JSC-09423

APOLLO PROGRAM SUMMARY REPORT

(NASA-TM-X-68725) [SYNOPSIS OF THE APOLLO PROGRAM ACTIVITIES AND TECHNOLOGY FOR LUNAR EXPLORATION] Apollo Program Summary Report (NASA) CSCL 22A

N75-21314

Unclas

G3/12 19372

National Aeronautics and Space Administration

LYNDON B. JOHNSON SPACE CENTER

Houston, Texas

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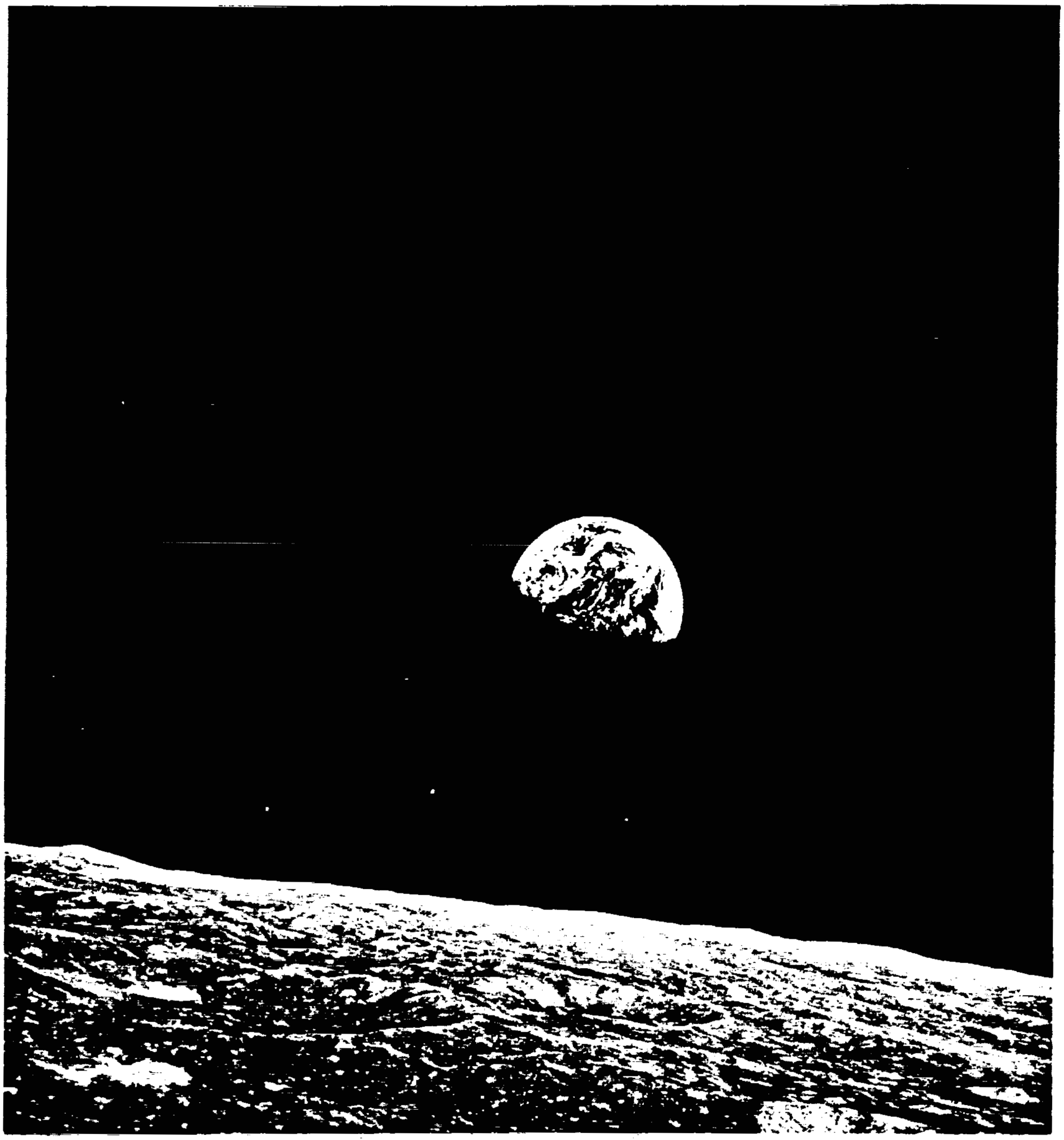

The Earth above the lunar horizon, photographed during the Apollo 8 mission with a 70-mm electric camera equipped with a medium telephoto (250-mm) lens.

FOREWORD

This report is intended to summarize the major activities of Apollo and to provide sources of reference for those who desire to pursue any portion to a greater depth. Personal recognition is not given in any case except for the crewmen who were assigned to the missions. Indeed, any step beyond this would literally lead to the naming of thousands of men and women who made significant contributions, and, unavoidably, the omission of the names of many others who played an equally significant part; however, all of these people must undoubtedly have a feeling of satisfaction in having been a part of one of man's most complex and, at the same time, noble undertakings.

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1.0 INTRODUCTION

The Apollo Program Summary Report is a synopsis of the overall program activities and the technology developed to accomplish lunar exploration. The report is intended, primarily, for the reader who desires a general knowledge of the technical aspects of the Apollo program, but was also edited for comprehension by the lay reader. Much of the information contained herein has been extracted or summarized from Apollo Mission Reports, Apollo Preliminary Science Reports, Apollo Experience Reports, and other applicable documents. However, some of the information has not been published elsewhere. A summary of the flights conducted over an 11-year period is followed by specific aspects of the overall program, including lunar science, vehicle development, flight operations, and biomedical results. Appendixes provide data on each of the Apollo missions (appendix A), mission type designations (appendix B), spacecraft weights (appendix C), records achieved by Apollo crewmen (appendix D), vehicle histories (appendix E), and a listing of anomalous hardware conditions noted during each flight beginning with Apollo 4 (appendix F). No attempt was made to include information pertaining to the management of the Apollo program since this area deserves special treatment. Several other areas were also considered to be beyond the scope of this document, although they were of great importance in accomplishing the established program objectives.

