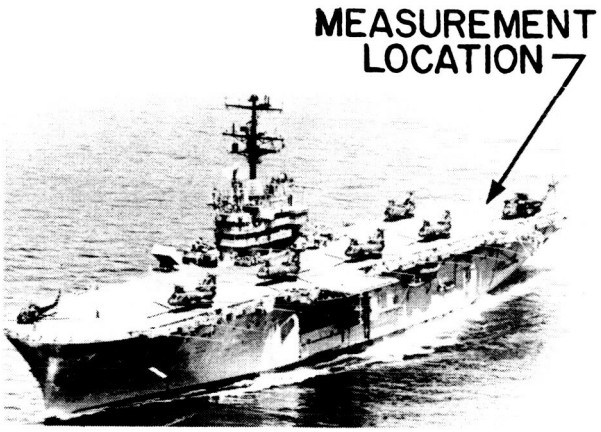
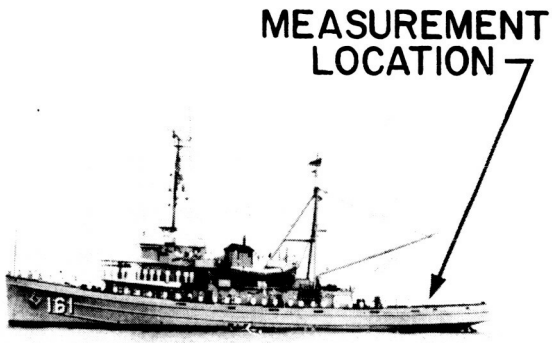


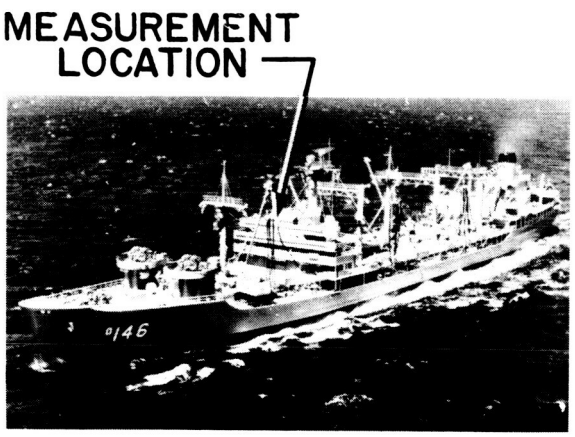
Figure 5.- Map of the North Pacific showing the positions of the three measurement ships along with the Apollo 15 ground track.



