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16. Abstract

This paper presents sonic-boom pressure signatures recorded during the launch and reentry phases of the Apollo 16 mission. Five measurements were obtained along the vehicle ground track: 69 km (37.3 n. mi.), 92 km (49.8 n. mi.), and 130 km (70.3 n. mi.) down range from the launch site during ascent, and at 185 km (100 n. mi.) and approximately 5.5 km (3 n. mi.) from the splash-down 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. Comparisons of the sonic-boom overpressures from Apollo 15 and 16 along with those from current aircraft are also presented.

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SUMMARY

This paper presents sonic-boom pressure signatures recorded during the launch and reentry phases of Apollo 16. The measurements were obtained along the spacecraft vehicle ground track at three surface ship locations during ascent and two surface ship locations during reentry. Tracings of the measured signatures are included along with values of the maximum positive 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 the N-waves associated with supersonic aircraft were observed during the ascent and reentry of Apollo 16. In addition, the sonic-boom signatures from Apollo 16 were similar and consistent with those observed during the ascent and reentry of Apollo 15 in that higher overpressures were observed compared with that expected on the basis of previous aircraft experience. These higher pressures are attributed to the increase in effective size of the rocket-engine exhaust plume. For the Apollo 16 reentry case, which was also consistent with Apollo 15 findings, the measured overpressures were of the order of magnitude and shape expected based on previous aircraft experience. For both the launch and reentry cases, the sonic-boom overpressure decreased as the vehicle altitude increased.

Overpressure values ranging from about 42 N/m^2 (0.87 psf) to 134 N/m^2 (2.8 psf) and 17 N/m^2 (0.36 psf) to 31 N/m^2 (0.65 psf) were measured during ascent and reentry, respectively. The signatures were not simple N-wave shapes but contained a number of intermediate shocks. These intermediate shocks observed during the ascent phase are

associated with the ground-focus boom regions resulting from the vehicle acceleration and flight-path angles. During the reentry phase, the intermediate shocks measured are believed to be associated with reflections from the surface of the ocean onto the sonic-boom measurement platform onboard the ships. All signatures exhibited rapid rise times which are of the order of those observed from supersonic aircraft. Very long wave periods were observed from the measurements made during the ascent and are attributed to the effects of the rocket-engine exhaust plume.

INTRODUCTION

In recent years a considerable amount of experimental and theoretical information relating to sonic booms from various aircraft studies (see refs. 1 to 6) has been accumulated. This information includes measurements for small and large aircraft in the weight range of 4535 kg (10 000 lb) to 181 468 kg (400 068 lb), operating at altitudes from 15 m (49 ft) to above 22 000 m (72 182 ft), and Mach numbers to 3.0. Also limited sonic-boom measurements have been accumulated from large space vehicles (see ref. 7) operating at altitudes to 179 000 m (587 000 ft) and Mach numbers up to 16.

The sonic-boom measurement obtained during the ascent phase of Apollo 15 mission (see ref. 7) indicated an apparent effect of exhaust plume geometry on the measured sonic-boom signature. Multiple shocks were also observed on the sonic-boom signatures measured at three measurement locations during reentry.

The Apollo 16 mission provided an opportunity to obtain additional sonic-boom information during the launch, ascent, and reentry phases of operation. Three measurement stations were employed during the ascent phase and were aimed at providing a better definition of the effects of the rocket-engine exhaust plume on the sonic-boom signatures and an indication of the location and overpressure levels in the sonic-boom focus areas. For the reentry phase, sonic-boom data were obtained at two stations along the entry ground track for the purpose of better defining the details of the sonic-boom pressure signatures generated by a relatively blunt but smooth body having detached shock waves and moving at hypersonic speeds. The work presented herein was a joint effort involving the NASA Langley Research Center, the NASA George C. Marshall Space Flight Center, the NASA Lyndon B. Johnson Space Center, and the U.S. Navy (Manned Spacecraft Recovery Forces, Atlantic and Pacific).

The purpose of this paper is to present results of the sonic-boom flight measurement program accomplished during the launch and reentry phase of Apollo 16. Included for the five measuring stations are tracings of the sonic-boom signature and tabulated values of positive 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. Comparisons of the sonic-boom overpressures from Apollo 15 and 16 with overpressure measured on current aircraft are also presented.

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

Δt_o time duration of positive phase 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:

CM command module

GMT Greenwich mean time

LET	launch escape tower
LM	lunar module
OH	overhead
S-IC	Saturn first stage
S-II	Saturn second stage
S-IVB	Saturn third stage
SM	service module
STA	station

APPARATUS AND METHODS

Test Vehicle

A photograph of the launch of the Apollo 16/Saturn V configuration is shown in figure 1 and a schematic diagram of the configuration is shown in figure 2. 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 2 965 226 kg (6 537 238 lb), and developed an average thrust of 35 MN (7 828 437 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 ft) and developed an average thrust of 4.8 MN (1 079 491 lb). The S-IVB stage flight configuration had a length of 34.83 m (114.27 ft) with a diameter of 6.6 m (21.7 ft) and developed an average thrust of 0.9 MN (206 935 lb). The Apollo 16 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 5904 kg (13 016 lb).

Test Area and Arrangement

In figure 3 are shown the general test areas associated with the launch and recovery operations of Apollo 16. Sonic-boom measurements in the Atlantic were made at three

stations which were positioned along the ground track of the spacecraft to encompass the focus boom region associated with the vehicle flight trajectory. (See schematic diagram in fig. 4.) Station 1 was located at approximately 69 km (37 n. mi.), station 2 at approximately 92 km (49 n. mi.), and station 3 at approximately 130 km (70 n. mi.) from the launch site, respectively. Measurements in the Pacific were obtained onboard two ships positioned along the ground track of the spacecraft: Station 4 at approximately 185 km (100 n. mi.) from splash down, and station 5 at approximately 5.5 km (3 n. mi.) from splash down.

Figure 5 is a map of the Atlantic test area in which are shown the positions of three ships and the spacecraft ground track. Figure 6 is a map of the general splash-down area in the Pacific showing the position of the two ships and an indication of the spacecraft ground track. In table I are listed the positions of the five ships at the time of sonic-boom arrival, the spacecraft altitude and velocity at the overhead position for each ship, and the exact arrival times of the sonic boom at each ship. Throughout this report, vehicle flight conditions are listed for the times that the spacecraft is directly overhead of each ship and at boom arrival. The vehicle conditions along the flight profile at which the booms are generated, which occur well up-range of the overhead positions, are not listed.

Measurement Platforms

The various ships on which sonic-boom measurements were obtained are shown in figure 7. The U.S.S. Opportune (station 1), U.S.S. Alacrity (station 2), and U.S.S. Exploit (station 3) shown on the left-hand side of the figure, were positioned in the Atlantic Ocean and the U.S.S. Ponchatoula (station 4) and the U.S.S. Ticonderoga (station 5) were positioned in the Pacific. The U.S.S. Opportune, a Diver class salvage ship is 64.9 m long (213 ft) with a 11.9-m beam (39 ft); the U.S.S. Alacrity, an Ability class ocean minesweeper is 57.9 m long (190 ft) with a 10.97-m beam (36 ft); and the U.S.S. Exploit, an Agile class ocean minesweeper is 52.4 m long (172 ft) with a 10.97-m beam (36 ft). The U.S.S. Ticonderoga, an Essex class aircraft carrier is 272.5 m long (894 ft) with a 31.4-m beam (103 ft); and the U.S.S. Ponchatoula, a Neosho class oiler, is 199.6 m long (655 ft) with a 26.2-m beam (86 ft). Also indicated in the photographs are the general areas of the ship in which the sonic-boom microphone measurement systems were located on each of the five ships. During the ascent and reentry of the spacecraft vehicle, sonic-boom measurements were obtained as the ships traveled in the direction of flight along the ground track at slow speed and utilized only enough power to maintain steerage and to keep the ship noise at a minimum.

Indicated in table II are the ships' speed, surface weather, and sea conditions existing during the measurement part of the test. Sea conditions in both the Atlantic and Pacific Oceans as described by ship personnel were essentially calm.

Spacecraft Positioning

The Apollo 16 space vehicle was launched from complex 39A at the Kennedy Space Center, Florida, along a 90° azimuth. Boost to orbit consisted of complete burns of the S-IC and S-II stages, and two partial burns of the S-IVB stage of the total launch vehicle. The mission had a duration of 11 days, and the command module reentered the Earth's atmosphere over the mid-Pacific Ocean south of Christmas Island. The command module landed approximately 2430 km (1311 n. mi.) down range of the reentry interface, which occurred at an altitude of 115 324 m (378 361 ft). In figures 8(a) and 8(b) are presented the launch and ascent, and reentry profiles, respectively. Shown in the figures are altitude and velocity as a function of time along with an indication of various events associated with the launch and reentry of the spacecraft such as time of arrival at overhead and boom arrival times of each measuring station. As was previously noted, the sonic boom is generated well up-range of the ship positions. The data of figure 8(a) were obtained from the Saturn V final postflight trajectory data report (Saturn V final postflight trajectory data for AS-511 metric units, Boeing Co., Huntsville, Alabama, May 8, 1972) and the data of figure 8(b) were obtained from the Apollo 16 final trajectory data report (AS 511/CSM 113/LM-11 prepared by the Data Processing Branch, Computation and Analysis Division, Lyndon B. Johnson Space Center, Houston, Texas). It should be noted from figure 8(a) that the total space vehicle (S-IC stage flight configuration) passed overhead of all three ships positioned in the Atlantic prior to engine cutout such that the booms measured during ascent were associated with only the S-IC stage.

Pressure-Measurement Instrumentation

The instrumentation employed for the Apollo 16 sonic-boom pressure measurements is similar to that used in references 1 and 5 for measurements of aircraft sonic-boom signatures and for measurements on the Apollo 15 launch and reentry (ref. 7). The main components of the sonic-boom measuring systems were specially modified condenser-type microphones, a tuning unit, a dc amplifier, and an FM tape recorder. A representative data acquisition system frequency response curve is shown in figure 9. A block diagram of a typical data acquisition system which was placed on board each ship is shown in figure 10. The microphone sensitivity ranges from about 70 to 150 dB, the total

sound-measuring system being calibrated on board ship by means of discrete frequency calibrators. These calibrators operated with a fixed frequency of 1 kHz and produced a root-mean-square sound pressure level of 130 dB ± 0.75 dB.

Based on previous Apollo 15 sonic-boom measurements (ref. 7), estimates of the expected pressure levels for the five measuring stations of the present tests were made. In order to allow for the uncertainties associated with sonic-boom focus factors, to provide for the maximum signal-noise ratio in the measurement, and also to allow for probable sonic-boom variations resulting from atmospheric effects, three microphones were used on each ship. The output of each microphone was routed through two separate amplifiers, which permitted six sensitivity settings (see fig. 10) and allowed for a range of overpressures.

Shown in figure 11(a) is a photograph of the signal-conditioning and recording equipment that was mounted in a compartment onboard each ship. Figure 11(b) shows a photograph of the microphone mounting arrangements, two arrangements complete with wind screens (consisting of two layers of cheese cloth) and one arrangement without, showing details of the microphone mount. 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 from the ship's superstructure.

The photographs of figure 12 illustrate typical microphone locations aboard the five ships. The three microphones located at station 4 were placed 15.24 cm (6 in.) above the deck of the bow, midship, and stern; for the remaining stations the three microphones were placed in a cluster 15.24 cm (6 in.) above the deck at a single location on the bow of the ship. Since the ray paths of the sonic-boom shock waves were nearly vertical, reflections from the various surfaces and superstructures of the ships were expected to be minimal. Also, since the microphones were mounted very close to the deck, the incident and reflected shocks were essentially in phase and the overpressure readings represent ground pressure values rather than free air values. It should be recognized, however, that the ocean surface does provide a reflecting surface; therefore, both the direct and reflected shocks would be observed at each measurement position to varying degrees depending upon the ship height, ocean surface condition, space vehicle altitude, and Mach number.

Atmospheric Soundings

Rawinsonde and rocketsonde observations from Cape Kennedy, Florida, were taken on April 16, 1972, at approximately 10 minutes and 90 minutes after lift-off. Measured values of wind direction and speed, temperature, dewpoint, pressure, relative and absolute humidity, sound speed, and density as a function of altitude are shown in tables III and IV.

Radiosonde observations from the prime recovery ship (station 5) and rocketsonde soundings from Kwajalein Missile Range, Marshall Islands, were taken on April 27, 1972, approximately at splash down and 2 hours before splash down, respectively. Measured values of wind direction and speed, temperature, dewpoint, pressure, relative and absolute humidity, sound speed, and density as a function of altitude are shown in tables V and VI. In addition to the weather measurements described, local climatological data (surface temperature, relative humidity, surface wind and direction) were obtained from each ship in the test area at the time of sonic-boom arrival and are presented in table II. At the Atlantic stations, surface temperatures were about 300 K (80° F) and surface winds ranged from 9 to 15 knots. At the Pacific stations, the temperature ranged around 302 K (83° F) and wind velocities were from 13 to 15 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 13, which shows an example Apollo 16 sonic-boom signature measured during reentry. Indicated are the various measured quantities of peak overpressure Δp, wave period ΔT, and the positive duration Δt_o, positive impulse I_o (integrated area of Δp against Δt_o for duration of positive pulse) and rise time τ. For the purpose of this paper Δt_o is the total time from the onset of the initial positive phase of the signature to the first crossing of the ambient pressure line during the expansion phase. The total time ΔT is defined as the time from the onset of the initial positive phase of the signature to the first indication of the return to ambient pressure during the recompression phase. For the signatures observed in the present studies, particularly during ascent, the total time ΔT is not as well defined as those for aircraft systems

wherein engine exhaust wake effects are not significant. These parameters were computed for each sonic-boom signature as recorded at each of the five stations and are listed in table VII.

Ascent Measurements

Figure 14 presents measured sonic-boom signatures obtained in the Atlantic at stations 1, 2, and 3 downrange from the launch site. It should be recalled that these stations were located so as to lie within the focus regions associated with the vehicle flight-path angle and acceleration profile during ascent. Listed in the figure are the velocity and altitude of the launch vehicle at the time it was approximately over the measurement station. Also indicated in the figure are the time scale for the signatures and the measured overpressure for each signature.

The onset and initial positive phase of the signatures as measured at stations 1, 2, and 3 appear as normal N-waves similar to those that have been measured during previous aircraft studies and the Apollo 15 mission (see ref. 7) and had peak overpressures of 134.21 N/m^2 (2.80 psf), 111.18 N/m^2 (2.32 psf), and 41.80 N/m^2 (0.87 psf) being observed at stations 1, 2, and 3, respectively. At stations 1 and 2 multiple shocks appear in the signatures which are similar to those observed from aircraft in maneuvering flight. (See ref. 8.) These multiple shocks are associated with disturbances emanating from different positions along the vehicle flight track that arrive at the measuring station at different times. When these disturbances arrive at the same time, a focus boom (overpressure enhancement) is observed. In figure 14(a) the fact that the two larger positive shocks are relatively close together suggests that the measurement station was very close to the focused boom region. As will be noted in figure 14(b) (station 2) the second shock (and signature) appears to be approximately 20 seconds after the initial onset of the primary signature. This result indicates that the measurement was made well downtrack of the focused boom region, in a region of only multiple signatures with little, if any, pressure enhancement. The signature of figure 14(c) (station 3) shows no indication of multiple shock signifying a measurement well out of the multiple-boom area beyond the focus region.