The names of installations and geographical locations used in the report are those that existed during the Apollo program. For example, the Lyndon B. Johnson Space Center is referred to by its former name, the Manned Spacecraft Center, and Cape Canaveral is referred to as Cape Kennedy. Customary units of measurement are used throughout the report except in lunar science discussions. Metric units were used in the lunar science discussions in the Apollo Mission Reports and are also used in this report. All references to miles mean nautical miles rather than statute miles.

2.0 FLIGHT PROGRAM

The Apollo program consisted of 33 flights, 11 of which were manned. The 22 unmanned flights were conducted to qualify the launch vehicle and spacecraft for manned space flight. Four of the manned flights were also conducted to man-rate the overall vehicle for lunar exploration. The final seven flights were conducted to explore the lunar environment and surface, providing man with detailed data concerning the moon and its characteristics.

Especially significant during the Apollo program was that no major launch vehicle failure occurred to prevent a mission from being accomplished and only one inflight failure of a spacecraft (Apollo 13) prevented the intended mission from being accomplished. This section of the report provides a summary of each of these flights and discusses some of the more significant findings.

2.1 SATURN LAUNCH VEHICLE AND APOLLO SPACECRAFT DEVELOPMENT FLIGHTS

The early development of the Saturn launch vehicle was conducted prior to the final decision that man would attempt to land on the lunar surface. The initial 10 flights provided man with the first insight of the capabilities of large boosters and how such a booster would operate. The primary purposes of these missions were to flight qualify the launch vehicle stages and systems and to determine the compatibility of the launch vehicle/spacecraft combination. A by-product of these flights was data obtained from experiments conducted to extend the knowledge of the ionosphere. Also, three Pegasus satellites were placed in orbit during this part of the flight test program to gather data on meteoroids.

2.1.1 Mission SA-1

Apollo mission SA-1 was the first flight of the Saturn I launch vehicle. The mission was unmanned and conducted for research and development purposes. The launch vehicle carried a dummy second stage and a nose cone from a Jupiter missile. The vehicle had no active path guidance, and the flight trajectory was suborbital.

The objectives of the mission included:

a. Flight test of the eight clustered H-1 engines

b. Flight test of the S-I stage clustered propellant tankage structure

c. Flight test of the S-I stage control system

d. Performance measurement of bending and flutter, propellant sloshing, base heating, aerodynamic-engine torque, and airframe aerodynamic heating

The SA-1 vehicle was launched on October 27, 1961, from Launch Complex 34 of the Eastern Test Range, Cape Kennedy, Florida, at 01:00:06 p.m. e.s.t. (15:00:06 G.m.t.). Two launch delays totaling 54 minutes were necessitated because of cloud cover over the launch pad. The lift-off is shown in figure 2-1.

The flight path of SA-1, from lift-off through the cutoff of the inboard engines, was very close to that predicted. The trajectory was slightly higher than predicted because of higher-than-expected accelerations. The trajectory parameters after inboard engine cutoff were proportionally lower than predicted because the cutoff signal occurred 1.61 seconds early. The vehicle reached a maximum altitude of 84.6 miles and a maximum range of 206 miles.

The mission was considered a complete success. The vehicle was instrumented for 505 inflight measurements, of which 485 performed reliably. All primary flight objectives were met.