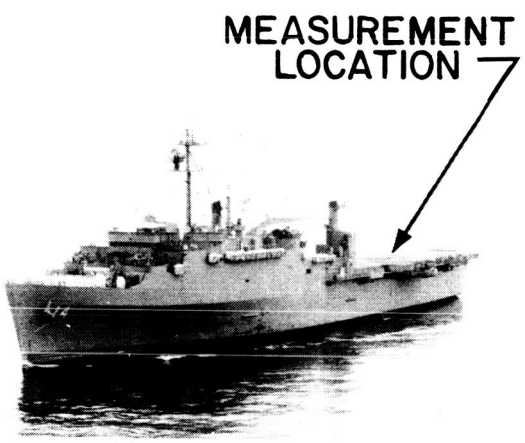
U.S.S. OKINAWA



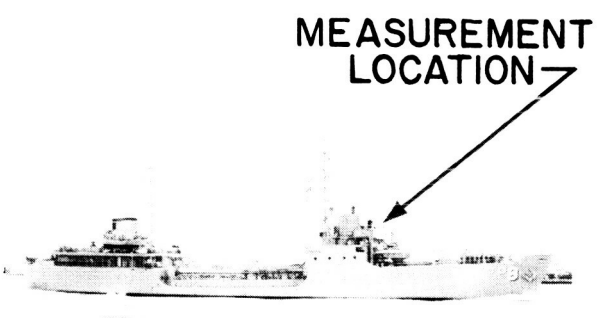
U.S.S. SALINAN



U.S.S. KAWISHIWI



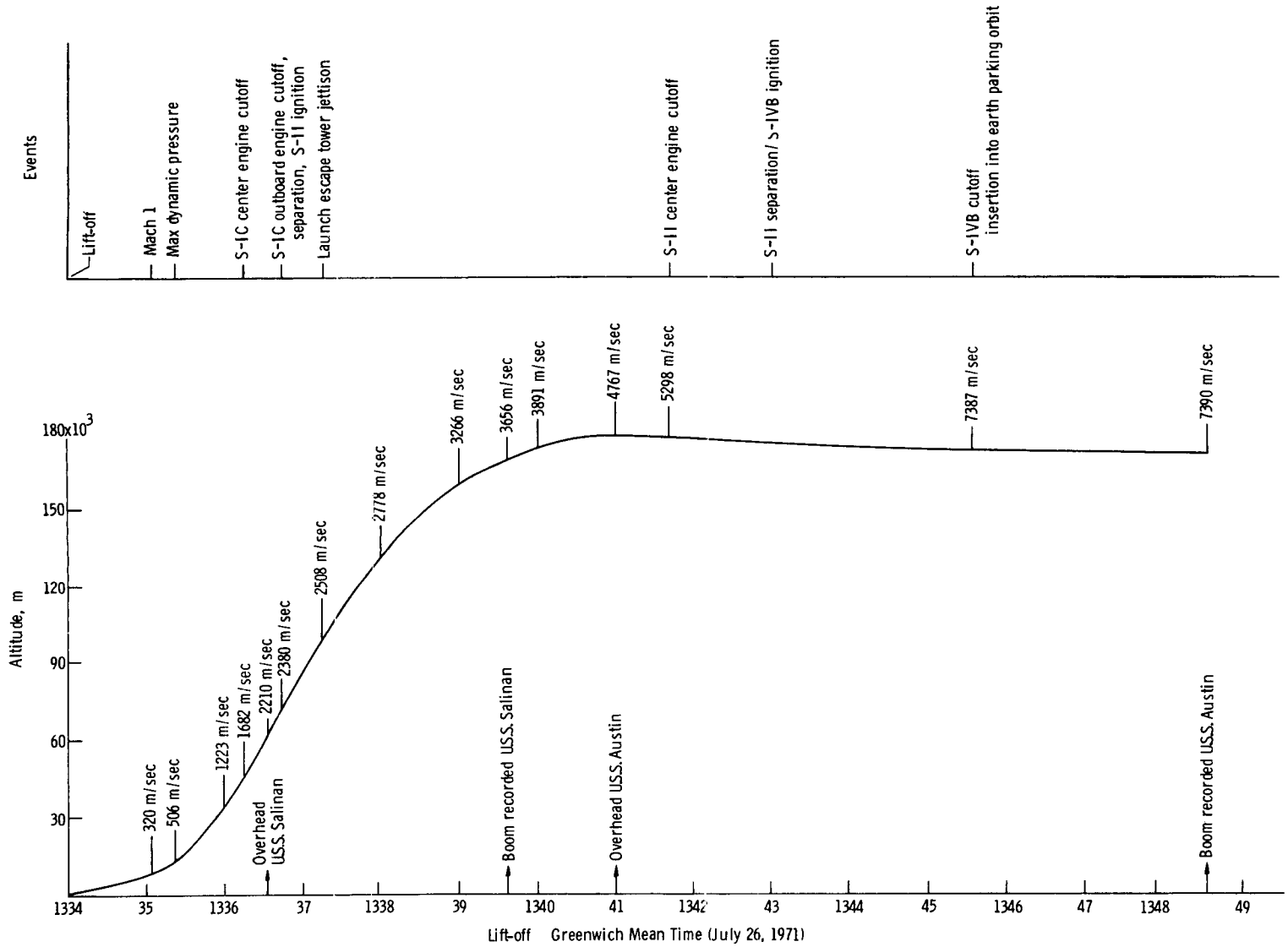
U.S.S. AUSTIN



U.S.S. GENESEE

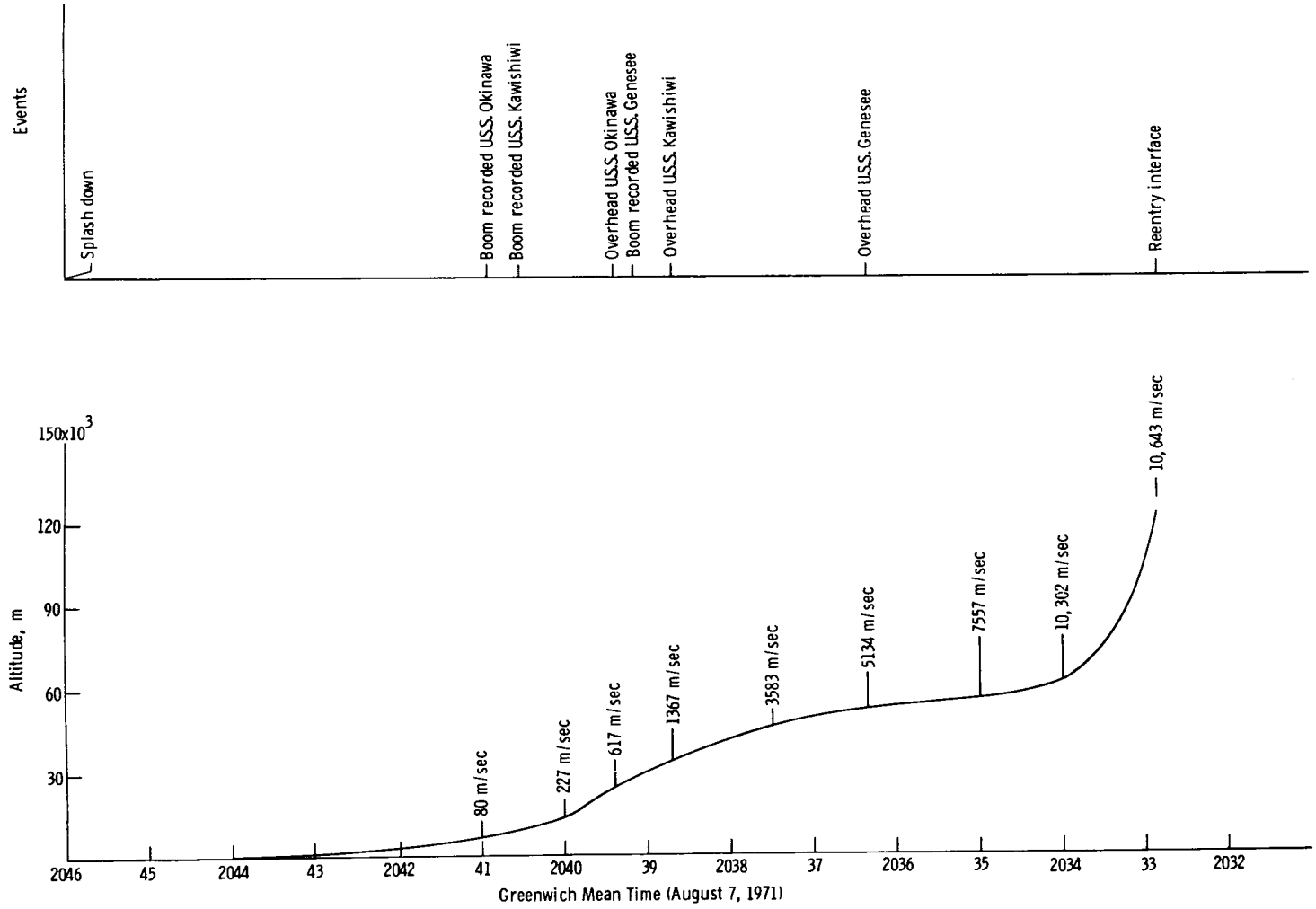
L-72-2483

Figure 6.- Photographs of the ships used during the tests, with approximate measurement locations indicated.



(a) Launch and ascent.

Figure 7.- Apollo 15 ascent and reentry profiles showing various events, vehicle altitude and velocity, and boom measurement times.



(b) Reentry and descent.

Figure 7.- Concluded.

