SONIC-BOOM GROUND-PRESSURE MEASUREMENTS FROM APOLLO 15

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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.
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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/m² (1.04 psf) and less than 10 N/m² (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/m² (0.188 psf), 20 N/m² (0.418 psf), and 38 N/m² (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.

\[ I_0 \] impulse of positive phase of sonic-boom ground-pressure signature, newton-seconds/meter\(^2\) (lb-sec/ft\(^2\))

\[ \Delta p \] maximum pressure rise across bow shock wave measured at ground level, newtons/meter\(^2\) (lb/ft\(^2\))

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\[ \Delta t_0 \] time duration of positive phase of sonic-boom ground-pressure signature, seconds

\[ \Delta T \] total time duration of sonic-boom ground-pressure signature, seconds

\[ \tau \] 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. Salina 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 I1 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 ± 0.2 dB and 0 to 20 kHz ± 0.2 dB, respectively. The magnetic tape recorders are of the frequency-modulated type operated at 30 ips with a ±40-percent deviation of the carrier having a center frequency of 54 kHz. The frequency response is 0 to 10 kHz ± 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 ± 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 $\Delta p$, wave period $\Delta T$, positive impulse $I_0$ (integrated area of $\Delta p$ versus time for duration of positive pulse), rise time $\tau$, and the positive duration $\Delta t_0$. 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 sec-
ondary 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 space-
craft 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 indi-
cated 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 definitively 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/m² (1.04 psf) and 10 N/m² (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/m² (0.188 psf), 20 N/m² (0.418 psf), and 38 N/m² (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


<table>
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<tr>
<th>Date</th>
<th>Measurement location</th>
<th>Ship</th>
<th>Boom arrival time, GMT</th>
<th>Ship position at time of boom arrival, deg</th>
<th>Spacecraft overhead time, GMT</th>
<th>Spacecraft altitude at overhead time</th>
<th>Spacecraft velocity at overhead time</th>
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<td>7-26-71</td>
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<td>U.S.S. Austin</td>
<td>1348:33:22</td>
<td>71.000 W 29.916 N</td>
<td>1341:06</td>
<td>178 778</td>
<td>586 571</td>
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<td>8- 7-71</td>
<td>Pacific</td>
<td>U.S.S. Okinawa</td>
<td>2040:56:00</td>
<td>158.266 W 26.213 N</td>
<td>2039:14:09</td>
<td>25 150</td>
<td>82 517</td>
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<tr>
<td>8- 7-71</td>
<td>Pacific</td>
<td>U.S.S. Genesee</td>
<td>2039:10:00</td>
<td>162.223 W 23.683 N</td>
<td>2036:20:09</td>
<td>52 485</td>
<td>172 203</td>
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</table>
TABLE II. - SUMMARY OF SHIP SPEED, SURFACE WEATHER DATA, AND SEA CONDITIONS
AT TIME OF BOOM MEASUREMENTS

<table>
<thead>
<tr>
<th>Date</th>
<th>Measurement location</th>
<th>Ship</th>
<th>Ship speed, knots</th>
<th>Surface temperature</th>
<th>Relative humidity, percent</th>
<th>Surface wind, knots</th>
<th>Wind direction, a deg</th>
<th>Sea condition</th>
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<tr>
<td>7-26-71</td>
<td>Atlantic</td>
<td>U.S.S. Salinan</td>
<td>2</td>
<td>301 82.13</td>
<td>74</td>
<td>6</td>
<td>215</td>
<td>0.8-meter swell</td>
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<tr>
<td>7-26-71</td>
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<td>U.S.S. Austin</td>
<td>2</td>
<td>301 82.13</td>
<td>74</td>
<td>6</td>
<td>145</td>
<td>1.0-meter swell</td>
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<td>U.S.S. Okinawa</td>
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<td>8</td>
<td>070</td>
<td>1.2-meter swell</td>
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<tr>
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<td>U.S.S. Kawishiwi</td>
<td>5</td>
<td>301 82.13</td>
<td>78</td>
<td>7</td>
<td>130</td>
<td>1.0-meter swell</td>
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<td>U.S.S. Genesee</td>
<td>4</td>
<td>300 80.3</td>
<td>76</td>
<td>4</td>
<td>090</td>
<td>1.0-meter swell</td>
</tr>
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</table>

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

<table>
<thead>
<tr>
<th>Altitude, m</th>
<th>Wind direction, deg</th>
<th>Wind speed, knots</th>
<th>Temperature, K</th>
<th>Relative humidity, percent</th>
<th>Absolute humidity, g/m³</th>
<th>Sound speed, m/sec</th>
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<tr>
<td>5</td>
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<td>8</td>
<td>301.3</td>
<td>69</td>
<td>19.12</td>
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<td>345</td>
</tr>
<tr>
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<td>7</td>
<td>294.0</td>
<td>64</td>
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<td>344</td>
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<td>7</td>
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<td>61</td>
<td>10.17</td>
<td>343</td>
</tr>
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<td>7</td>
<td>290.8</td>
<td>57</td>
<td>7.51</td>
<td>342</td>
</tr>
<tr>
<td>2 134</td>
<td>182</td>
<td>5</td>
<td>289.0</td>
<td>49</td>
<td>6.68</td>
<td>341</td>
</tr>
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<td>161</td>
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<td>286.7</td>
<td>55</td>
<td>6.41</td>
<td>340</td>
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TABLE V.- SUMMARY OF SONIC-BOOM DATA FOR LAUNCH
AND REENTRY OF APOLLO 15

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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.
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.

(b) Microphone, mount, and windscreen.

Figure 9. - Typical data-acquisition system.
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 63422 meters.

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

Overhead conditions: Velocity 4762 m/sec and altitude of 178778 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.
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.