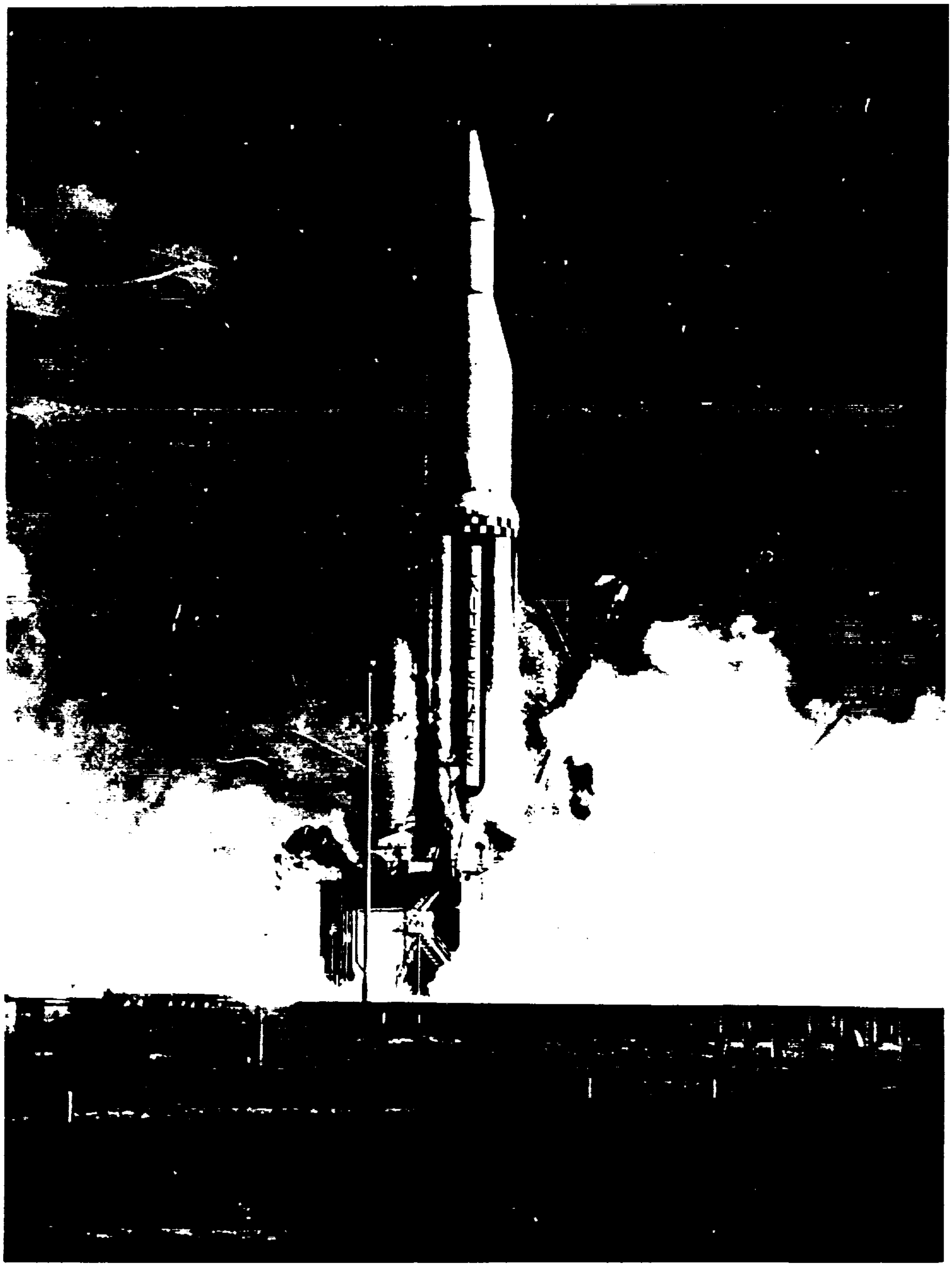

Figure 2-1.- First Saturn vehicle lift-off.

2.1.2 Mission SA-2

Apollo mission SA-2, an unmanned, research and developmental mission, was the second flight of the Saturn I launch vehicle. The vehicle carried a dummy second stage and a Jupiter missile nose cone. The vehicle had no active path guidance, and the flight trajectory was suborbital.

The objectives of the mission were:

a. Prove the first stage propulsion system, structural design, and control system

b. Prove the launch facilities and ground support equipment of Launch Complex 34

c. Confirm the vehicle aerodynamic characteristics in flight

d. Prove the inflight performance of first stage engines and their adequacy to reach design velocity

e. Verify the structural design of the booster airframe

f. Demonstrate the capability of the guidance and control system to perform as required

g. Release 22 900 gallons of water in space as Project High Water 1

Mission SA-2 was launched on April 25, 1962, from Cape Kennedy Launch Complex 34 at 09:00:34 a.m. e.s.t. (14:00:34 G.m.t.). There was a 30-minute launch delay because a ship was in the downrange area.

The flight path of SA-2 agreed closely with the predicted trajectory. However, the trajectory during powered flight was somewhat lower because of lower-than-anticipated accelerations. The destruct signal for detonating the water container of Project High Water 1 was transmitted 162.56 seconds after lift-off when the vehicle was at an altitude of 65.2 miles. Five seconds thereafter, the water formed into a 4.6-mile-diameter ice cloud, which continued to climb to an altitude of 90 miles. The purpose of the Project High Water experiment was to upset the concentration of water vapor in the ionosphere and to study the conditions as equilibrium was regained. Several measurements were made during the experiment. For example, the electron production process rates in and near the E-region were measured. Measurements were also made of the rates of reactions involving water, the hydroxyl ion, diatomic and triatomic oxygen, and hydrogen in the region between 62 and 83.7 miles altitude. The experiment was performed for NASA's Office of Space Sciences and was the first such large-scale test ever made in space.

2.1.3 Mission SA-3

Apollo mission SA-3 was the third flight of the Saturn I launch vehicle. Like SA-1 and SA-2, the mission was unmanned and conducted for research and development purposes. This launch vehicle also carried a dummy second stage and a Jupiter missile nose cone. The vehicle had no active path guidance, and the trajectory was suborbital. The payload was Project High Water 2. The objectives were the same as those of mission SA-2.

The SA-3 vehicle was launched on November 16, 1962, from Cape Kennedy Launch Complex 34 at 12:45:02 p.m. e.s.t. (17:45:02 G.m.t.). There was a 45-minute launch delay due to a power failure in the ground support equipment.

The actual flight path of SA-3 was close to the predicted one. A slightly lower acceleration than planned caused the altitude and range to be less than predicted throughout powered flight. However, a longer firing period than planned caused both to be greater after first-stage cutoff. The destruct signal for the container of Project High Water 2 was transmitted at 292 seconds after lift-off when the vehicle was at an altitude of 103.7 miles. The 22 900 gallons of water formed an ice cloud that continued along the flight path of the vehicle, as had the cloud formed by Project High Water 1 on the SA-2 mission. All objectives of the mission were met.

2.1.4 Mission SA-4

Apollo mission SA-4 was the fourth launch of the Saturn I launch vehicle. Like the three previous missions, an unmanned, research and developmental vehicle was used. The SA-4 vehicle was equipped with a dummy second stage and a Jupiter missile nose cone. The vehicle had no path guidance, and the trajectory was suborbital.

The objectives of the mission were the same as those of SA-2 and SA-3, with the following two exceptions.

a. Programmed premature cutoff of one of the eight engines of the first stage was used to demonstrate that the vehicle could perform the mission with an engine out.

b. Project High Water payload was not carried on SA-4.

Mission SA-4 was launched on March 28, 1963, from Cape Kennedy Launch Complex 34 at 03:11:55 p.m. e.s.t. (20:11:55 G.m.t.). Three technical delays, totaling 102 minutes, were experienced in the countdown.

The flight path was close to the predicted one. A slightly higher acceleration and an early cutoff signal caused the maximum altitude to be 0.96 mile higher and the range to be 0.13 mile shorter than planned. First-stage engine 5 was cut off at 100.6 seconds after lift-off, 0.22 second earlier than planned. The vehicle responded to the early shutdown as predicted and the flight continued, successfully accomplishing the objective.

2.1.5 Mission SA-5

Apollo mission SA-5 was the fifth launch of the Saturn I launch vehicle and the first of a more advanced research and development configuration which had a live second stage and a functional instrument unit for onboard guidance. The launch vehicle had a Jupiter missile nose cone ballasted with sand to simulate the Apollo spacecraft mass characteristics.

SA-5 was an unmanned, research and developmental mission with the following objectives.

a. Flight test of the launch vehicle propulsion, structure, and flight control systems

b. Flight test of the live second stage

c. Flight test of the vehicle instrument unit

d. Separation test of the first and second launch vehicle stages

e. Checkout of Launch Complex 37B

f. Recovery of movie cameras and film showing oxidizer sloshing, stage separation and other performance characteristics

g. Flight test of the S-I stage fins

h. Demonstration test of liquid hydrogen venting in the second stage

i. Functional test of the function of the eight holddown arms on the launcher

j. Functional test of the stage separation timer

k. Operational test of a passenger ST-124 stabilized platform in the guidance unit

l. Orbiting of a payload weighing 37 700 pounds

Mission SA-5 was launched on January 29, 1964, from Cape Kennedy Launch Complex 37B at 11:25:01 a.m. e.s.t. (16:25:01 G.m.t.). Seventy-three minutes of launch delays during the countdown were necessitated because of interference on the C-band radar and the command destruct frequencies.