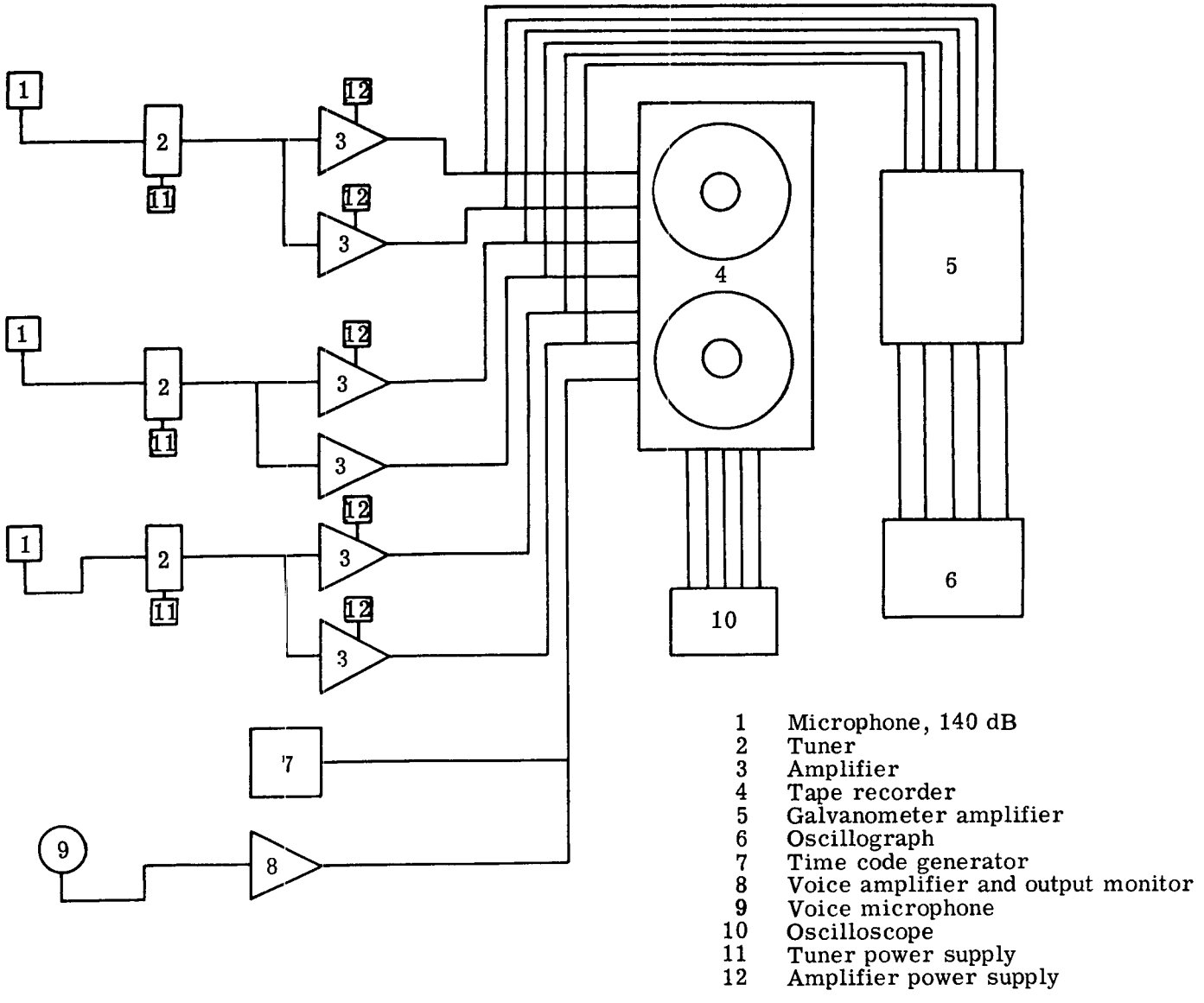
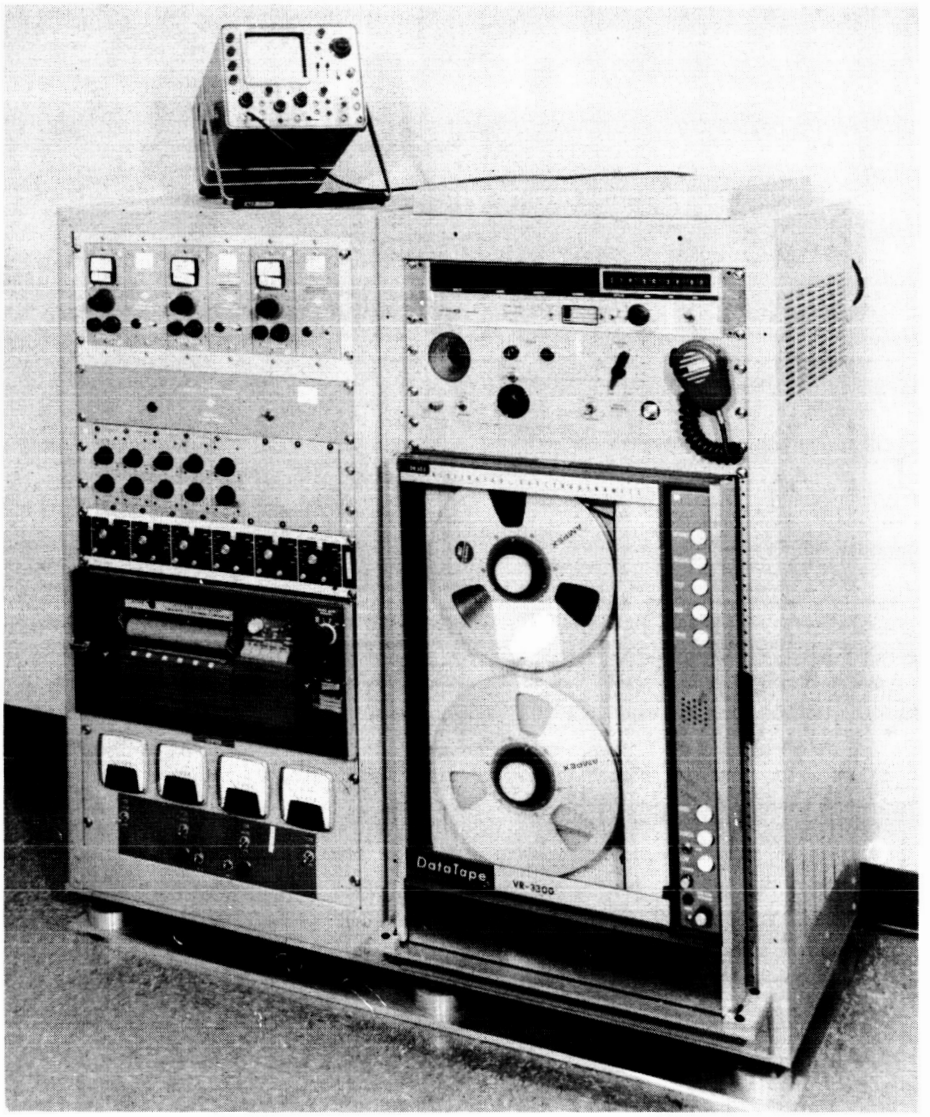
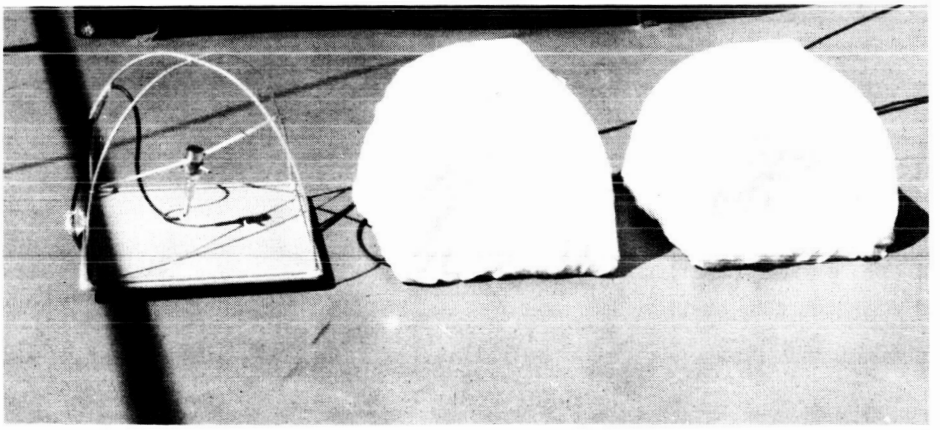


Figure 8.- Block diagram showing typical instrumentation system for sonic-boom data acquisition.