The duration times for the signatures measured at all three stations are very long (2.85 sec, 2.10 sec, and 4.14 sec, respectively) and are comparable with those measured for the Apollo 15 launch vehicle (ref. 7) during the ascent phase. The launch-vehicle physical length does not nearly account for the long signature duration observed; these

durations can be explained to a result from an effective increase in vehicle diameter and length due to the rocket-motor exhaust plume.

The overpressure signatures measured during the launch at stations 1, 2, and 3 exhibited moderate rise times. These rise times were on the same order of magnitude as those previously measured for various aircraft sonic-boom signatures. In figure 15 the signatures from stations 1, 2, and 3 are presented on an expanded time scale to give an indication of rise times; however, only part of the signature is shown. As indicated in table VII, these rise times range from 30 to 42 milliseconds. Previous flight studies involving aircraft have indicated that as the altitude increases, the signature rise time also increases. (See ref. 9 and fig. 17 of ref. 5.) It is interesting to note, however, that the subjective comments received from the crewmen on the ships, particularly during ascent, indicate that the booms from the spacecraft had a dull sound rather than a sharp sound which one usually associates with rapid rise time.

Reentry Measurements

The signatures of figure 16 exhibit multiple shock waves which are thought to be caused by reflections from the ocean surface as discussed previously. These multiple-shock signatures were also observed during the reentry of Apollo 15 (ref. 7); however, these multiple-shock waves were not indicated in the tunnel studies of a 0.016-scale model of the Apollo Command Module (ref. 10). Duration times for the signatures measured at stations 4 and 5 are 0.387 sec and 0.136 sec, respectively, and are comparable with those measured during reentry of Apollo 15 (ref. 7). It can be noted that the reentry signatures from stations 4 and 5 exhibit moderate to rapid rise times as illustrated by the data of figure 17 on the expanded time scale. The rise times at stations 4 and 5 are 0.043 and 0.0038 sec, respectively. Measured values of the rise times are indicated in table VII. These rise times are of the same order as those measured for the Apollo 15 (ref. 7) reentry vehicle.

Comparison With Other Measured Data

Figure 18 presents a summary of predicted and measured overpressure data as a function of altitude for several aircraft of varying size and weight (ref. 3) along with measured boom data for the launch and reentry phases of the Apollo 15 (ref. 7) and Apollo 16 space vehicles. It can be noted that for aircraft, the agreement between these measurements and prediction (stippled region) is very good throughout the altitude, size,

and weight range encountered. In addition, Δp is noted to decrease with increasing aircraft altitude. The overpressure data measured during the reentry of the Apollo 15 and Apollo 16 vehicles are very consistent in themselves and follow the same general trend exhibited by the aircraft measurements; that is, the peak boom overpressures decrease with increasing altitude. The overpressures measured during ascent for both launch vehicles are higher than those observed during reentry, as would be expected based on the larger vehicle size which is also influenced by the rocket-engine exhaust plume. These ascent boom pressures are also noted to decrease as vehicle altitude increases.

CONCLUDING REMARKS

This paper presents sonic-boom pressure signatures recorded during the launch and reentry phases of Apollo 16. The measurements were obtained along the spacecraft vehicle ground track at three locations during ascent and two locations during reentry.

Sonic-boom pressure signatures similar in nature to the N-waves associated with supersonic aircraft were observed during the ascent and reentry of Apollo 16. In addition, the sonic-boom signatures from Apollo 16 were similar and consistent with those observed during the ascent and reentry of Apollo 15 in that higher overpressures were observed compared with that expected on the basis of previous aircraft experience and these higher pressures are attributed to the increase in effective size of the rocket-engine exhaust plume. For the Apollo 16 reentry case, which was also consistent with Apollo 15 findings, the measured overpressures were of the order of magnitude and shape expected based on previous aircraft experience. For both the launch and reentry cases, the sonic-boom overpressure decreased as the vehicle altitude increased.

Overpressure values ranging from about 42 N/m^2 (0.87 psf) to 134 N/m^2 (2.8 psf) and 17 N/m^2 (0.36 psf) to 31 N/m^2 (0.65 psf) were measured during ascent and reentry, respectively. The signatures were not simple N-wave shapes but contained a number of intermediate shocks. These intermediate shocks observed during the ascent phase are associated with the ground focus boom regions resulting from the vehicle acceleration and flight-path angles. During the reentry phase, the intermediate shocks measured are believed to be associated with reflections from the surface of the ocean onto the sonic-boom measurement platform onboard the ships. All signatures exhibited rapid rise times which are of the order of those observed from supersonic aircraft. Very long wave

periods were observed from the measurements made during the ascent and are attributed to the effects of the rocket-engine exhaust plume.

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Hampton, Va., April 1, 1974.

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TABLE I.- SHIP POSITION AND APOLLO 16 OPERATIONAL PARAMETERS

Date	Measurement location	Ship	Boom arrival time, GMT	Ship position at boom time, deg	Spacecraft overhead time,* GMT	Spacecraft overhead altitude		Spacecraft overhead velocity	
						meters	feet	m/sec	ft/sec
4/16/72	Atlantic	U.S.S. Opportune, station 1	17:58:48	28.758 N 79.908 W	17:56:30	56 377	184 964	2024	6 641
4/16/72	Atlantic	U.S.S. Alacrity, station 2	17:59:33	28.867 N 79.700 W	17:56:42	66 278	217 449	2368	7 770
4/16/72	Atlantic	U.S.S. Exploit, station 3	18:00:39	28.967 N 79.333 W	17:56:59	81 139	266 204	2402	7 880
4/27/72	Pacific	U.S.S. Ponchatoula, station 4	19:38:44	02.290 S 156.666 W	19:36:18	44 123	144 768	3156	10 355
4/27/72	Pacific	U.S.S. Ticonderoga, station 5	19:39:32	00.784 S 156.206 W	19:37:58	24 600	80 698	528	1 731

*Time at which spacecraft arrives over the station.

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

[1 knot = 0.5144 m/sec]

Date	Measurement location	Ship	Ship speed, knots	Surface temperature		Relative humidity	Surface wind, knots	Wind direction, deg	Sea condition
				K	°F				
4/16/72	Atlantic	U.S.S. Opportune, station 1	2	299.8	80	78	15	240	0.61-m (2-ft) swell
4/16/72	Atlantic	U.S.S. Alacrity, station 2	2	299.8	80	80	9	200	.61-m (2-ft) swell
4/16/72	Atlantic	U.S.S. Exploit, station 3	3	300.9	82	80	13	270	.91-m (3-ft) swell
4/27/72	Pacific	U.S.S. Ponchatoula, station 4	8	301.5	83	89	15	112	1.22-m (4-ft) swell
4/27/72	Pacific	U.S.S. Ticonderoga, station 5	3	301.5	83	76	13	110	.91-m (3-ft) swell

TABLE III. - SUMMARY OF WEATHER DATA OBTAINED BY RADIOSONDE FROM CAPE KENNEDY 10 MINUTES AFTER LAUNCH

[1 knot = 0.5144 m/sec; 1 bar = 1×10^5 N/m^2]

Altitude, m	Wind direction, deg	Wind speed, knots	Temperature, K	Dewpoint, K	Pressure, millibars	Relative humidity, percent	Absolute humidity, g/m^3	Speed of sound, m/sec	Density, g/m^3
5	150	9.7	302.4	294.15	1018.00	61	17.81	349	1161.72
250	198	5.8	299.0	290.9	990.30	61	14.72	347	1144.58
500	226	7.8	297.0	289.1	962.60	61	13.20	345	1121.00
750	242	11.7	295.0	289.1	935.48	69	13.33	344	1096.34
1 000	248	15.6	293.6	286.7	908.98	65	11.41	343	1071.95
1 250	251	17.5	291.8	285.4	883.06	66	10.55	342	1048.13
1 500	259	21.4	288.6	284.9	857.68	79	10.37	341	1029.19
1 750	268	21.4	286.2	281.6	832.75	73	8.37	339	1008.36
2 000	267	19.4	284.0	281.4	808.38	83	8.28	338	986.28
2 250	241	13.6	286.2	262.8	784.63	18	2.09	339	953.52
2 500	238	11.7	285.8	252.8	761.63	8	.92	339	927.97
2 750	246	11.7	284.2	252.0	739.22	9	.86	338	905.40
3 000	254	13.6	283.0	252.0	717.37	9	.86	337	882.87
3 250	254	15.6	280.8	251.8	696.04	11	.85	336	863.01
3 500	252	19.4	278.6	251.4	675.18	12	.83	334	843.54
3 750	247	21.4	277.0	249.0	654.81	11	.68	333	823.27
4 000	231	21.4	275.2	247.7	634.93	11	.60	332	803.63
4 250	206	21.4	274.8	----	615.57	--	----	332	780.36
4 500	192	25.3	275.2	----	596.79	--	----	332	755.70
4 750	192	29.2	274.2	----	578.58	--	----	332	735.30
5 000	192	31.1	272.6	237.9	560.85	5	.24	331	716.54
5 250	192	33.0	270.6	----	543.55	--	----	330	699.74
5 500	195	31.1	268.6	235.2	526.66	5	.18	328	682.99
5 750	202	31.1	267.4	----	510.20	--	----	328	664.82
6 000	208	31.1	265.6	----	494.19	--	----	327	648.00
6 250	210	33.0	263.6	----	478.56	--	----	326	632.33
6 500	212	35.0	261.4	----	463.30	--	----	324	617.39
6 750	216	36.9	259.0	229.6	448.40	6	.10	323	603.11
7 000	221	35.0	257.0	228.2	433.86	6	.09	322	588.11
7 250	225	35.0	256.4	227.3	419.71	6	.08	321	570.36
7 500	229	35.0	254.2	226.2	405.97	6	.07	319	556.32
7 750	232	35.0	252.6	225.8	392.57	7	.07	318	541.19
8 000	237	33.0	250.8	224.4	379.54	7	.06	317	527.13
8 250	239	33.0	248.6	222.6	366.84	7	.05	316	514.05
8 500	240	33.0	247.6	222.4	354.48	7	.05	315	498.82
8 750	243	35.0	247.6	221.9	342.51	7	.05	315	482.09
9 000	248	35.0	246.0	220.9	330.92	7	.04	314	468.74
9 250	250	35.0	245.7	219.5	319.62	7	.03	313	457.01
9 500	250	35.0	241 6	218.2	308.63	8	.03	312	444.85
9 750	251	35.0	239.6	216.8	297.92	8	.03	310	433.13
10 000	253	35.0	237.6	215.9	287.50	9	.02	309	421.68
10 250	252	36.9	235.6	214.6	277.35	9	.02	308	410.10
10 500	251	36.9	233.6	213.2	267.49	9	.02	307	398.79
10 750	253	38.9	232.0	211.9	257.90	9	.01	305	387.40
11 000	255	42.8	230.6	210.9	248.60	9	.01	304	375.71
11 250	259	46.7	228.8	209.7	239.58	10	.01	303	364.93
11 500	260	48.6	226.8	208.4	230.81	10	.01	302	354.47
11 750	259	48.6	225.2	207.4	222.30	11	.01	301	343.88
12 000	258	48.6	223.6	206.4	214.04	11	.01	299	333.62
12 250	258	46.7	222.2	205.3	206.04	11	.01	299	322.92
12 500	259	44.7	221.1	204.4	198.30	11	.01	298	312.37
12 750	260	42.8	219.0	202.6	190.80	11	.00	297	303.50
13 000	261	40.8	217.4	201.8	183.52	12	.00	296	293.96
13 250	260	36.9	216.6	201.2	176.48	12	.00	295	283.91
13 500	263	31.1	215.2	200.0	169.68	12	.00	294	274.77
13 750	270	27.2	213.0		163.08			292	266.80
14 000	272	25.3	210.4		156.68			291	259.45
14 250	268	23.3	208.6		150.45			290	251.19
14 500	261	23.3	207.2		144.43			289	242.95
14 750	263	27.2	205.8		138.61			288	234.54
15 000	268	29.2	204.4		133.00			287	226.75
15 250	276	31.1	203.2		127.57			286	218.72
15 500	284	31.1	203.2		122.36			286	209.75
15 750	288	31.1	202.6		117.35			286	201.73
16 000	287	31.1	201.4		112.53			284	194.71
16 250	290	29.2	200.0		107.87			283	187.83

TABLE III.- SUMMARY OF WEATHER DATA OBTAINED BY RADIOSONDE FROM CAPE KENNEDY 10 MINUTES AFTER LAUNCH – Concluded

Altitude, m	Wind direction, deg	Wind speed, knots	Temperature, K	Dewpoint, K	Pressure, millibars	Relative humidity, percent	Absolute humidity, g/m^3	Speed of sound, m/sec	Density, g/m^3
16 500	302	27.2	200.0		103.39			283	180.09
16 750	316	23.3	199.0		99.10			283	173.50
17 000	318	17.5	198.2		94.95			282	166.92
17 250	303	11.7	197.6		90.97			282	160.39
17 500	290	15.6	197.4		87.15			281	153.81
17 750	294	19.4	197.4		83.49			281	147.39
18 000	309	19.4	198.2		79.98			282	140.65
18 250	338	17.5	201.0		76.66			284	132.93
18 500	2	17.5	199.2		73.48			283	128.46
18 750	12	13.6	197.0		70.40			281	124.45
19 000	24	11.7	198.2		67.44			282	118.52
19 250	45	7.8	201.2		64.64			284	111.90
19 500	91	3.9	200.8		61.98			284	107.54
19 750	130	1.9	201.0		59.42			284	102.99
20 000	71	5.8	205.8		56.99			288	96.48
20 250	82	9.7	207.6		54.70			289	91.82
20 500	91	9.7	208.8		52.52			290	87.66
20 750	90	7.8	208.6		50.43			290	84.27
21 000	80	7.8	210.2		48.43			291	80.24
21 250	66	11.7	210.6		46.52			291	76.95
21 500	58	15.6	211.8		44.70			292	73.55
21 750	57	15.6	213.8		42.95			293	69.97
22 000	60	15.6	214.2		41.29			293	67.13
22 250	70	13.6	214.4		39.69			293	64.50
22 500	86	13.6	214.2		38.15			293	62.03
22 750	99	11.7	214.6		36.67			294	59.54
23 000	121	11.7	216.8		35.26			295	56.64
23 250	136	11.7	218.4		33.92			296	54.10
23 500	157	11.7	218.2		32.63			296	52.10
23 750	181	9.7	218.2		31.39			296	50.13
24 000	205	7.8	218.6		30.19			296	48.12
24 250	234	5.8	219.0		29.05			297	46.20
24 500	288	3.9	220.2		27.95			297	44.23
24 750	322	3.9	220.4		26.90			297	42.52
25 000	324	5.8	220.6		25.89			298	40.90
25 250	315	7.8	220.8		24.91			298	39.31
25 500	301	9.7	221.4		23.98			298	37.73
25 750	285	11.7	222.0		23.08			298	36.22
26 000	273	11.7	221.8		22.22			298	34.90
26 250	260	11.7	222.0		21.39			298	33.57
26 500	264	11.7	222.4		20.59			299	32.25
26 750	275	13.6	222.2		19.82			299	31.08
27 000	283	13.6	222.2		19.08			299	29.91
27 250	285	13.6	222.2		18.37			299	28.81
27 500	285	13.6	223.4		17.69			299	27.57
27 750	280	13.6	225.2		17.03			301	26.35
28 000	274	15.6	226.4		16.41			301	25.24
28 250	267	17.5	226.4		15.81			301	24.32
28 500	258	21.4	227.0		15.23			302	23.36
28 750	251	23.3	227.4		14.67			302	22.48
29 000	249	25.3	227.8		14.14			302	21.63
29 250	256	27.2	229.6		13.62			304	20.68
29 500	265	27.2	232.4		13.14			306	19.69
29 750	271	29.2	233.0		12.67			306	18.94
30 000	275	31.1	232.9		12.22			306	18.28
30 250	276	31.1	233.2		11.78			306	17.60
30 500	275	33.0	233.8		11.36			307	16.94
30 750	273	33.0	234.4		10.96			307	16.29
31 000	272	35.0	234.9		10.57			307	15.69
31 250	271	36.9	235.0		10.20			307	15.12
31 500	269	38.9	236.4		9.84			308	14.50
31 750	266	40.8	237.4		9.50			309	13.94
32 000	264	42.8	238.4		9.17			309	13.40
32 250	264	46.7	238.6		8.85			310	12.91
32 500	---	---	237.8		8.54			309	12.51
32 750	---	---	239.6		8.24			310	11.98