The flight path of SA-5 was close to the predicted one. However, at outboard engine cutoff of the S-I stage, the cross-range deviation was 1 mile to the left of the planned point. By the end of the S-IV stage firing, the deviation had increased to 13.2 miles. The 37 700-pound payload of nose cone, including 11 500 pounds of sand, was placed into an orbit with a perigee of 162.6 miles and an apogee of 478.3 miles. The flight produced several firsts for the Saturn I vehicle. It marked the first flight of the improved H-1 engines in the S-I stage. The new model produced 188 000 pounds of thrust. Also, several cameras that recorded data during flight were ejected and recovered. Of the eight cameras used, seven were recovered. An onboard television camera also transmitted data during the flight. The second or S-IV stage operated as planned, as did the instrument unit.

2.1.6 Mission A-101

Apollo mission A-101 was the first of two flights of Apollo boilerplate spacecraft to demonstrate the compatibility of the Apollo spacecraft with the Saturn I launch vehicle in a launch environment similar to that expected for Apollo Saturn V orbital flights. Another important objective of this mission was to demonstrate the primary mode of launch escape tower jettison using the escape tower jettison motor.

In addition to the boilerplate command and service module, the spacecraft included a production-type launch escape system and a service module/launch vehicle adapter. Also, the spacecraft was equipped with instrumentation to obtain flight data for engineering analysis and evaluation. The assembly was designated BP-13. The launch vehicle (SA-6) consisted of an S-I first stage, an S-IV second stage, and an instrument unit. Figure 2-2 shows the vehicle undergoing tests on the launch pad approximately 1 month before launch.

The space vehicle was launched into earth orbit on May 28, 1964, at 12:07:00 p.m. e.s.t. (17:07:00 G.m.t.) from Cape Kennedy Launch Complex 37B. The spacecraft, S-IV stage, and instrument unit were inserted into orbit as a single unit.

The trajectory provided the launch environment required for the spacecraft mission, and all spacecraft systems fulfilled their specified functions throughout the countdown and flight test. Telemetry reception was continuous during launch and exit except for about 3 seconds during launch vehicle staging. Data were obtained by telemetry until the batteries were expended in the fourth orbital pass.

Aerodynamic heating produced a maximum truss member bond-line temperature on the launch escape tower that was less than 20 percent of the design limit (550° F). Postflight examination of strain gage, pressure, and acceleration data indicated that the spacecraft structure was adequate for the flight environment encountered.

The launch vehicle flight performance was acceptable in meeting the required spacecraft test objectives and all spacecraft objectives were satisfactorily fulfilled before insertion. The network maintained radar skin tracking until spacecraft entry over the Pacific Ocean near Canton Island during the 54th orbital pass. The spacecraft was not designed to survive entry and was not recovered.

2.1.7 Mission A-102

Mission A-102 was the second of the two boilerplate spacecraft flights conducted to demonstrate the compatibility of the Apollo spacecraft with the Saturn I launch vehicle. The alternate mode of launch escape tower jettison was also to be demonstrated using the launch escape motor and pitch control motor. The launch trajectory for this mission was similar to that of mission A-101.

The spacecraft consisted of a boilerplate command and service module, a launch escape system, and a service module/launch vehicle adapter (BP-15). The instrumentation was similar to that of the spacecraft for the A-101 mission. A significant difference, however, was that one of the four simulated reaction control system assemblies on the service module was instrumented to provide data on the aerodynamic heating and vibration levels experienced by the assemblies during launch. The launch vehicle (SA-7) consisted of an S-I first stage, an S-IV second stage, and an instrument unit.