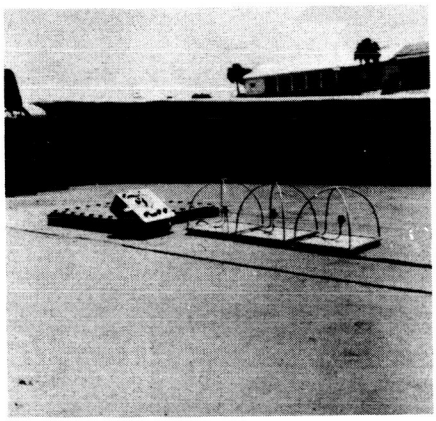
(a) Recording console and signal-conditioning equipment.



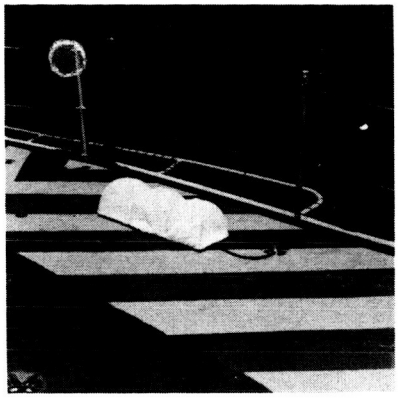
L-72-2484

(b) Microphone, mount, and windscreen.

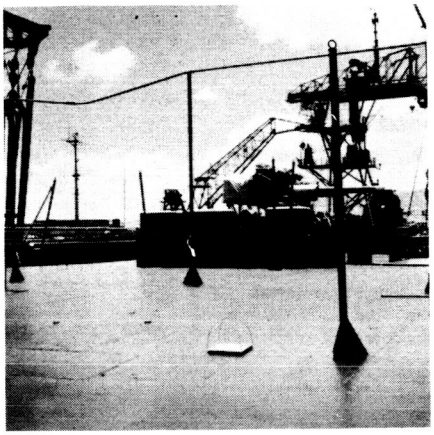
Figure 9.- Typical data-acquisition system.



U.S.S. SALINAN

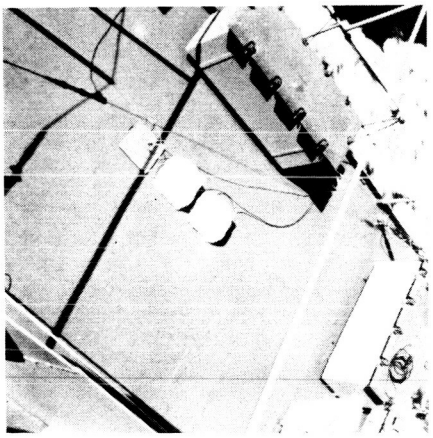


U.S.S. OKINAWA



U.S.S. KAWISHIWI

U.S.S. AUSTIN



U.S.S. GENESEE

L-72-2485

Figure 10.- Microphone locations aboard the measurement ships.