TABLE IV.- SUMMARY OF WEATHER DATA OBTAINED BY ROCKETSONDE FROM CAPE KENNEDY 90 MINUTES AFTER LAUNCH

[1 knot = 0.5144 m/sec; 1 bar = 1×10^5 N m^2]

Altitude, m	Wind direction, deg	Wind speed, knots	Temperature, K	Dewpoint, K	Pressure, millibars	Relative humidity, percent	Absolute humidity, g/m^3	Speed of sound, m/sec	Density, g/m^3
25 250	---	---	220.8		24.91			298	39.31
25 500	---	---	220.6		23.97			298	37.86
25 750	---	---	220.4		23.07			298	36.46
26 000	298	11.7	220.2		22.20			298	35.12
26 250	294	13.6	220.9		21.37			298	33.70
26 500	290	13.6	221.6		20.57			299	32.35
26 750	286	15.6	222.2		19.80			299	31.04
27 000	283	17.5	222.9		19.06			299	29.79
27 250	280	17.5	223.4		18.36			300	28.62
27 500	276	17.5	223.9		17.68			300	27.50
27 750	273	19.4	224.4		17.02			300	26.42
28 000	270	19.4	224.9		16.39			301	25.39
28 250	270	21.4	225.1		15.79			301	24.43
28 500	271	21.4	225.3		15.21			301	23.51
28 750	271	23.3	225.5		14.65			301	22.63
29 000	271	25 3	225.7		14.11			301	21.78
29 250	271	27.2	227.6		13.60			303	20.82
29 500	271	27.2	229.5		13.11			304	19.90
29 750	271	29.2	231.4		12.63			305	19.02
30 000	271	29.2	233.3		12.18			306	18.18
30 250	272	31.1	233.8		11.75			307	17.50
30 500	272	33.0	234.2		11.33			307	16.85
30 750	272	36.9	234.7		10.93			307	16.22
31 000	273	38.9	235.2		10.54			308	15.62
31 250	272	38.9	235.9		10.17			308	15.02
31 500	272	40.8	236.6		9.82			308	14.46
31 750	272	42.8	237.3		9.47			309	13.91
32 000	271	44.7	238.0		9.14			309	13.38
32 250	272	46.7	238.6		8.82			310	12.89
32 500	272	48.6	239.1		8.52			310	12.41
32 750	273	48.6	239.6		8.22			310	11.95
33 000	273	50.5	240.2		7.94			311	11.51
33 250	275	52.5	240.9		7.67			311	11.09
33 500	277	52.5	241.6		7.40			312	10.67
33 750	279	52.5	242.3		7.15			312	10.28
34 000	281	52.5	243.0		6.90			313	9.90
34 250	282	50.5	243.8		6.67			313	9.53
34 500	283	50.5	244.6		6.44			314	9.18
34 750	284	48.6	245.4		6.22			314	8.84
35 000	286	46.7	246.2		6.01			315	8.51
35 250	286	44.7	246.6		5.81			315	8.21
35 500	286	40.8	246.9		5.62			315	7.92
35 750	287	38.9	247.3		5.43			315	7.64
36 000	287	36.9	247.7		5.25			316	7.38
36 250	282	35.0	248.1		5.07			316	7.12
36 500	276	33.0	248.6		4.90			316	6.87
36 750	270	31.1	249.1		4.74			317	6.63
37 000	263	29.2	249.6		4.58			317	6.40
37 250	258	31.1	249.9		4.43			317	6.17
37 500	254	31.1	250.3		4.28			317	5.96
37 750	250	33.0	250.7		4.14			318	5.76

TABLE IV.- SUMMARY OF WEATHER DATA OBTAINED BY ROCKETSONDE FROM CAPE KENNEDY 90 MINUTES AFTER LAUNCH – Continued

Altitude, m	Wind direction, deg	Wind speed, knots	Temperature, K	Dewpoint, K	Pressure, millibars	Relative humidity, percent	Absolute humidity, g m^3	Speed of sound, m sec	Density, g m^3
38 000	246	35.0	251.0		4.00			318	5.56
38 250	247	36.9	252.2		3.87			318	5.35
38 500	249	38.9	253.4		3.75			319	5.15
38 750	250	38.9	254.5		3.62			320	4.96
39 000	251	40.8	255.7		3.51			321	4.78
39 250	253	40.8	257.0		3.39			322	4.60
39 500	255	40.8	258.3		3.28			322	4.43
39 750	257	42.8	259.7		3.18			323	4.27
40 000	259	42.8	261.0		3.08			324	4.11
40 250	261	40.8	261.7		2.98			324	3.97
40 500	264	38.9	262.4		2.89			325	3.83
40 750	266	36.9	263.2		2.80			325	3.70
41 000	269	35.0	263.9		2.71			326	3.57
41 250	267	33.0	265.4		2.62			327	3.44
41 500	264	29.2	266.8		2.54			328	3.32
41 750	261	25.3	268.3		2.46			329	3.20
42 000	257	21.4	269.8		2.39			329	3.08
42 250	252	21.4	270.6		2.31			330	2.96
42 500	248	21.4	271.4		2.24			330	2.88
42 750	242	19.4	272.2		2.17			331	2.78
43 000	237	19.4	273.0		2.11			331	2.69
43 250	234	21.4	272.8		2.04			331	2.61
43 500	231	21.4	272.6		1.98			331	2.53
43 750	228	21.4	272.4		1.92			331	2.46
44 000	226	23.3	272.2		1.86			331	2.39
44 250	229	23.3	272.2		1.81			331	2.31
44 500	231	23.3	272.3		1.75			331	2.24
44 750	234	23.3	272.4		1.70			331	2.17
45 000	237	25.3	272.4		1.65			331	2.11
45 250	236	21.4	272.3		1.60			331	2.04
45 500	234	17.5	272.1		1.55			331	1.98
45 750	231	15.6	272.0		1.50			331	1.92
46 000	228	11.7	271.8		1.46			331	1.87
46 250	221	9.7	271.4		1.41			330	1.81
46 500	212	9.7	271.1		1.37			330	1.76
46 750	202	9.7	270.7		1.33			330	1.71
47 000	191	7.8	270.3		1.29			330	1.66
47 250	181	9.7	270.2		1.25			330	1.61
47 500	174	11.7	270.0		1.21			330	1.56
47 750	168	11.7	269.8		1.17			329	1.51
48 000	164	13.6	269.6		1.14			329	1.47
48 250	173	11.7	269.9		1.10			329	1.42
48 500	186	11.7	270.2		1.07			330	1.38
48 750	201	9.7	270.5		1.03			330	1.33
49 000	218	9.7	270.8		1.00			330	1.29
49 250	228	9.7	271.0		.97			330	1.25
49 500	241	7.8	271.2		.94			330	1.21
49 750	256	7.8	271.3		.91			330	1.17
50 000	271	7.8	271.5		.89			330	1.14
50 250	282	7.8	271.5		.86			330	1.10
50 500	296	5.8	271.5		.83			330	1.07

TABLE IV.- SUMMARY OF WEATHER DATA OBTAINED BY ROCKETSONDE FROM CAPE KENNEDY 90 MINUTES AFTER LAUNCH – Concluded

Altitude, m	Wind direction, deg	Wind speed, knots	Temperature, K	Dewpoint, K	Pressure, millibars	Relative humidity, percent	Absolute humidity, g m^3	Speed of sound, m sec	Density, g m^3
50 750	312	.8	271.4		0.81			330	1.04
51 000	326	5.8	271.4		.78			330	1.01
51 250	360	1.9	271.2		.76			330	.98
51 500	104	3.9	270.9		.74			330	.95
51 750	119	7.8	270.6		.71			330	.92
52 000	124	13.6	270.4		.69			330	.89
52 250	134	17.5	270.0		.67			330	.87
52 500	141	21.4	269.6		.65			329	.84
52 750	145	27.2	269.2		.63			329	.82
53 000	148	31.1	268.8		.61			329	.79
53 250	154	35.0	268.4		.59			329	.77
53 500	159	38.9	267.9		.57			328	.75
53 750	163	40.8	267.5		.56			328	.72
54 000	167	44.7	267.0		.54			328	.70
54 250	172	38.9	265.9		.52			327	.68
54 500	180	33.0	264.8		.51			326	.67
54 750	190	29.2	263.7		.49			326	.65
55 000	205	25.3	262.6		.47			325	.63
55 250	213	21.4	262.2		.46			325	.61
55 500	224	19.4	261.8		.45			324	.59
55 750	238	17.5	261.3		.43			324	.58
56 000	254	17.5	260.9		.42			324	.56
56 250	269	15.6	261.0		.40			324	.54
56 500	287	13.6	261.1		.39			324	.52
56 750	305	15.6	261.2		.38			324	.51
57 000	320	17.5	261.3		.37			324	.49
57 250	334	13.6	261.3		.36			324	.47
57 500	359	9.7	261.3		.34			324	.46
57 750	30	9.7	261.4		.33			324	.45
58 000	55	13.6	261.4		.32			324	.43
58 250	62	13.6	261 0		.31			324	.42
58 500	68	13.6	260.5		.30			324	.41
58 750	74	15.6	260.1		.29			323	.39
59 000	80	15.6	259.7		.28			323	.38
59 250	83	13.6	259.4		.28			323	.37
59 500	87	11.7	259.2		.27			323	.36
59 750	94	9.7	259.0		.26			323	.35
60 000	102	7.8	258.7		.25			323	.34
60 250	132	9.7	258.2		.24			322	.33
60 500	153	11.7	257.8		.23			322	.32
60 750	165	15.6	257.3		.23			322	.31
61 000	173	19.4	256.8		.22			321	.30
61 250	---	---	256.0		.21			321	.29
61 500	---	---	255.1		.21			320	.28
61 750	---	---	254.3		.20			320	.27
62 000	---	---	253.5		.19			320	.26
62 250	---	---	252.7		.19			319	.26
62 500	---	---	251.9		.18			319	.25
62 750	---	---	251.1		.17			318	.24
63 000	---	---	250.3		.17			318	.23
63 240	---	---	250.0		.16			317	.23

TABLE V.- SUMMARY OF WEATHER DATA OBTAINED BY RADIOSONDE ABOARD

STATION 5 DURING SPLASH DOWN OF APOLLO 16

[1 knot = 0.5144 m/sec; 1 bar = 1×10^5 N/m^2]

Altitude, m	Wind direction, deg	Wind speed, knots	Temperature, K	Dewpoint, K	Pressure, millibars	Relative humidity, percent	Absolute humidity, g/m^3	Speed of sound, m sec	Density, g/m^3
3	120	15	300.2	297.51	1007.7	84	21.77	347	1156.13
305	120	15	295.8	292.99	973.8	83	16.84	345	1136.52
610	120	14	294.2	289.13	940.3	72	13.28	344	1105.52
914	---	--	292.6	285 62	907.8	64	10.67	343	1074.69
1 219	---	--	291.0	283.51	876.1	61	9.33	342	1043.28
1 524	120	13	289.2	284 03	845.4	71	9.71	341	1012.68
1 829	---	--	287.8	281 29	815.7	64	8.15	340	982.60
2 134	---	--	286.2	278.07	786.8	66	7.53	338	953.34
2 438	120	10	284.6	275.36	758 8	69	7.20	338	924.14
2 743	---	--	283.4	277.54	731.6	66	6.39	337	895.21
3 048	120	9	282.4	274.87	705.2	59	5.32	336	867.05
3 353	---	--	280.8	271.94	679.7	53	4.33	335	840.68
3 658	120	8	279.4	269.57	655.0	49	3.65	335	814.71
3 962	115	8	277.6	267.69	631.0	48	3.19	334	790.10
4 267	---	--	275.6	265.94	607.8	48	2.81	332	766.55
4 572	---	--	273.8	263.44	585.3	45	2.35	331	742.96
4 877	090	6	272.2	258.90	563.4	35	1.64	330	719.87
5 182	---	--	270.6	257.17	542.2	35	1.42	329	697.42
5 486	---	--	269.1	254.88	521.7	32	1.18	328	674.92
5 791	020	8	267.3	252.56	501.9	30	.97	327	653.34
6 096	---	--	265.8	247.33	482.7	21	.61	327	6 .25
6 401	355	9	264.0	248.15	464.1	26	.67	325	612.17
6 706	---	--	262.6	246.07	446.1	24	.56	325	591.63
7 010	---	--	260.4	238.77	428.7	14	.28	323	573.16
7 315	---	--	258.2	237.15	411.9	14	.24	322	555.43
7 620	340	13	256.0	236.00	395.6	15	.21	320	537.96
7 925			254.4	234.68	379.8	15	.19	319	519.87
8 230			252.8	232.38	364.5	14	.15	318	502.11
8 534			251.2	231.74	349.7	15	.14	317	485.10
8 839			249.4	230.44	335.5	15	.12	316	468.43
9 144			247.4	228.83	321.8	15	.10	315	452.91
9 449			245.0	226.78	308.5	15	.08	313	438.40
9 754			242.6	224.74	295.6	15	.07	312	424.20
10 058			240.4	222.91	283.1	15	.06	311	410.17
10 363			237.6	219.83	271.1	14	.04	309	397.32
10 668			234.4	217.02	259.4	14	.03	307	385.32
10 973			231.8	0	248.0	0	0	305	372.59
11 278			229.2		237.1			303	360.36
11 582			226.0		226.5			301	349.01
11 887			223.2		216.2			299	337.57
12 192			220.4		206.3			297	326.21
12 497			217.2		196.7			295	315.50
12 802			214.8		187.5			294	304.00
13 106			212.2		178.6			292	293.13
13 411			210.0		170.0			290	282.01
13 716			207.8		161.7			289	271.04
14 021			205.6		153.8			287	260.50
14 326			204.0		146.2			286	249.67
14 630			202.8		138.9			285	238.51
14 935			202.0		131.9			284	227.59
15 240			201.0		125.3			284	217.05
15 545			200.2		119.0			283	206.98
15 850			199.2		112.9			282	197.38
16 154			198.6		107.2			282	187.88
16 459			197.8		101.7			281	179.11
16 764			198.6		96.5			282	169.24
17 069			200.2		91.6			283	159.32
17 374			201.8		87.0			284	150.06
17 678			202.4		82.6			285	142.22
17 983			202.6		78.5			285	134.97
18 288			203.0		74.5			285	127.89
18 593			204.8		70.8			287	120.47
18 898			207.2		67.3			288	113.20
19 202			208.6		64.1			289	107.00
19 507			209.0		60.9			290	101.59
19 812			209.4		58.0			290	96.48