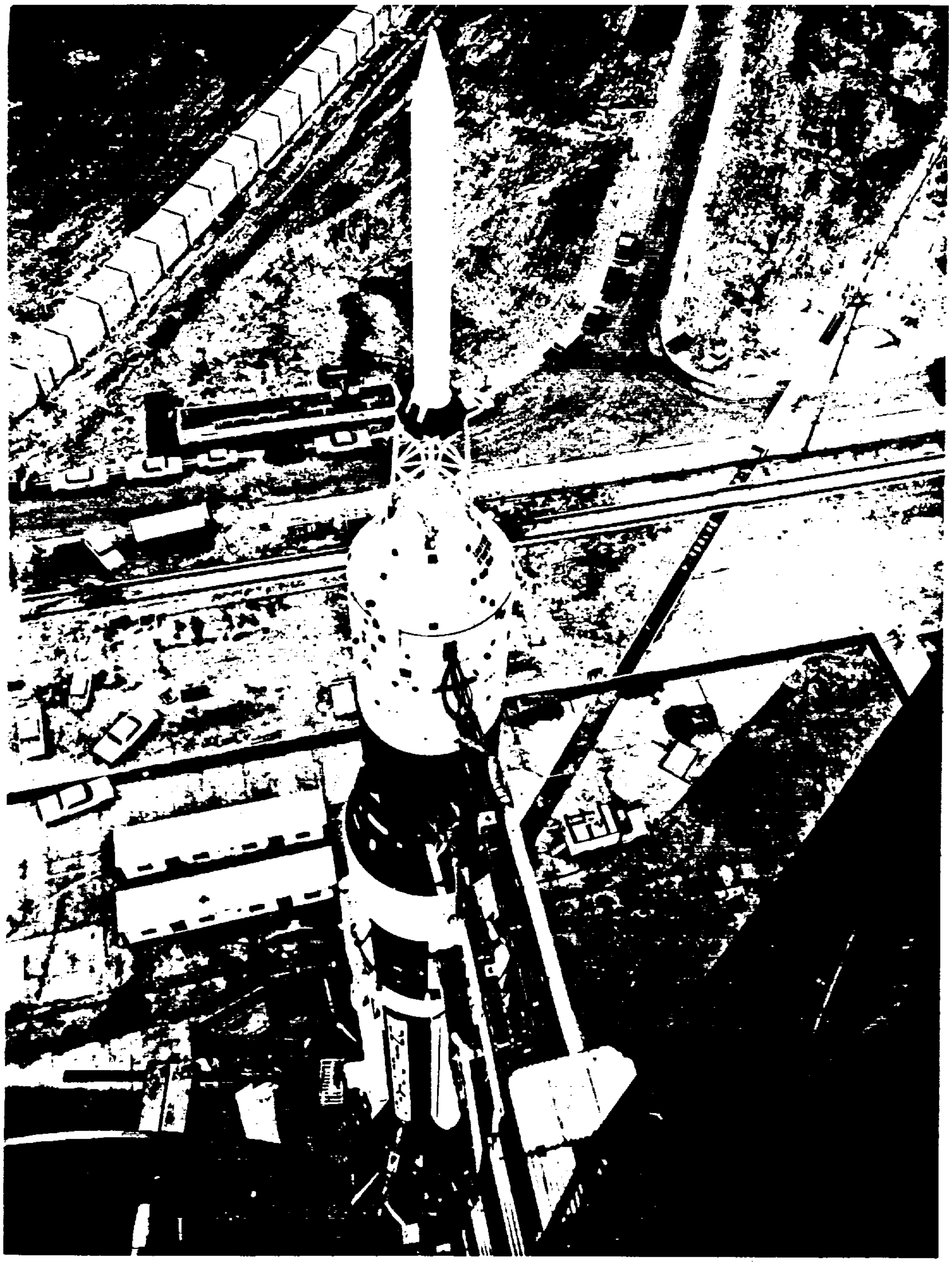

Figure 2-2.- Saturn vehicle SA-6 undergoing tests on Launch Complex 37B.

The spacecraft was launched into earth orbit on September 18, 1964, at 11:22:43 a.m. e.s.t. (16:22:43 G.m.t.) from Cape Kennedy Launch Complex 37B. The velocity, altitude, and flight-path angle at the time of S-I stage cutoff were slightly higher than planned. At S-IV stage cutoff, the altitude was slightly lower and the velocity was slightly higher than planned, resulting in a more elliptical orbit than planned. The S-IV, instrument unit, and the attached spacecraft (without the launch escape system which was jettisoned) were inserted into orbit as a single unit.

The instrumentation system was successful in determining the launch and exit environment, and telemetry reception of the data was continuous through launch and exit except for a short period during vehicle staging. The measurements indicated that the spacecraft performed satisfactorily in the launch environment.

The launch-heating environment of the spacecraft was similar to that encountered on the A-101 mission. Peak values at most points for the two flights were approximately equal: however, the influence of surface irregularities and circumferential variations on the amount of heating experienced was somewhat different for the two flights because of differences in trajectory and angle of attack. The command and service module heating rates were within the predicted range. The heat protection equipment on the launch escape system was subjected to temperatures much lower than the design limits, which were established on the basis of an aborted mission.

Jettisoning of the launch escape tower by the alternate mode was successful. Positive ignition of the pitch control motor could not be determined; however, the general trajectory indicated that the motor operated properly. The launch escape motor, together with the pitch control motor, carried the tower structure safely out of the path of the spacecraft.

The command module instrumentation compartment differential pressure reached a maximum of 13.3 psi, but vented rapidly after launch escape system separation. A 1.8g, peak-to-peak, 10-hertz vibration was noted during holddown. Other vibration modes were similar to those experienced during the A-101 mission. The measured vibration levels of the instrumented reaction control system assembly were above the design limit.

Radar skin tracking of the spacecraft was continued by the network until it entered over the Indian Ocean during the 59th revolution. No provisions had been made for recovery of the spacecraft and it disintegrated during entry. All spacecraft test objectives for the mission were satisfactorily fulfilled; launch vehicle performance was also satisfactory.

2.1.8 Mission A-103

Mission A-103 was the eighth unmanned Saturn flight. It was the initial vehicle in the operational series of Saturn I launch vehicles and the third to carry an Apollo boilerplate payload. The vehicle also orbited the first of three meteoroid technology satellites, Pegasus A (fig. 2-3).

Of 12 flight objectives assigned, two were concerned with the operation of the Pegasus satellite, eight with launch vehicle systems performance, one with jettisoning the launch escape system, and one with separation of the boilerplate spacecraft. The satellite objectives were (1) demonstration of the functional operations of the mechanical, structural, and electronic systems and (2) evaluation of meteoroid data sampling in near-earth orbit. Since the launch trajectory was designed to insert the Pegasus satellite into the proper orbit, it differed substantially from the Apollo/Saturn V trajectory used in missions A-101 and A-102.

The launch vehicle (SA-9) consisted of an S-I first stage, an S-IV second stage, and an instrument unit. The spacecraft consisted of a boilerplate command and service module, a launch escape system, and a service module/launch vehicle adapter (BP-16). The service module enclosed the Pegasus satellite. The orbital configuration consisted of the satellite mounted on the adapter, which remained attached to the instrument unit and the expended S-IV stage. The launch escape system was jettisoned during launch and the command module was jettisoned after orbital insertion. The satellite weighed approximately 3080 pounds and was 208 inches high, 84 inches wide, and 95 inches deep. The width of the deployed wings was 96 feet.