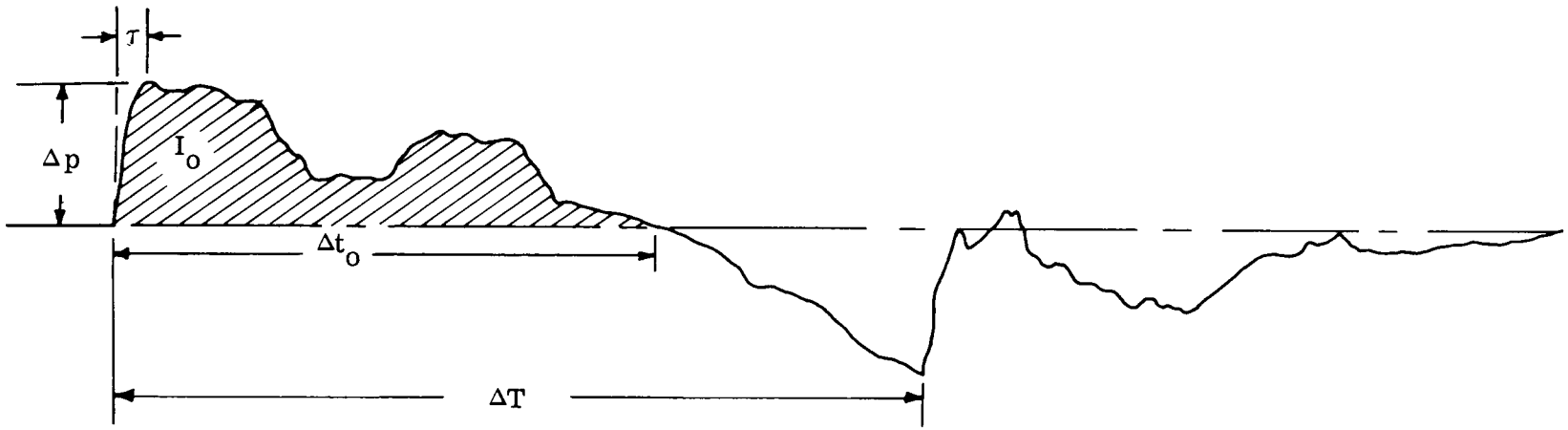
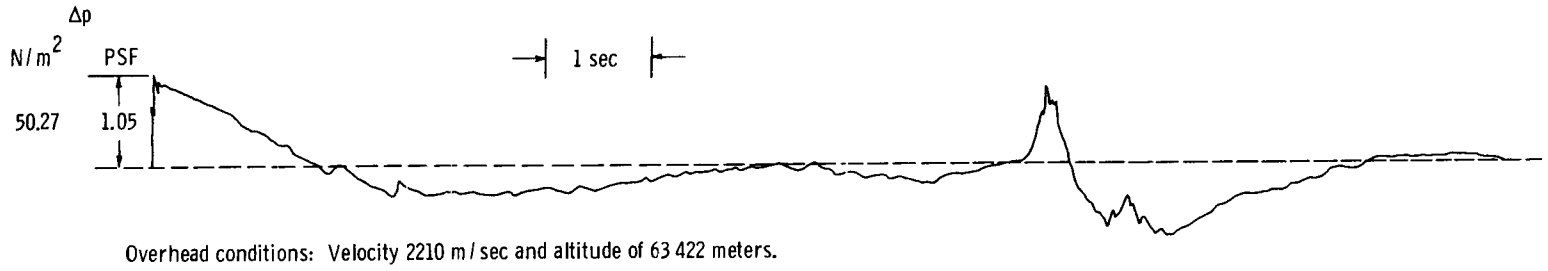
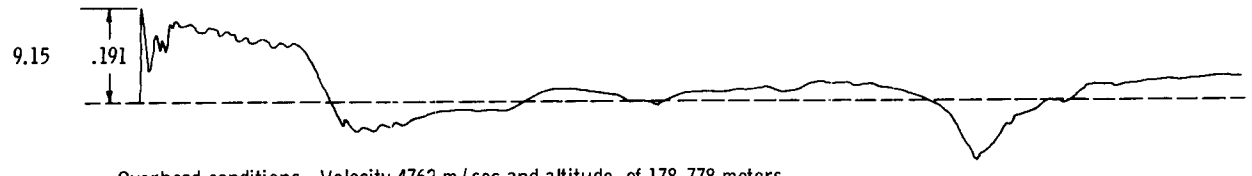


Figure 11.- Tracing of Apollo 15 sonic-boom signature measured during reentry and the identification of the various signature characterizations.



Overhead conditions: Velocity 2210 m/sec and altitude of 63 422 meters.

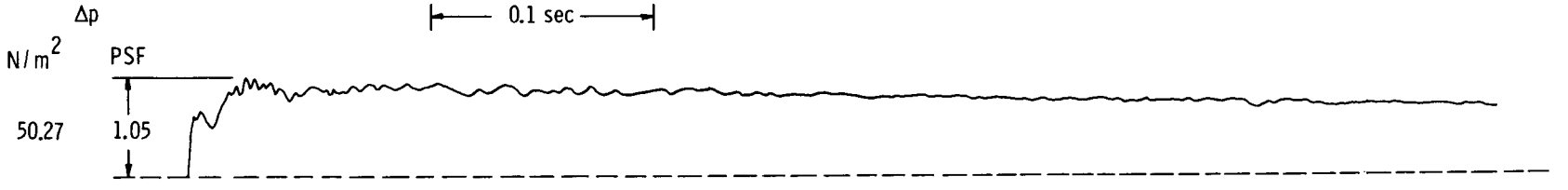
(a) Measured on U.S.S. Salinan.



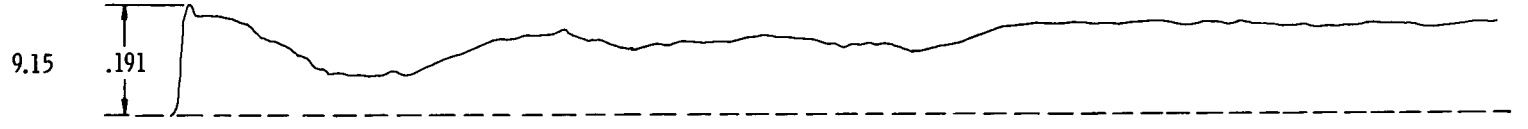
Overhead conditions: Velocity 4762 m/sec and altitude of 178 778 meters.

(b) Measured on U.S.S. Austin.

Figure 12.- Measured sonic-boom signatures during ascent as recorded at positions 87 km and 970 km from the launch site. Along the Apollo 15 ground track.