TABLE VI.- SUMMARY OF WEATHER DATA OBTAINED BY ROCKETSONDE FROM KWAJALEIN MISSILE RANGE APPROXIMATELY 3 HOURS BEFORE SPLASH DOWN

[1 knot = 0.5144 m/sec; 1 bar = 1×10^5 N/m^2]

Altitude, m	Wind direction, deg	Wind speed, knots	Temperature, K	Dewpoint, K	Pressure, millibars	Relative humidity, percent	Absolute humidity, g/m^3	Speed of sound, m/sec	Density, g/m^3
4	50	11	299.5	297.8	1006.80	90	22.39	347	1158.83
305	51	11	297.3	297.0	973.15	98	21.60	346	1128.75
610	56	12	295.4	294.6	940.00	95	18.72	345	1098.45
914	64	11	293.6	293.4	907.78	99	17.58	344	1067.90
1 219	77	10	291.9	291.8	876.45	100	15.98	343	1037.67
1 524	80	9	290.1	290.1	846.02	100	14.40	342	1008.52
1 829	88	10	288.4	288.4	816.46	100	13.00	341	979.62
2 134	102	9	286.7	286.7	787.73	100	11.72	340	951.28
2 438	104	7	284.7	284.6	759.84	100	10.34	338	924.57
2 743	86	6	282.9	280.2	732.73	84	7.77	337	898.64
3 048	75	5	281.5	278.3	706.42	80	6.77	336	871.02
3 353	71	6	280.9	278.0	680.97	82	6.67	336	841.31
3 658	67	8	279.8	275.9	656.35	76	5.78	335	814.55
3 962	93	7	278.2	274.6	632.52	77	5.28	334	789.64
4 267	92	6	275.9	273.2	609.38	82	4.82	333	767.28
4 572	74	5	273.9	267.9	586.89	65	3.32	332	745.30
4 877	73	5	272.4	264.8	565.09	58	2.62	331	721.92
5 182	91	4	270.4	268.0	543.96	84	3.34	330	699.50
5 486	160	2	268.7	268.7	523.51	100	3.55	329	677.27
5 791	170	2	267.3	267.0	503.72	98	3.13	328	655.40
6 096	143	3	265.5	265.3	484.56	99	2.77	327	634.77
6 401	114	4	263.8	262.9	466.01	93	2.30	326	614.63
6 706	70	7	262.1	260.1	448.04	85	1.85	325	595.03
7 010	52	10	260.3	258.4	430.65	85	1.62	324	576.00
7 315	51	11	258.3	256.4	413.81	85	1.38	322	557.94
7 620	36	8	256.6	254.0	397.52	80	1.14	321	539.60
7 925	322	8	254.5	251.4	381.75	76	.91	320	522.56
8 230	297	17	252.4	249.4	366.48	77	.77	318	506.01
8 534	293	22	250.7	243.1	351.72	52	.46	317	488.97
8 839	303	25	248.3	239.0	337.44	41	.29	316	473.74
9 144	304	25	246.1	237.6	323.60	44	.26	315	458.45
9 449	298	25	243.6	233.3	310.21	36	.17	313	444.05
9 754	291	24	240.8	227.2	297.23	24	.09	312	430.34
10 058	285	18	238.4	228.0	284.67	36	.10	310	416.35
10 363	280	16	236.5	229.6	272.53	48	.12	309	401.86
10 668	275	20	234.5	225.7	260.82	39	.08	308	387.86
10 973	268	23	231.9	221.7	249.50	32	.05	306	375.16
11 278	265	23	229.0	219.0	238.55	31	.04	305	363.32
11 582	262	21	226.3	216.9	227.95	33	.03	303	351.33
11 887	265	21	223.6	214.9	217.71	35	.02	301	339.62
12 192	279	26	220.6	212.5	207.81	36	.02	299	328.47
12 497	284	29	217.9	210.0	198.23	36	.01	298	317.23
12 802	286	32	215.4	207.7	189.00	36	.01	296	305.99
13 106	288	36	212.5		180.09			294	295.54
13 411	286	39	209.7		171.48			293	285.23
13 716	284	39	207.0		163.17			291	274.96
14 021	285	38	204.1		155.17			289	265.13
14 326	282	33	201.6		147.46			288	255.04
14 630	275	28	199.6		140.05			287	244.76
14 935	267	24	197.6		132.97			286	234.63
15 240	271	23	195.8		126.15			284	224.65
15 545	283	18	194.0		119.65			283	215.05
15 850	325	12	192.8		113.43			282	205.22
16 154	4	13	191.8		107.49			282	195.47

TABLE VI. - SUMMARY OF WEATHER DATA OBTAINED BY ROCKETSONDE FROM KWAJALEIN MISSILE RANGE APPROXIMATELY 3 HOURS BEFORE SPLASH DOWN – Concluded

Altitude, m	Wind direction, deg	Wind speed, knots	Temperature, K	Dewpoint, K	Pressure, millibars	Relative humidity, percent	Absolute humidity, g/m^3	Speed of sound, m/sec	Density, g/m^3
16 459	21	15	191.0		101.85			281	186.00
16 764	30	15	190.6		96.48			281	176.49
17 069	43	10	192.0		91.41			282	166.07
17 374	276	1	192.9		86.64			282	156.61
17 678	262	12	194.4		82.14			283	147.37
17 983	276	21	195.5		77.91			284	138.99
18 288	286	27	195.5		73.90			284	131.82
18 593	292	27	194.4		70.09			283	125.71
18 898	287	21	196.1		66.49			284	118.24
19 202	275	17	197.7		63.09			286	111.30
19 507	271	16	199.1		59.90			287	104.93
19 812	282	19	201.7		56.89			288	98.38
20 117	290	21	204.5		54.07			290	92.23
20 422	296	20	205.5		51.42			290	87.27
20 726	306	20	206.7		48.91			291	82.52
21 031	303	15	207.6		46.53			292	78.16
21 336	278	9	208.8		44.28			292	73.95
21 641	244	6	209.8		42.16			293	70.08
21 946	195	7	210.5		40.14			293	66.50
22 250	159	9	211.0		38.22			294	63.19
22 555	131	9	211.7		36.40			294	59.97
22 860	105	8	213.6		34.68			295	56.63
23 165	88	11	215.1		33.06			296	53.59
23 470	83	16	216.4		31.51			297	50.79
23 774	89	21	215.2		30.04			296	48.68
24 079	95	24	214.8		28.64			296	46.49
24 384	99	27	215.3		27.30			296	44.22
24 689	99	29	216.1		26.02			297	42.00
24 994	99	30	219.9		24.82			299	39.37
25 298	97	30	221.2		23.69			300	37.36
25 603	93	32	221.8		22.62			300	35.56
25 908	88	36	223.1		21.59			301	33.75
26 213	83	39	222.5		20.62			300	32.31
26 518	82	41	221.9		19.68			301	30.94
26 822	85	42	222.1		18.79			300	29.51
27 127	89	43	223.4		17.94			301	28.01
27 432	86	45	223.5		17.13			301	26.73
27 737	82	47	226.5		16.37			303	25.20
28 042	79	47	228.7		15.65			304	23.86
28 346	77	45	229.3		14.96			305	22.75
28 651	78	43	229.9		14.30			305	21.70
28 956	84	44	230.7		13.68			306	20.68
29 260	94	47	231.7		13.08			306	19.69
29 566	100	49	232.1		12.52			307	18.80
29 870	102	47	232.6		11.97			307	17.95
30 175	101	44	233.0		11.46			307	17.14
30 480	99	43	233.6		10.96			307	16.37
30 785	99	41	234.2		10.49			308	15.63
31 090	102	39	235.0		10.04			308	14.90
31 394	104	39	235.4		9.61			308	14.24
31 699	103	43	235.3		9.20			308	13.64
32 004	99	50	235.2		8.81			308	13.06
32 309	---	--	235.2		8.43			308	12.50

TABLE VII.- SUMMARY OF MEASURED SONIC-BOOM DATA FROM LAUNCH AND REENTRY OF APOLLO 16

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. Opportune, station 1	134.21	2.803	79.19	1.6540	0.038	2.162	2.853
U.S.S. Alacrity, station 2	111.18	2.322	50.87	1.0624	.030	1.055	2.099
U.S.S. Exploit, station 3	41.80	.873	36.33	.7587	.042	1.915	4.142
U.S.S. Ponchatoula, station 4	17.43	.364	1.36	.0283	.043	.204	.387
U.S.S. Ticonderoga, station 5	31.26	.653	1.59	.0332	.0038	.0936	.1358

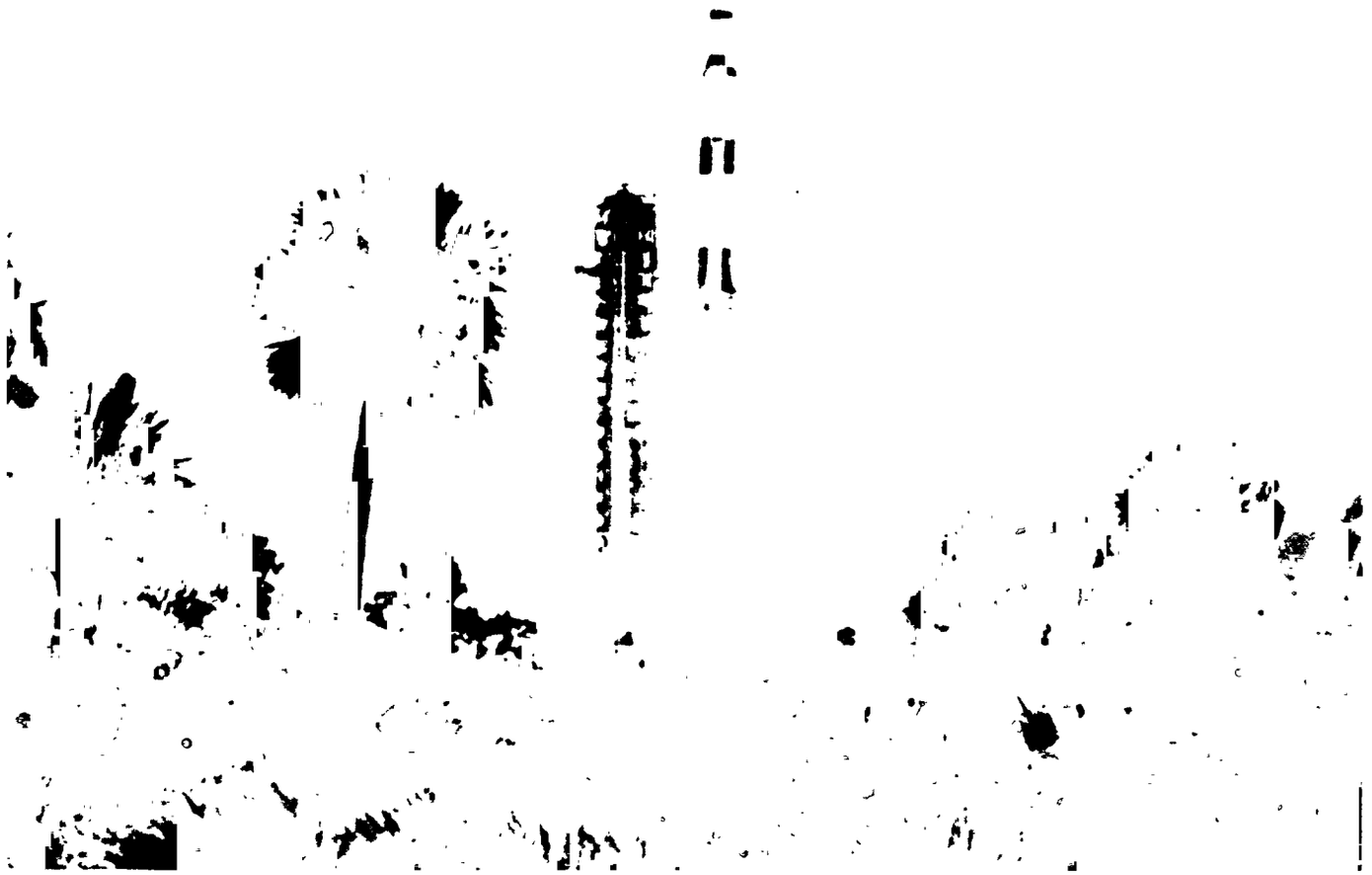

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Figure 1.- Photograph of Apollo 16 launch (April 16, 1972).

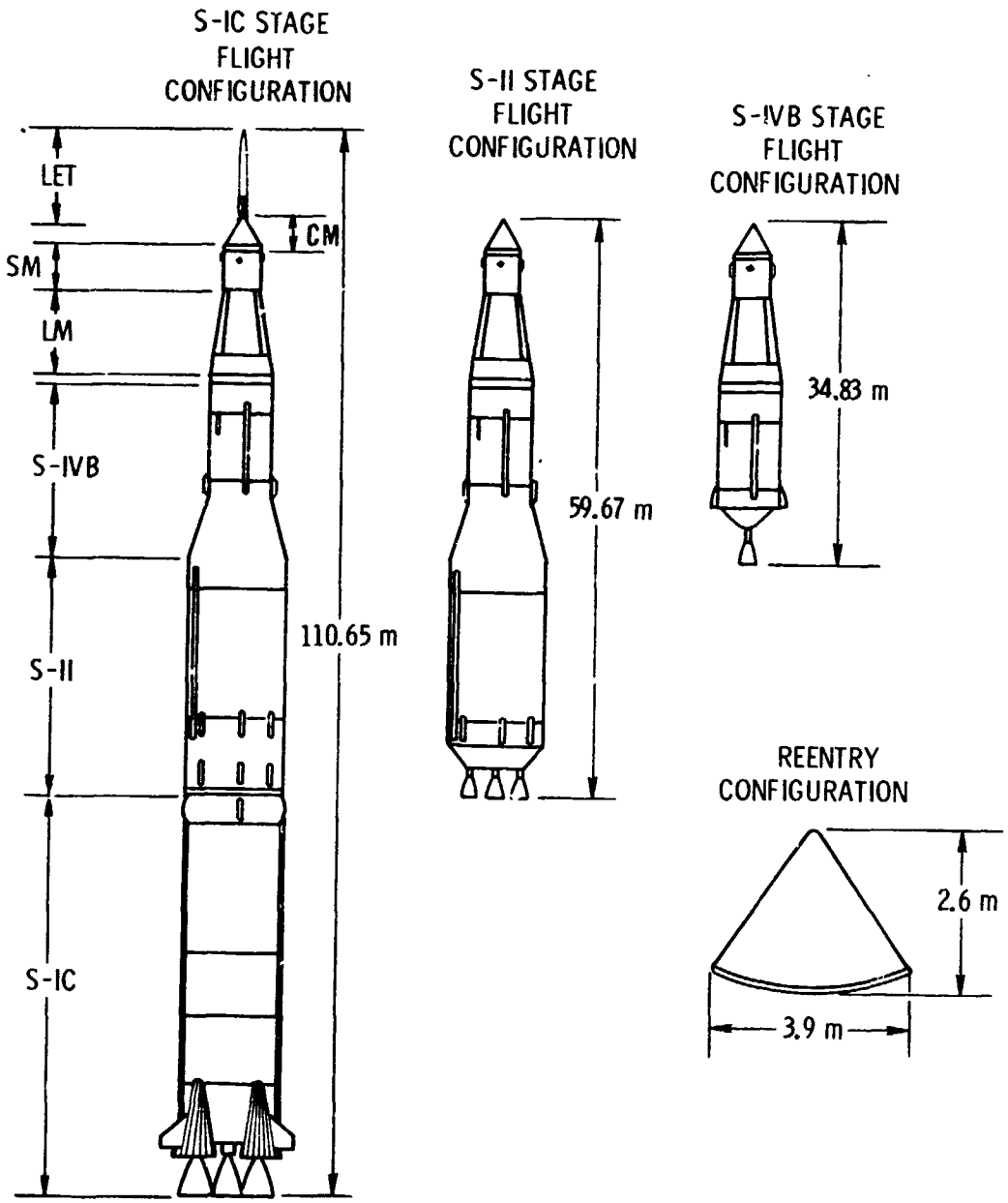

Figure 2.- Schematic diagram of Apollo 16/Saturn V launch vehicle and reentry vehicle configurations.