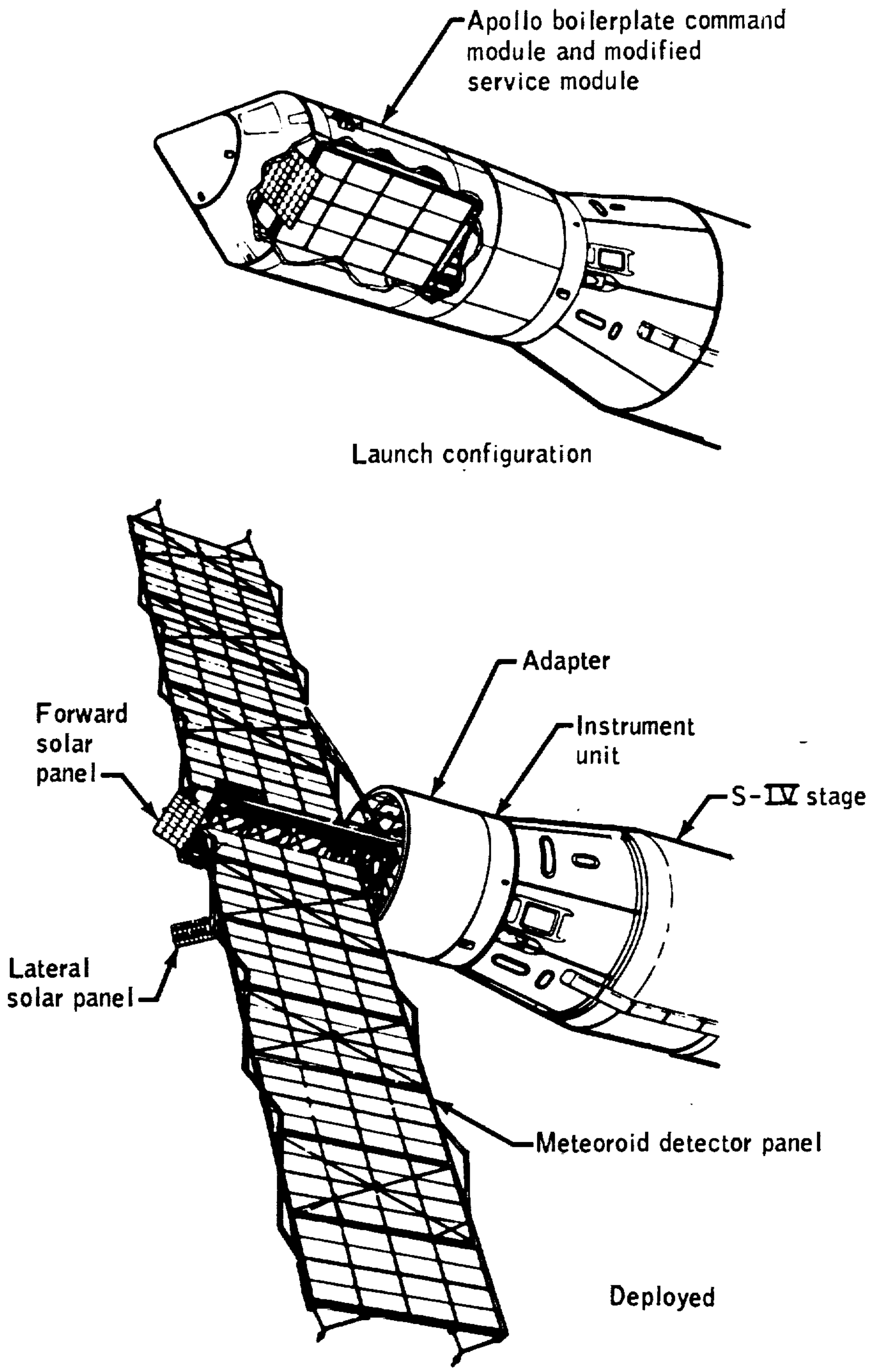

Figure 2-3.- Deployment of Pegasus satellite.

The vehicle was launched from Cape Kennedy Launch Complex 37B at 09:37:03 a.m. e.s.t. (14:37:03 G.m.t.) on February 16, 1965. A hold of 1 hour and 7 minutes was caused by a power failure in the Eastern Test Range flight safety computer. A built-in hold of 30 minutes was also used to discharge and recharge a battery in the Pegasus satellite as a check that it was functioning properly.

The launch was normal and the payload was inserted into orbit approximately 10.5 minutes after launch. The total mass placed in orbit was 33 895 pounds. The perigee was 307.8 miles, the apogee was 461.9 miles, and the orbital inclination was 31.76°. The Pegasus satellite had a period of 97.1 minutes.

The trajectory and space-fixed velocity were very nearly as planned. The Apollo shroud separated from the Pegasus satellite about 804 seconds after lift-off and deployment of two meteoroid detection panel wings of the Pegasus satellite commenced about 1 minute later. The predicted useful lifetime of Pegasus A in orbit was 1188 days. The satellite was commanded off on August 29, 1968. Although minor malfunctions occurred in both the launch vehicle and the Pegasus A satellite, mission A-103 was a success in that all objectives were met.

2.1.9 Mission A-104

Mission A-104 was the ninth test flight of the Saturn I. This mission was the second flight in the Saturn I operational series and the fourth vehicle to carry an Apollo boilerplate spacecraft. The vehicle also launched the Pegasus B meteoroid technology satellite. The two primary mission objectives were (1) evaluation of meteoroid data sampling in near-earth orbit and (2) demonstration of the launch vehicle iterative guidance mode and evaluation of system accuracy. The launch trajectory was similar to that of mission A-103.

The Saturn launch vehicle (SA-8) and payload were similar to those of mission A-103 except that a single reaction control engine assembly was mounted on the boilerplate service module (BP-26) and the assembly was instrumented to acquire additional data on launch environment temperatures. This assembly also differed from the one on the A-101 mission in that two of the four engines were of a prototype configuration instead of all engines being simulated. Pegasus B weighed approximately 3080 pounds and had the same dimensions as Pegasus A.

Mission A-104 was launched from Cape Kennedy Launch Complex 37B at 02:35:01 a.m. e.s.t. (07:35:01 G.m.t.) on May 25, 1965, the first nighttime launch in the Saturn I series (fig. 2-4). A built-in 35-minute hold was used to ensure that launch time coincided with the opening of the launch window.

The launch was normal and the payload was inserted into orbit approximately 10.6 minutes after lift-off. The total mass placed in orbit, including the spacecraft, Pegasus B, adapter, instrument unit, and S-IV stage, was 34 113 pounds. The perigee and apogee were 314.0 and 464.1 miles, respectively; the orbital inclination was 31.78°.