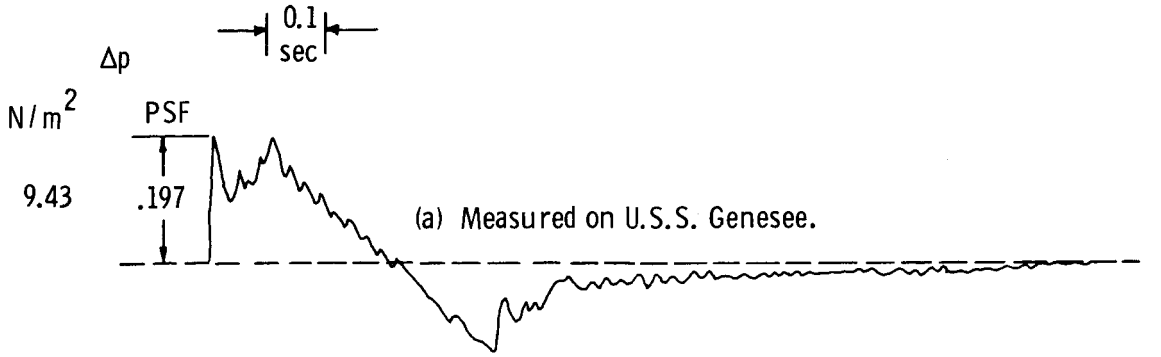


(a) Measured on U.S.S. Salinan.

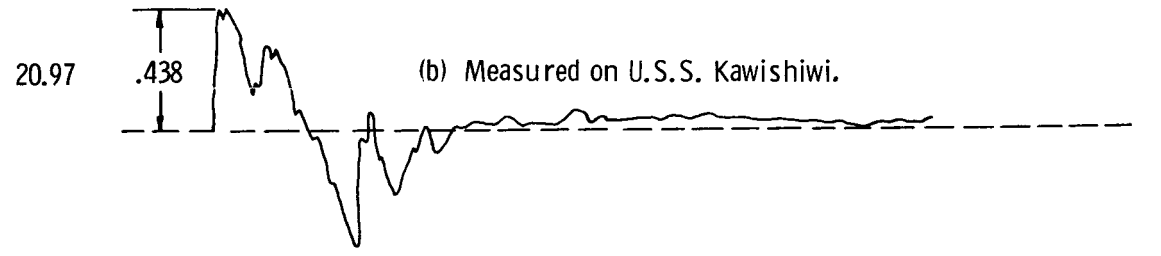


(b) Measured on U.S.S. Austin.

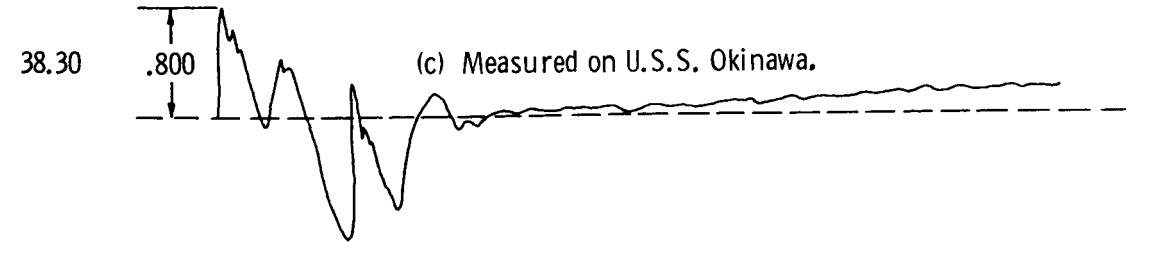
Figure 13.- Measured sonic-boom signatures during ascent showing details of bow shock-wave rise time.



Overhead conditions: Velocity 5134 m/sec and altitude 52 485 meters.

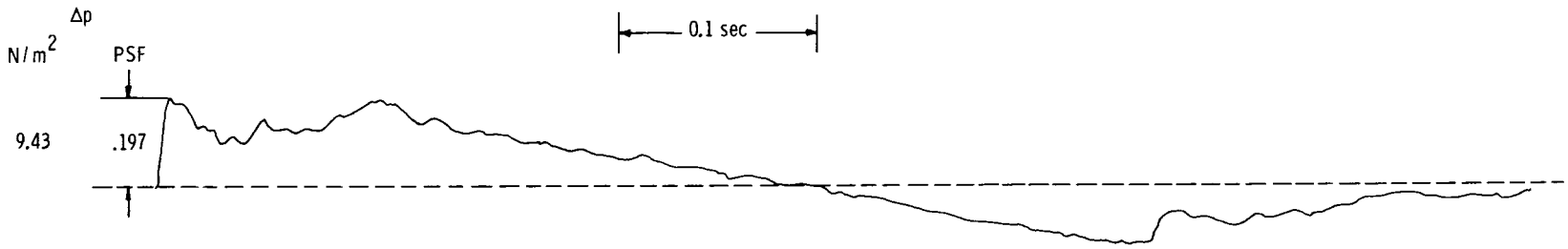


Overhead conditions: Velocity 1367 m/sec and altitude 33 147 meters.