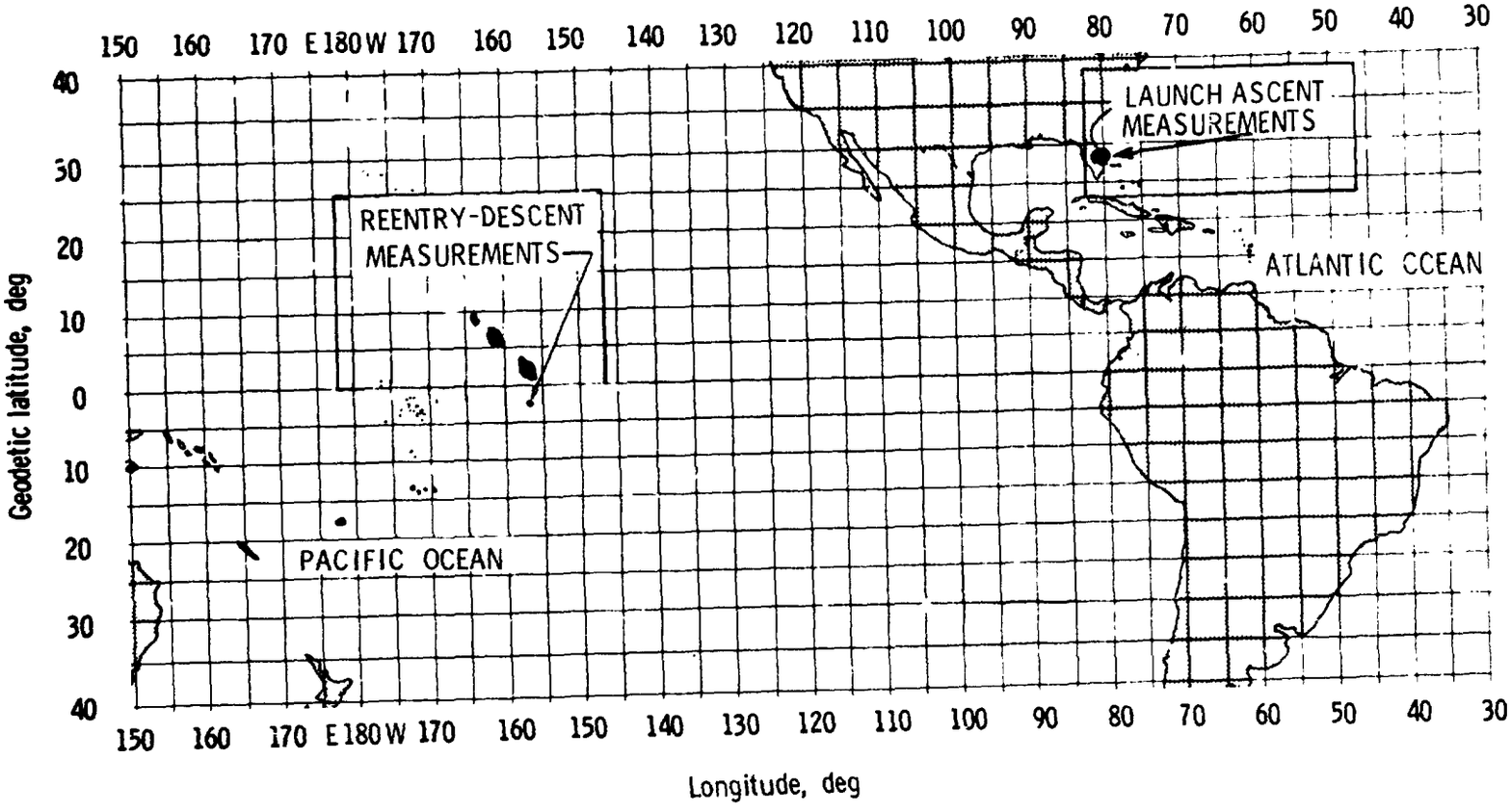

Figure 3.- Map showing general areas in which sonic-boom measurements were obtained.

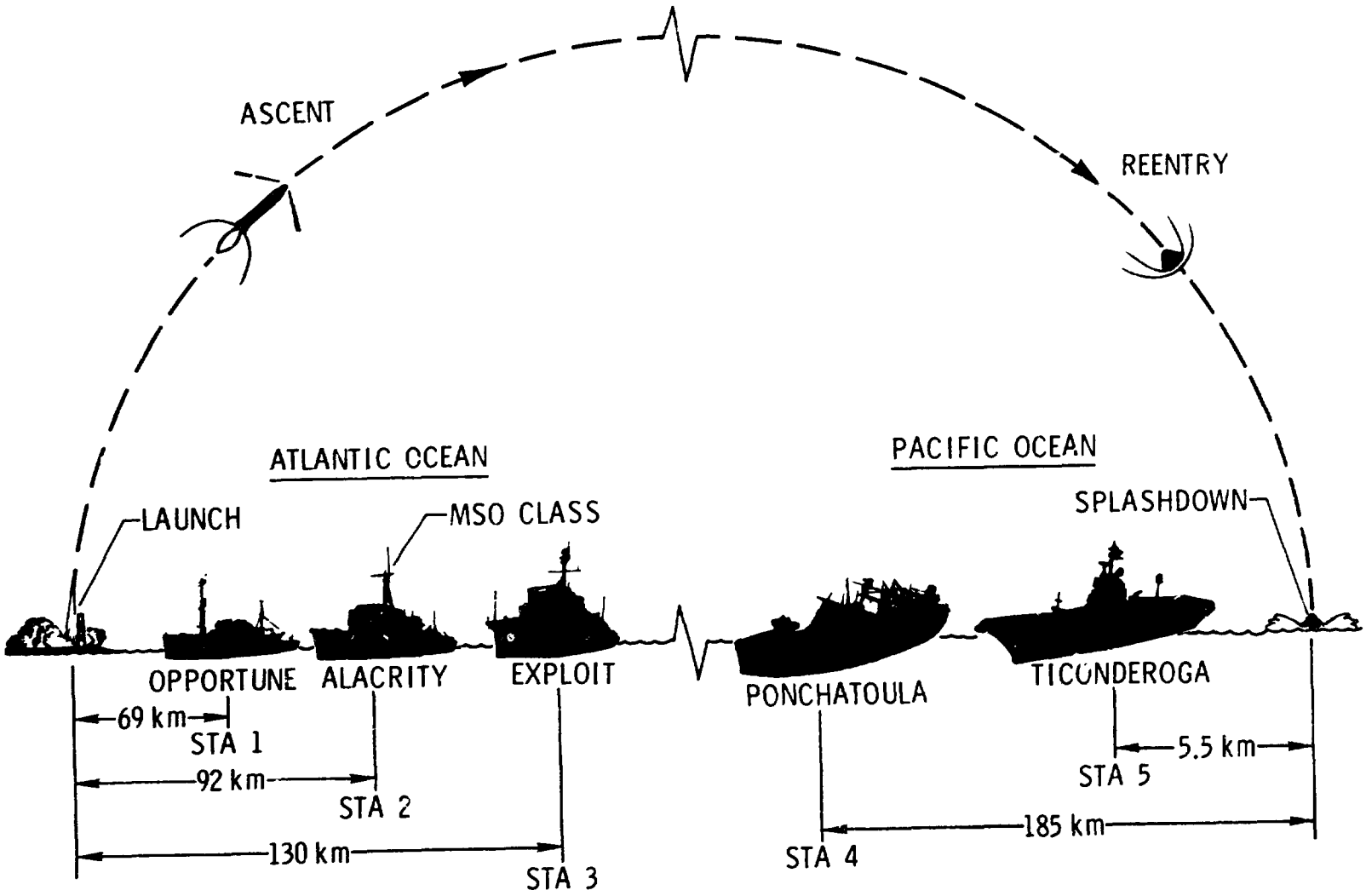

Figure 4.- Schematic showing ship position for data acquisition during launch and reentry.

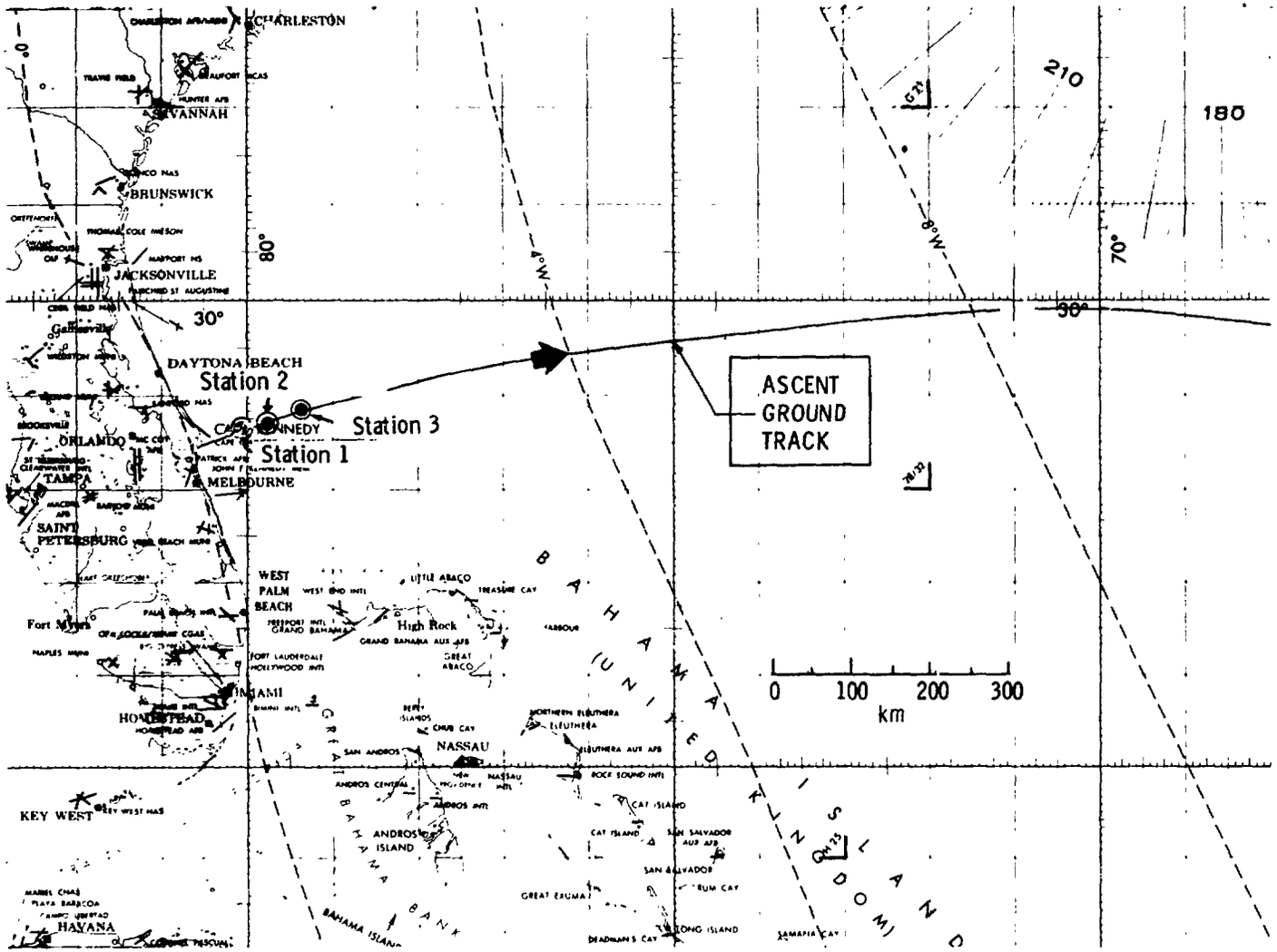

Figure 5.- Map of the Atlantic Ocean showing the position of the three measurement ships along with the Apollo 16 ground track.

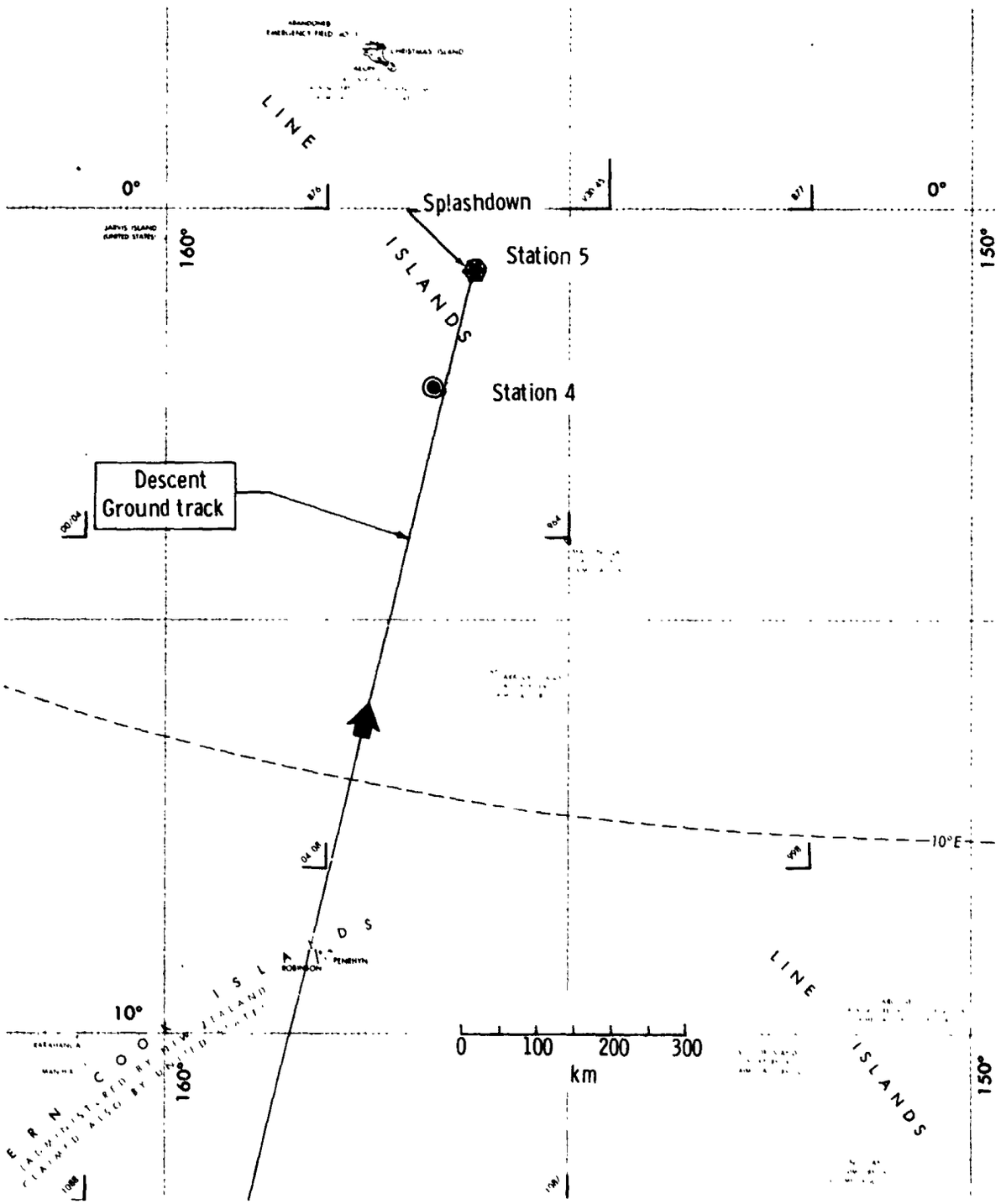

Figure 6.- Map of the Pacific Ocean showing the position of the two measurement ships and an indication of the Apollo 16 ground track.