The actual trajectory was close to the one predicted, and the spacecraft was separated 806 seconds after lift-off. The deployment of the Pegasus B wings began about 1 minute later. The predicted orbital lifetime of Pegasus B was 1220 days. The satellite instrumentation and beacons were commanded off on August 29, 1968. Several minor malfunctions occurred in the S-I stage propulsion system; however, all mission objectives were successfully achieved.

2.1.10 Mission A-105

Mission A-105, the third flight of an operational Saturn I, was the last in the series of Saturn I flights. The payload consisted of an Apollo boilerplate spacecraft (BP-9A) which served as a shroud for the third Pegasus meteoroid technology satellite, Pegasus C. The two primary flight objectives were (1) the collection and evaluation of meteoroid data in near-earth orbit and (2) the continued demonstration of the launch vehicle iterative guidance mode and evaluation of system accuracy.

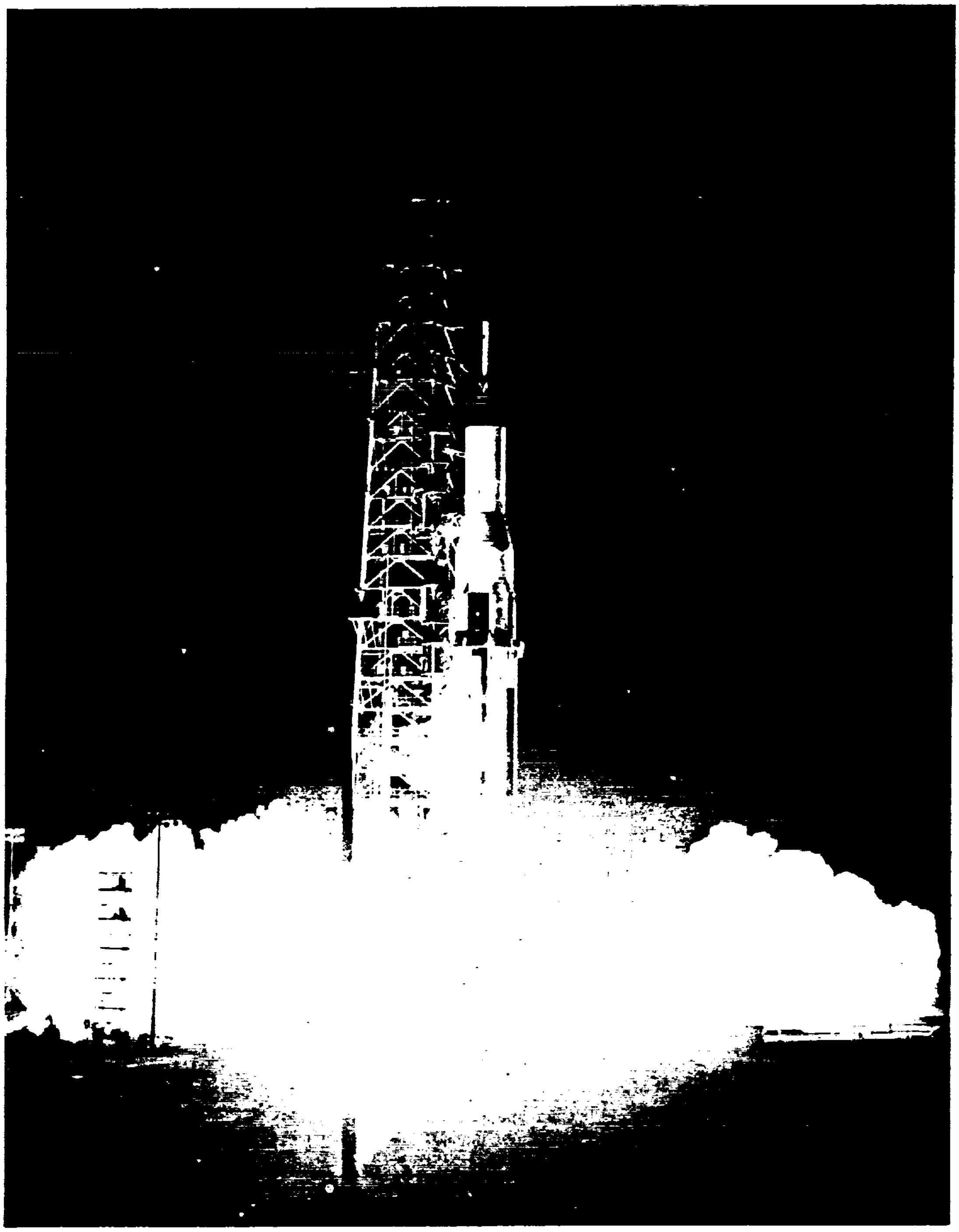

Figure 2-4.- Space vehicle lift-off for mission A-104.

The Saturn launch vehicle (SA-10) was similar to those of missions A-103 and A-104. As on the previous mission, the boilerplate service module was equipped with a test installation of a reaction control engine package. Pegasus C weighed 3138.6 pounds and had the same dimensions as its predecessors.

Mission A-105 was launched from Cape Kennedy Launch Complex 37B at 08:00:00 a.m. e.s.t. (13:00:00 G.m.t.) on July 30, 1965. A planned 30-minute hold ensured that launch time coincided with the opening of the Pegasus launch window. The launch was normal and the payload was inserted into orbit approximately 10.7 minutes after lift-off. The total mass placed in orbit, including the spacecraft, Pegasus C, adapter, instrument unit, and S-IV stage, was 34 438 pounds.

The spacecraft was separated 812 seconds after lift-off. The separation and ejection system operated as planned. The two meteoroid detection panel wings of the satellite were deployed from their folded position 40 seconds after command initiation at 872 seconds.

The predicted useful lifetime of the satellite (720 days) was exceeded, and the beacons and telemetry transmitters were commanded off on August 29, 1968. Pegasus C entered the earth atmosphere on August 4, 1969. All primary and secondary objectives were attained.

Details of the three Pegasus flights are contained in references 2-1, 2-2 and 2-3.