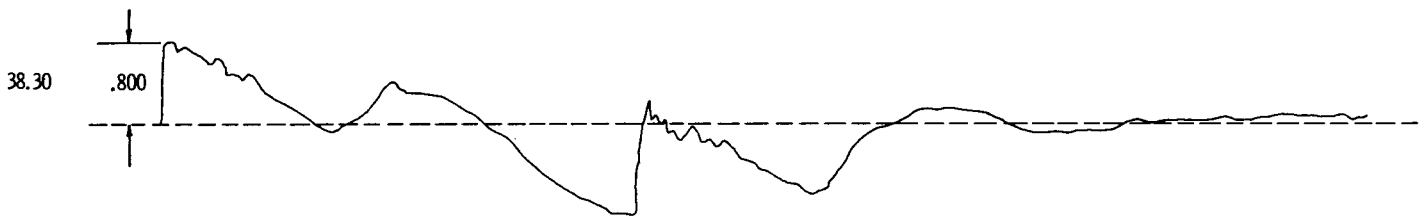
Overhead conditions: Velocity 617 m/sec and altitude 25 150 meters.

Figure 14.- Measured sonic-boom signatures during descent as recorded at positions 9.26 km, 55.6 km, and 500 km from splashdown. Along the Apollo 15 ground track.



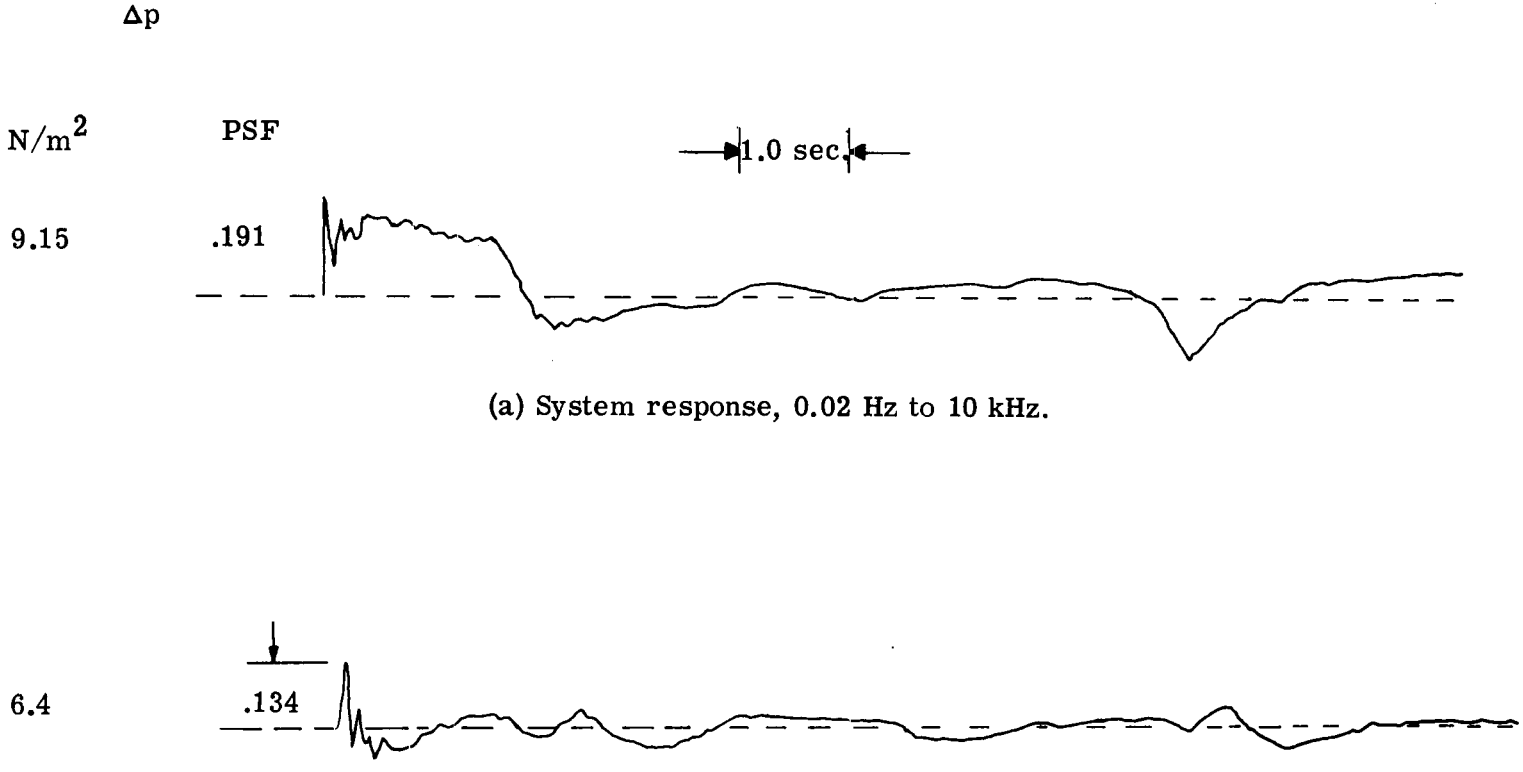
(a) Measured on U.S.S. Genesee.

(b) Measured on U.S.S. Kawishiwi.



(c) Measured on U.S.S. Okinawa.

Figure 15.- Measured sonic-boom signatures during descent, showing details of bow shock-wave rise time.



(a) System response, 0.02 Hz to 10 kHz.

(b) System response, 0.3 Hz to 10 Hz.

Figure 16.- Sonic-boom signatures during ascent measured aboard the U.S.S. Austin, showing variations in signature characteristics when two systems having different frequency-response characteristics are utilized.