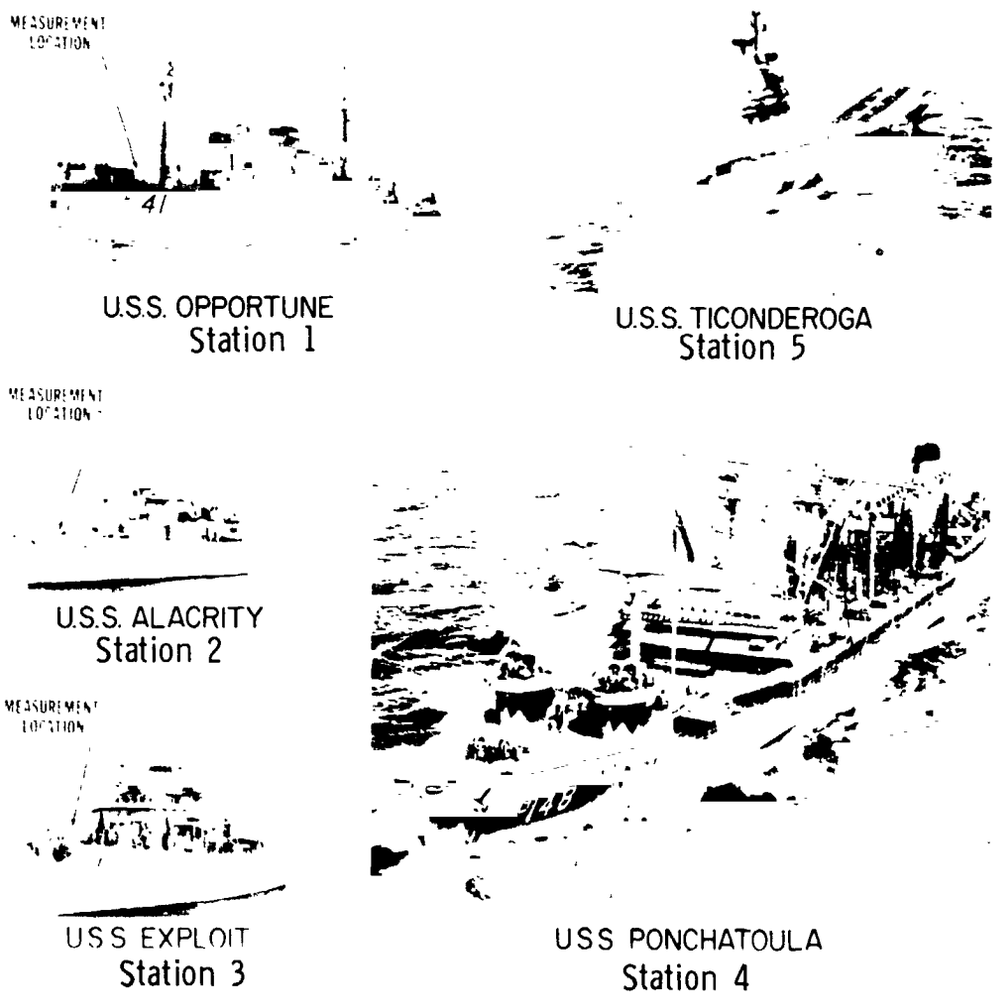

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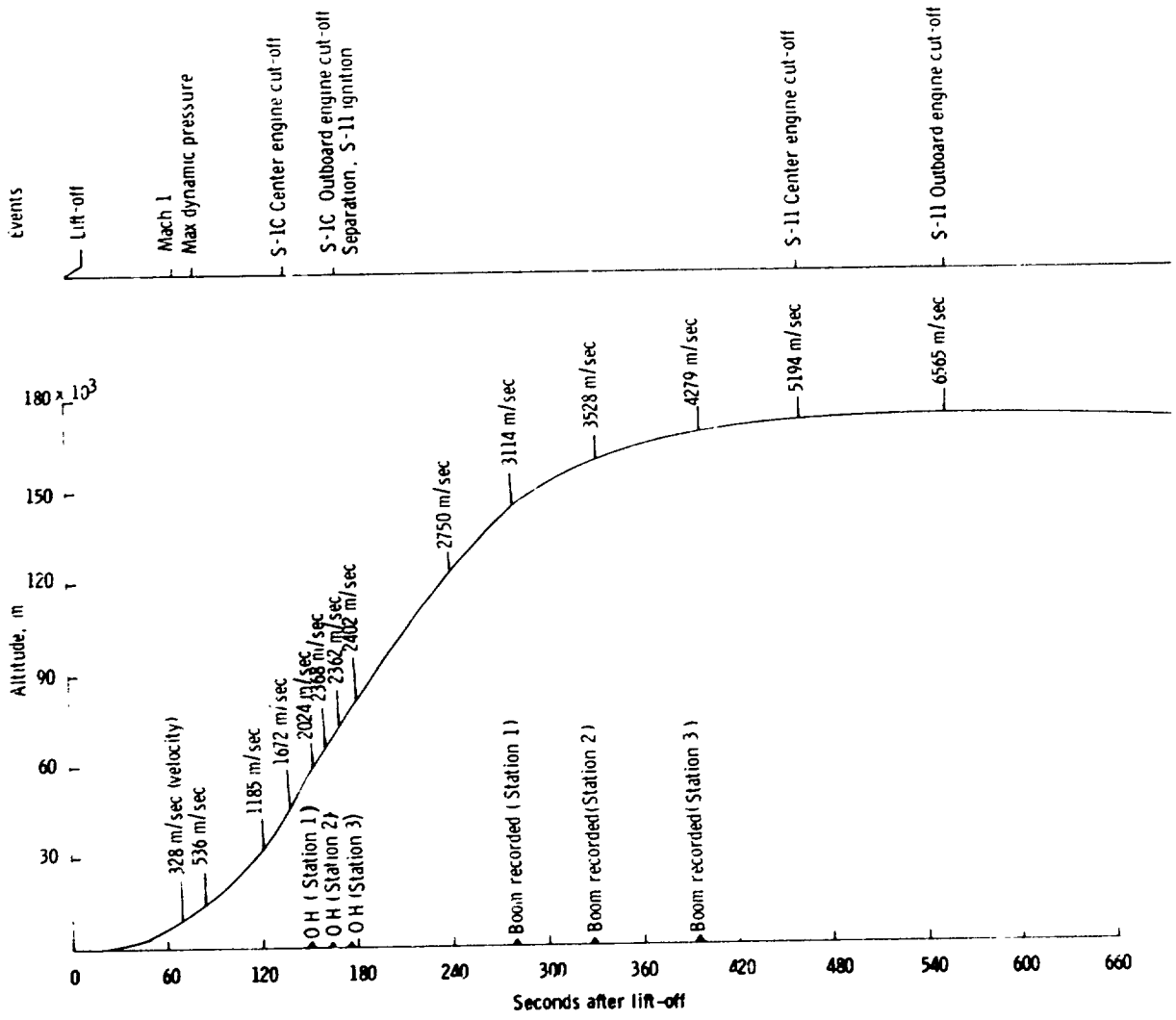
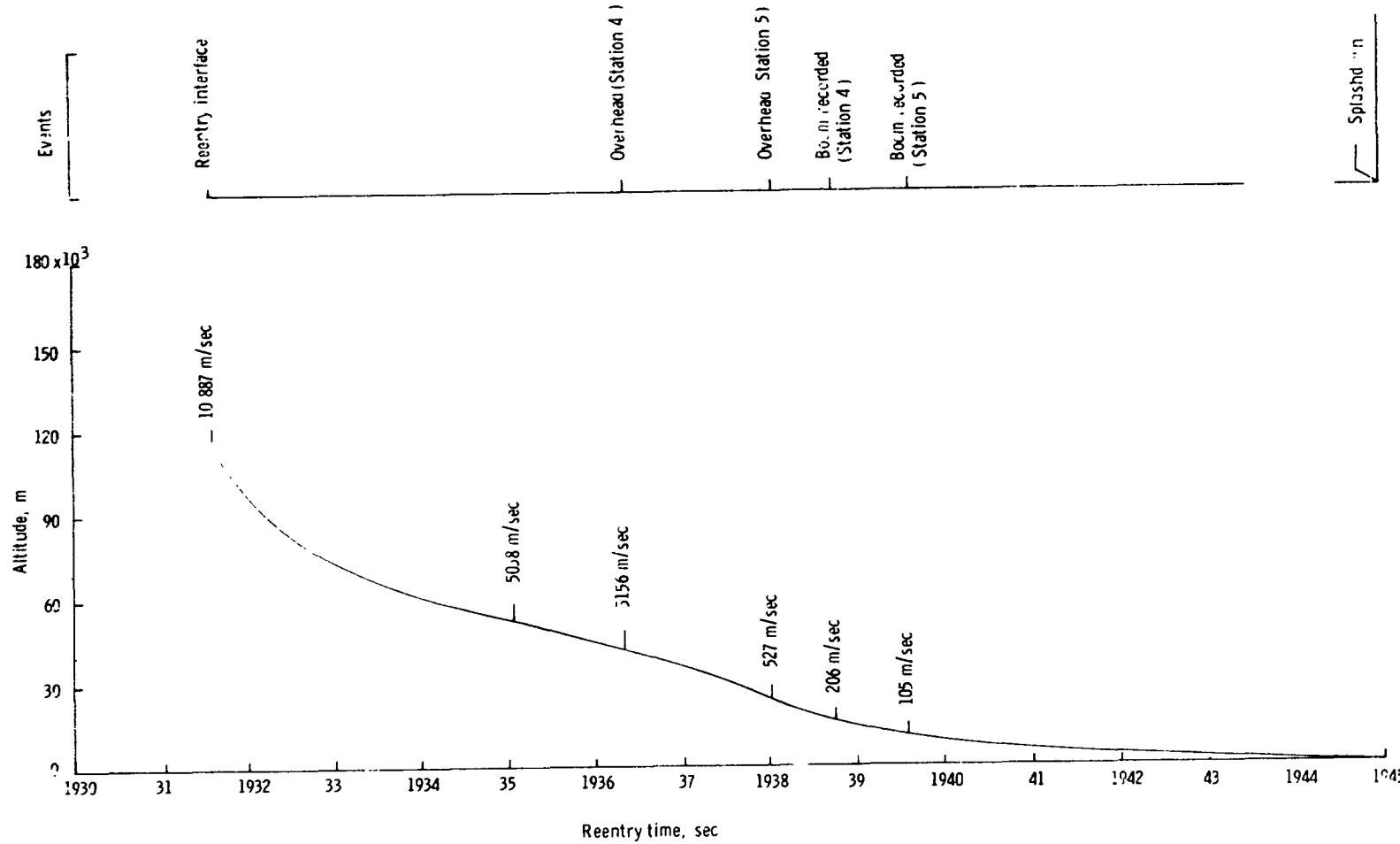
Figure 7.- Photograph of the ships used during the test, with approximate measurement locations indicated.



(a) Lau nch and ascent. Lift-off occurred at 1754 GMT April 16, 1972. OH denotes overhead.

Fig re 8.- Apollo 16 ascent and reentry profiles showing various events, vehicle altitude and velocity, and boom measurement times.



(b) Reentry and descent. Entry interface occurred at approximately 1932 GMT April 27, 1972; splash down occurred at 19:44:46 GMT.

Figure 8.- Concluded.

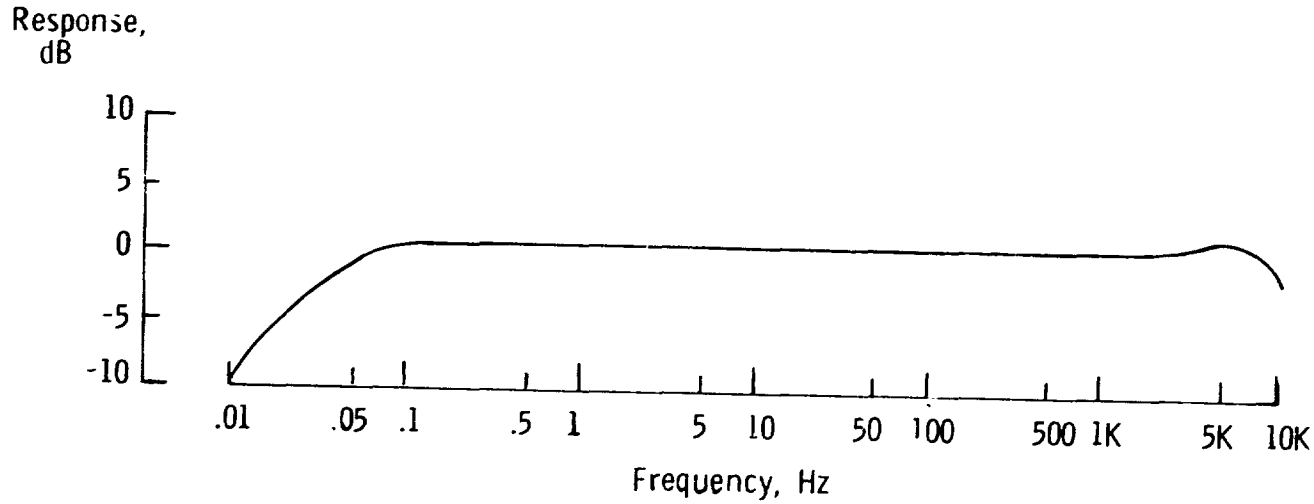


Figure 9.- Typical system response of the sonic-boom measurement equipment used for data acquisition.

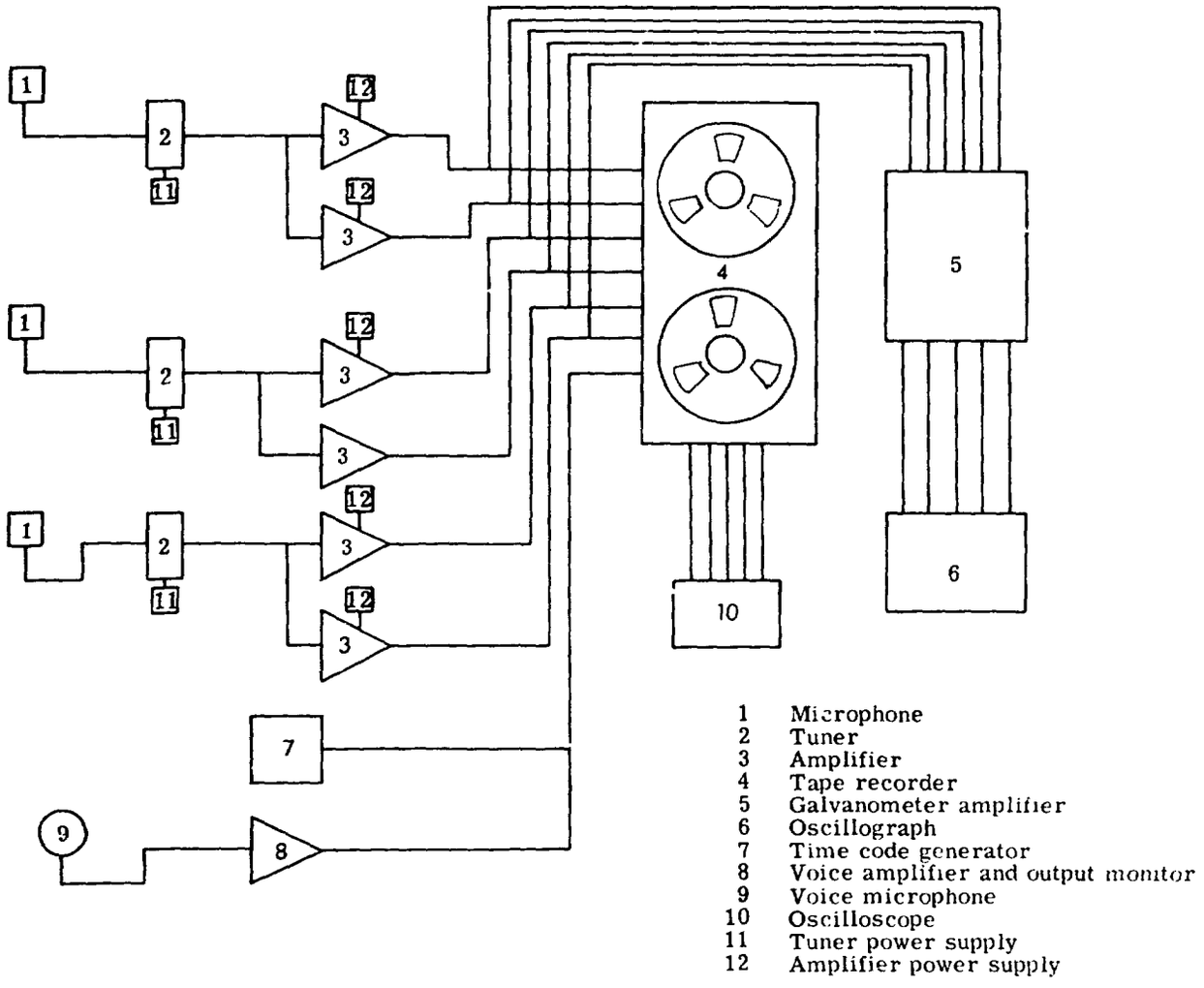
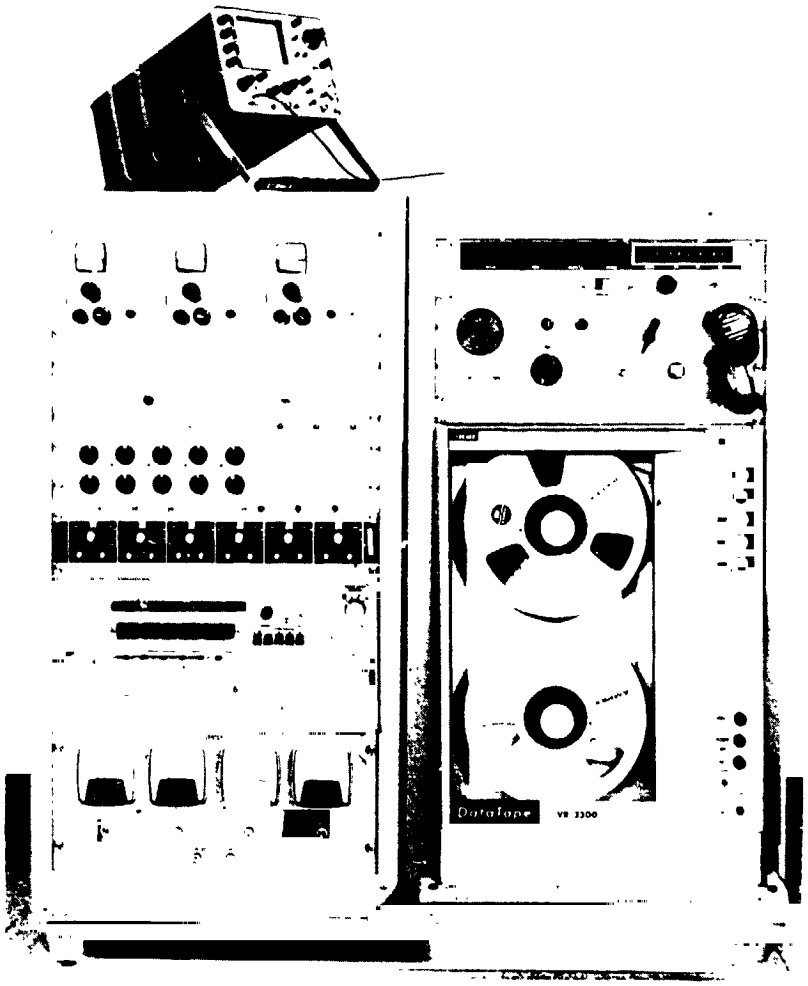


Figure 10.- Block diagram showing typical instrumentation system for sonic-boom data acquisition on board each measurement station.



(a) Recording console and signal conditioning equipment.

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(b) Microphone, mount, and windscreen.

Figure 11.- Typical data-acquisition system.

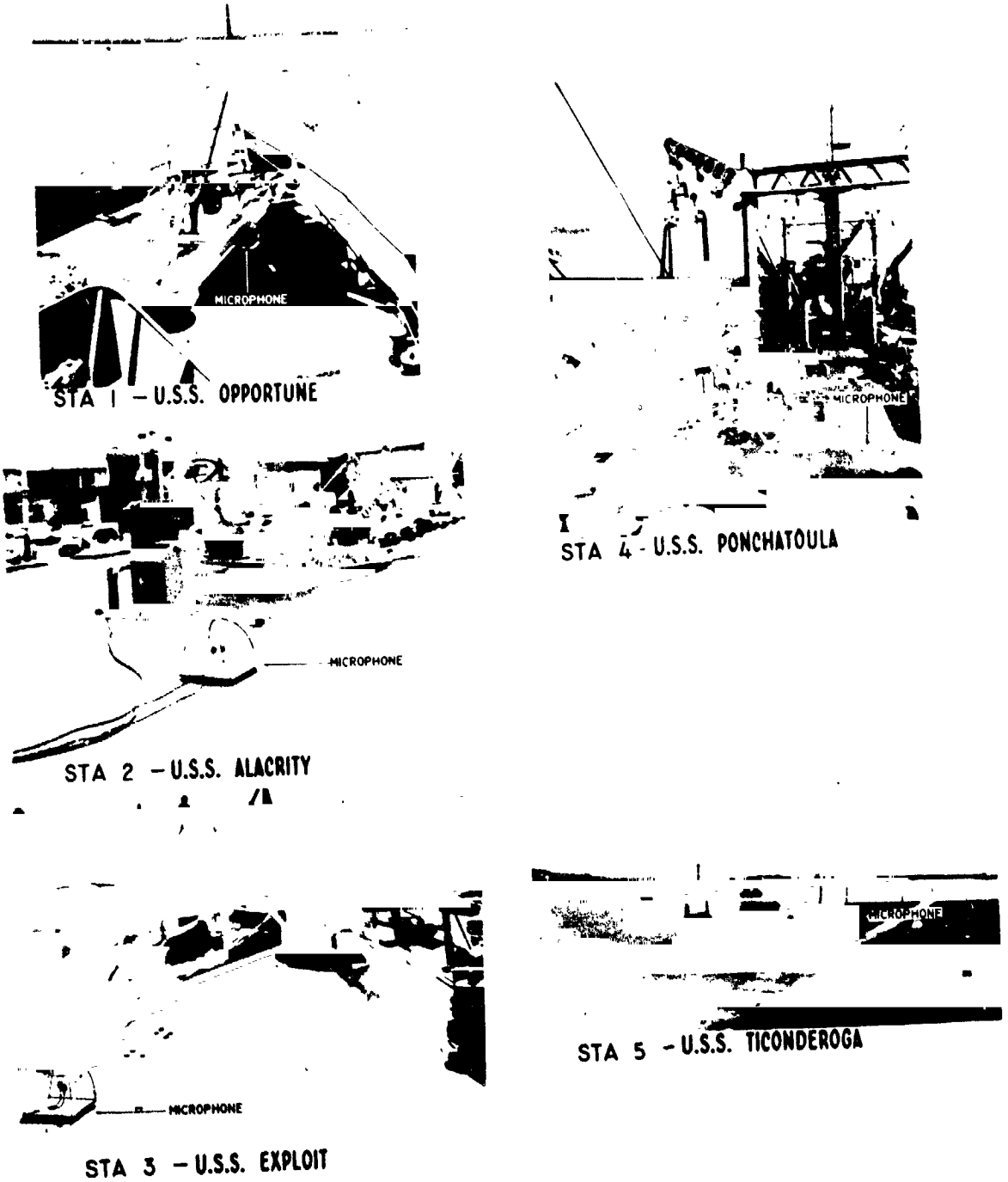

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Figure 12.- Typical microphone locations on the measurement ships.

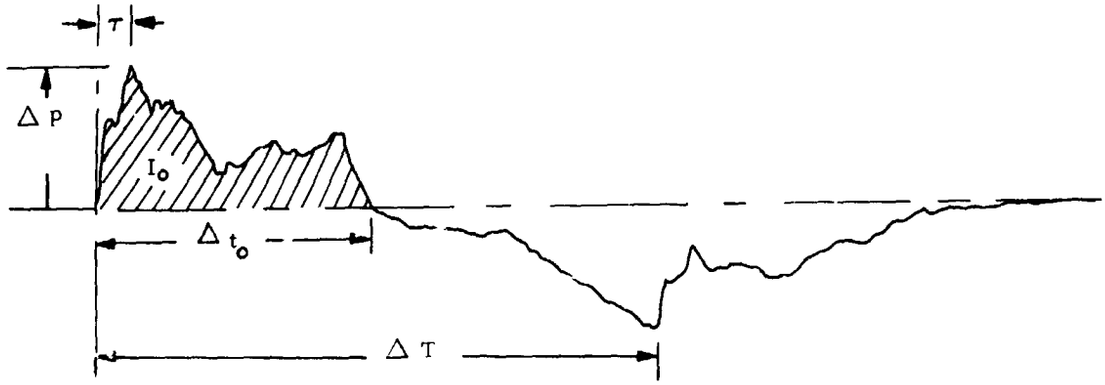
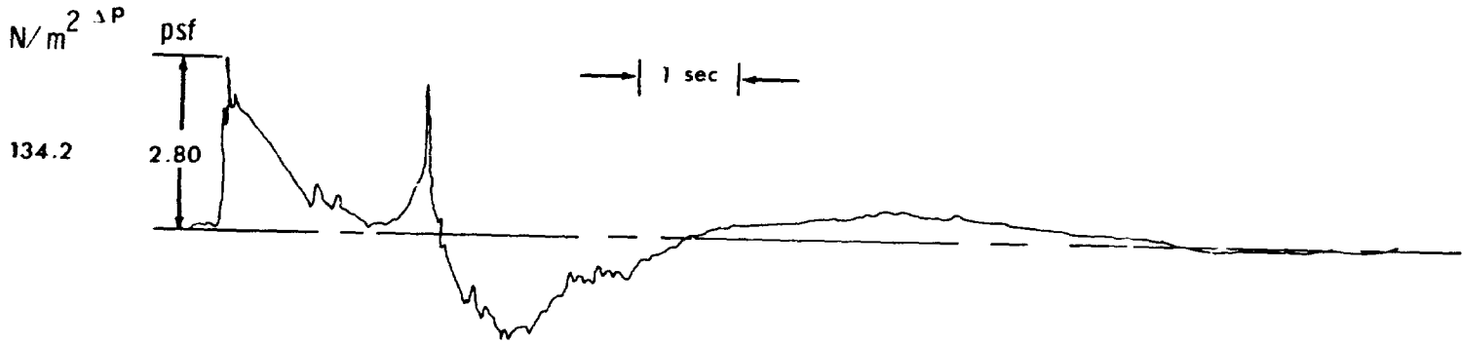
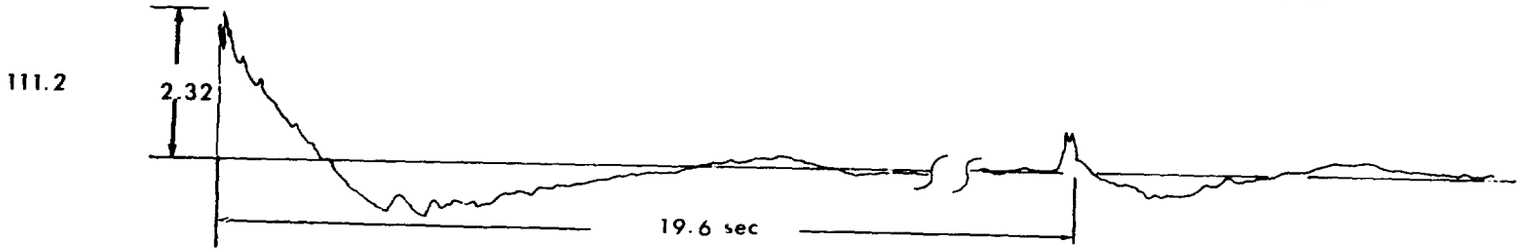


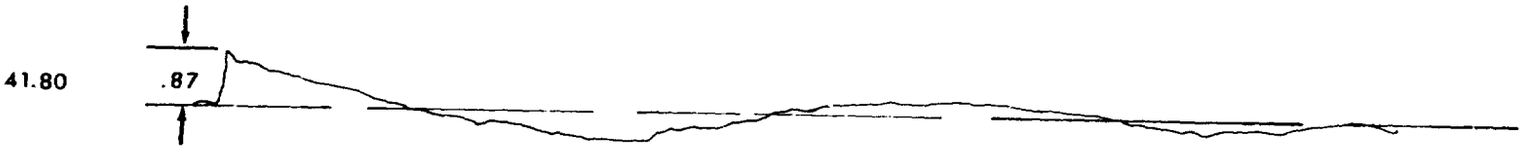
Figure 13.- Tracing of Apollo 16 sonic-boom signature measured during reentry and the identification of the various signature characterization.



(a) Station 1; overhead conditions: velocity 2024 m/sec and altitude 56 377 meters.



(b) Station 2; overhead conditions: velocity 2368 m/sec and altitude 66 278 meters.



(c) Station 3; overhead conditions: velocity 2402 m/sec and altitude 81 139 meters.

Figure 14.- Measured sonic-boom signatures during ascent recorded at stations 1, 2, and 3 along the Apollo 16 ground track.

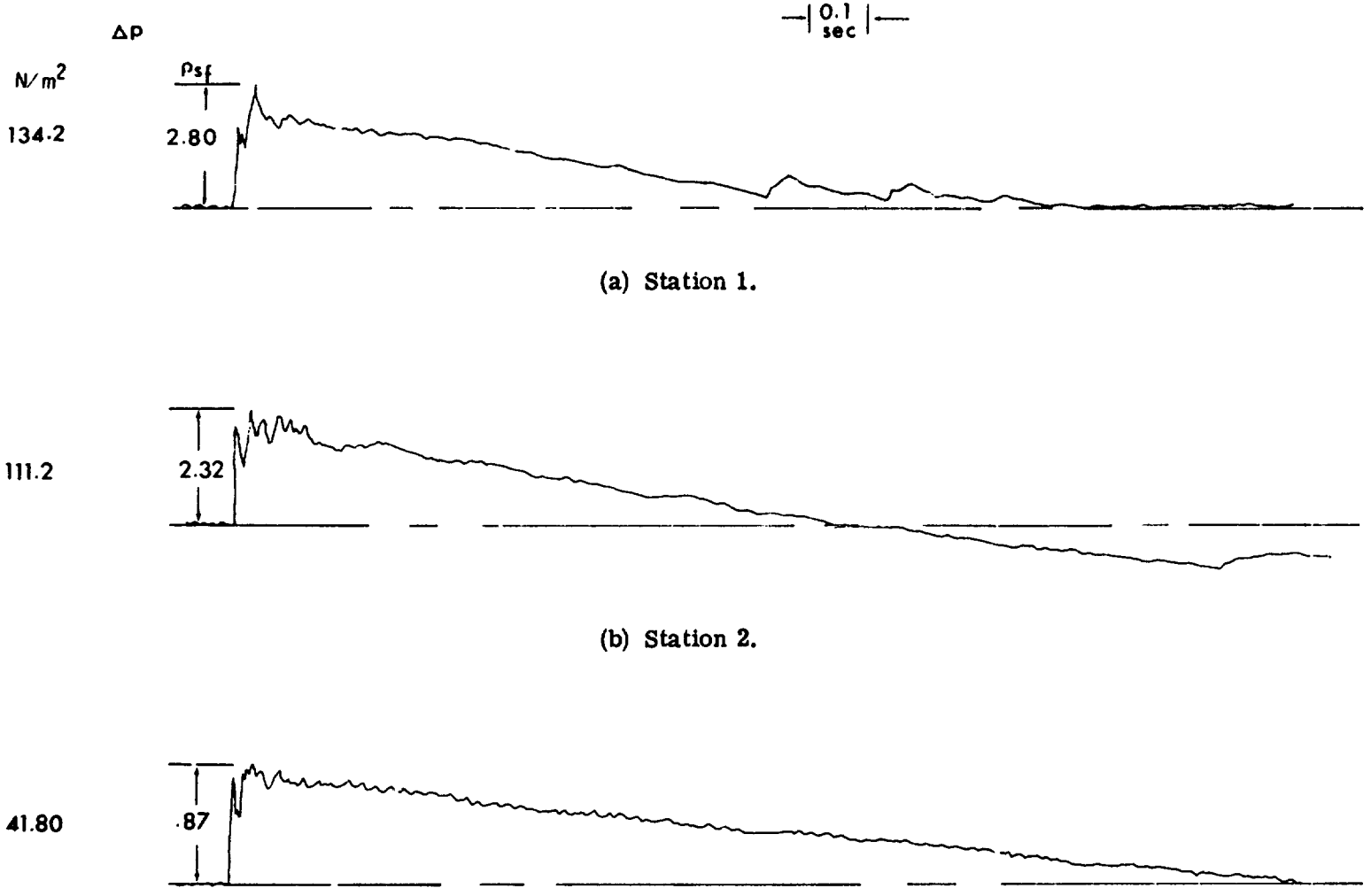
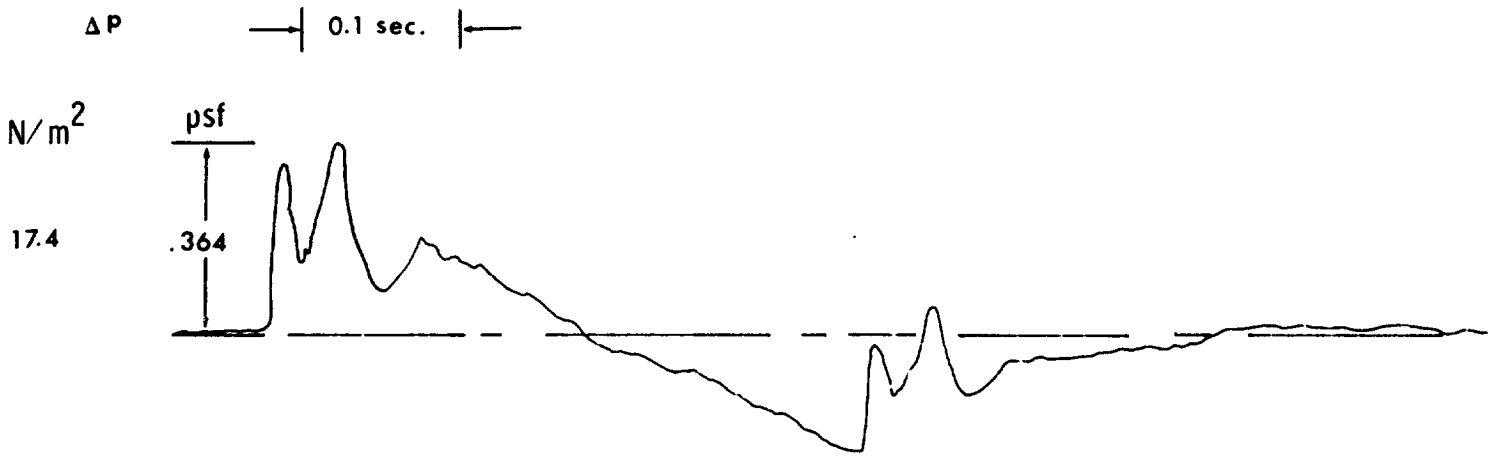
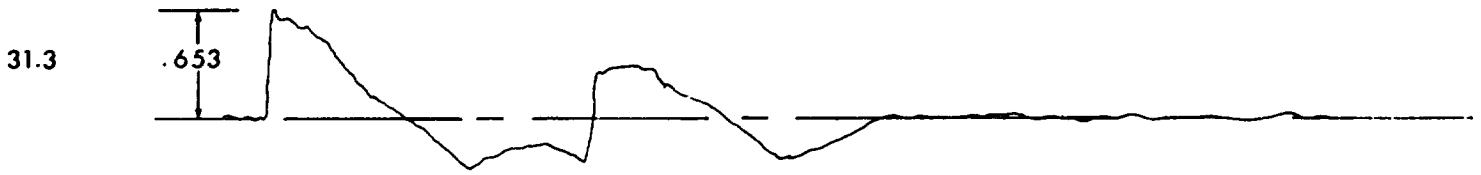


Figure 15.- Measured sonic-boom signatures during ascent showing details of bow-shock-wave rise time.

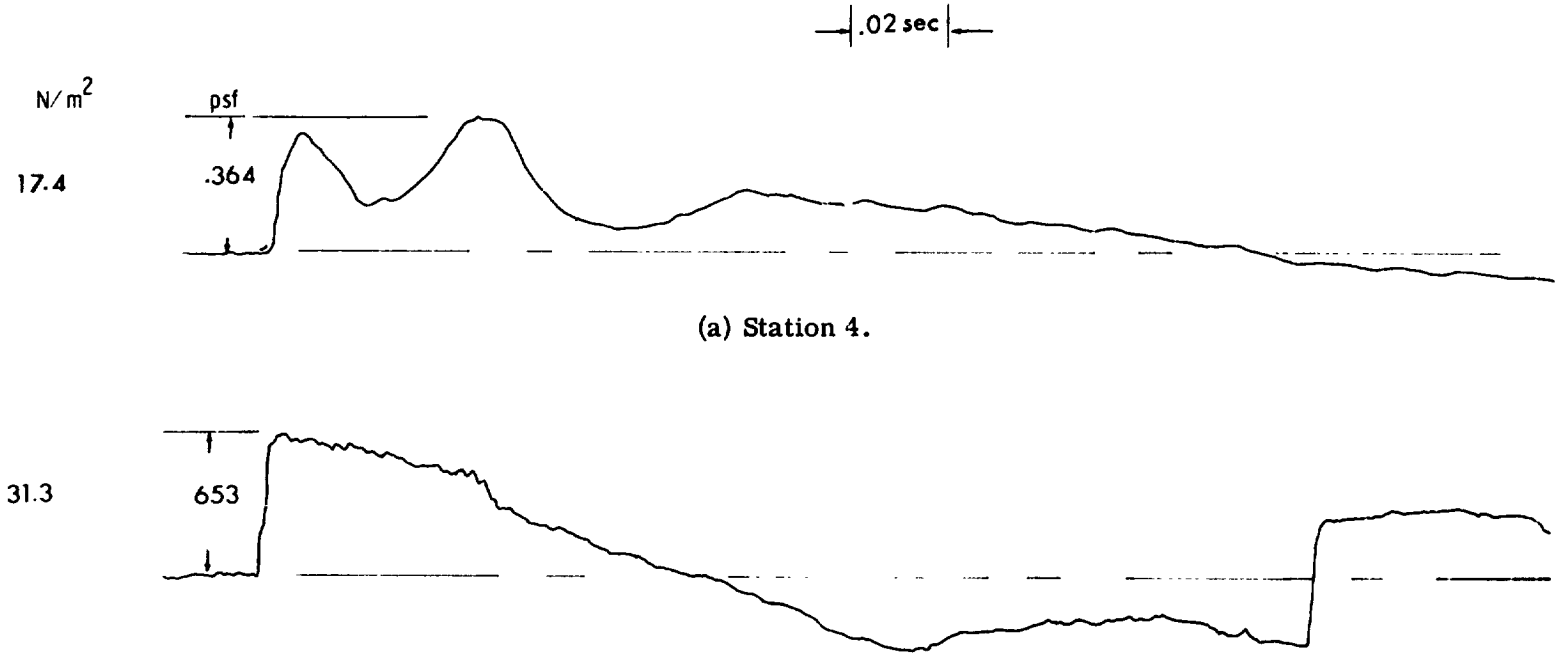


(a) Station 4; overhead conditions: velocity 3156 m/sec and altitude 44 123 meters.



(b) Station 5; overhead conditions: velocity 528 m/sec and altitude 24 600 meters.

Figure 16.- Measured sonic-boom signatures during descent recorded at stations 4 and 5 along the Apollo 16 ground track.



(a) Station 4.

(b) Station 5.

Figure 17.- Measured sonic-boom signatures during reentry showing details of bow-shock-wave rise time.

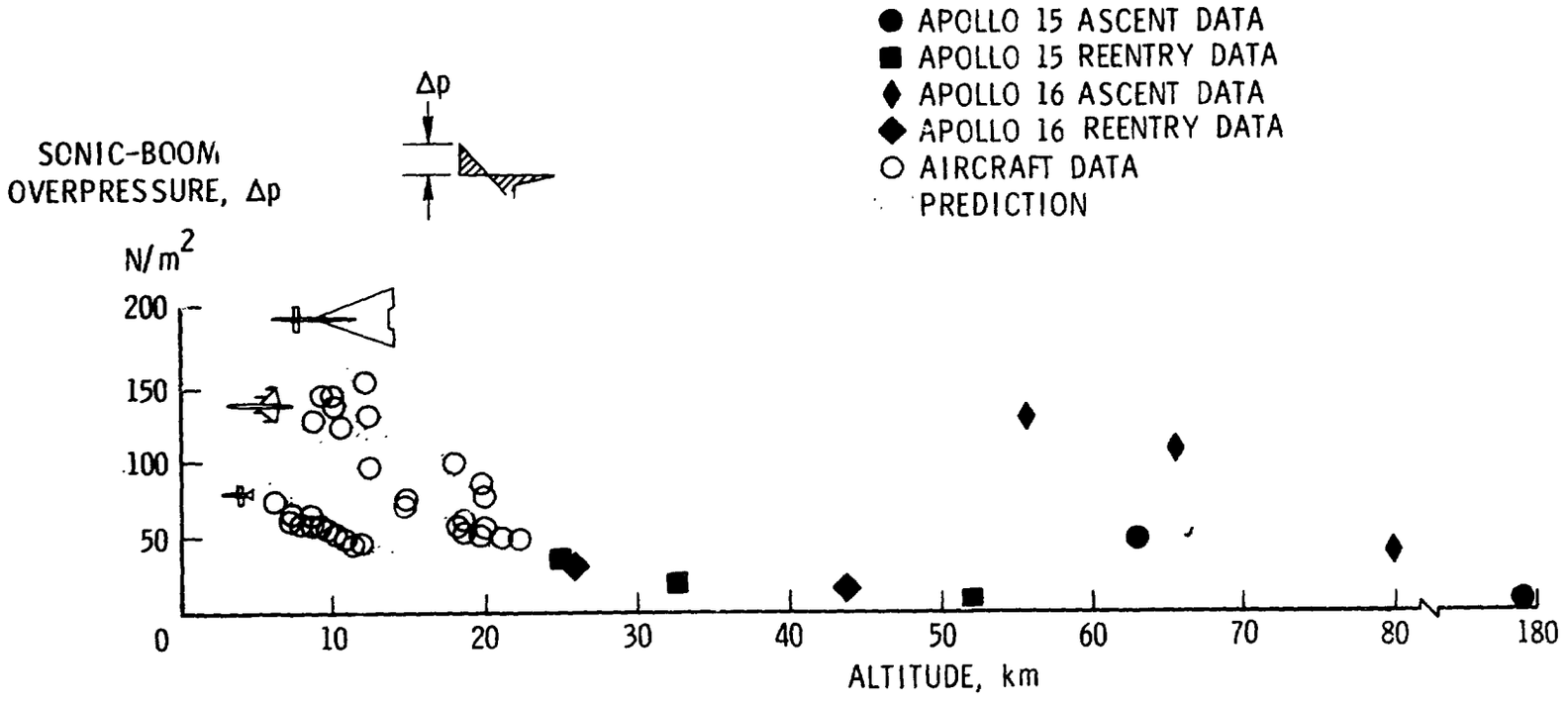


Figure 18.- Predicted and measured overpressure data as a function of altitude for various aircraft and Apollo space vehicles.