2.2 APOLLO SPACECRAFT ABORT TESTS

The Apollo spacecraft abort tests consisted of six flights to demonstrate the adequacy of the Apollo launch escape system and to verify the performance of the command module earth landing system. These flights were launched from Complex 36 at White Sands Missile Range, New Mexico, which is approximately 4000 feet above mean sea level. Two of the tests were conducted with the launch escape system motors being ignited at ground level, while the remaining tests were conducted using the Little Joe II launch vehicle to boost the spacecraft to various points in the Saturn launch trajectory for abort initiation. A significant event in this series of flights was an unplanned failure of a launch vehicle resulting in an actual abort situation in which all spacecraft systems operated satisfactorily.

2.2.1 Pad Abort Test 1

Apollo Pad Abort Test 1 was an unmanned flight using the launch escape system to demonstrate the capability of the Apollo spacecraft to abort from the launch pad and thus provide crew safety. Of the six first-order test objectives assigned, those of primary importance were to (1) determine the aerodynamic stability characteristics of the Apollo escape configuration during a pad abort, (2) demonstrate the capability of the escape system to propel a command module a safe distance from a launch vehicle during a pad abort, and (3) demonstrate the earth landing timing sequence and proper operation of the parachute system.

The test vehicle consisted of a production launch escape system in combination with a boilerplate command module (BP-6), the first Apollo boilerplate spacecraft to be flown (fig. 2-5). Since the command module was not representative of the actual spacecraft, no instrumentation was provided to determine structural loads. Measurements of such characteristics as vehicle accelerations, angle of attack, Mach number, and dynamic pressure allowed determination of inflight loads resulting from the external environment or vehicle dynamics. The command module was mounted in a vertical position on three bearing points of a supporting structure attached to a concrete pad.

The test was initiated on November 7, 1963, at 09:00:01 a.m. m.s.t. (16:00:01 G.m.t.) by transmitting a ground commanded abort signal to the command module. The signal activated the abort relay in the launch escape system sequencer, which in turn sent a signal to ignite the launch escape and pitch control motors. These motors ignited almost simultaneously and lifted the command module along a planned trajectory. The launch escape tower was separated about 15 seconds after engine ignition and followed a ballistic trajectory. The command module made a normal parachute descent at a velocity of 24 feet per second. Landing of the command module occurred at 165.1 seconds.

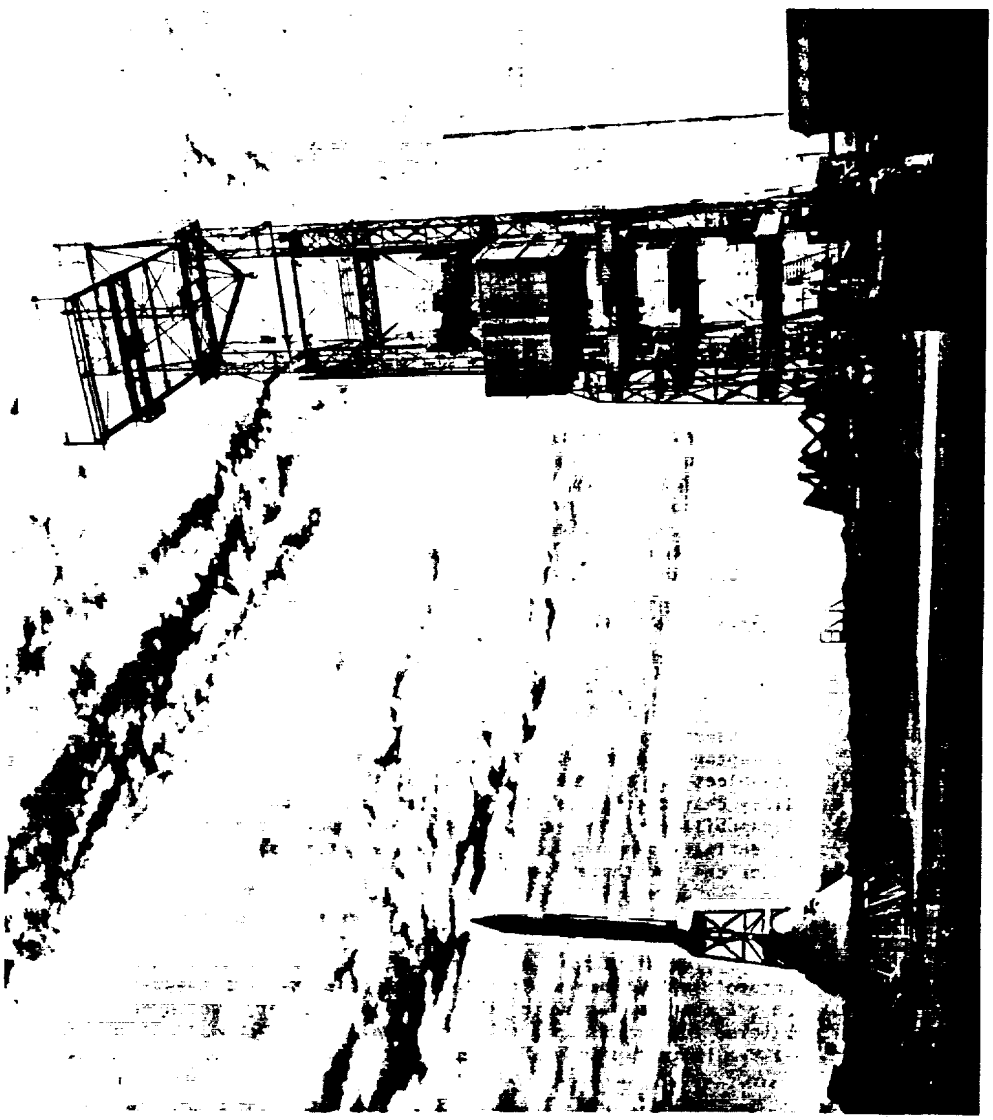

Figure 2-5.- Pad abort test of launch escape vehicle.

The vehicle exceeded the Apollo minimum altitude and range requirements for a pad abort by 970 feet and 1525 feet, respectively. Although the vehicle stability was less than predicted during the powered phase of flight, all objectives of the flight were satisfied.

2.2.2 Mission A-001

Mission A-001 was the second in the series of tests conducted to demonstrate that the launch escape system could safely remove the command module under critical abort conditions. Unlike Pad Abort Test 1, in which the launch escape system was ignited at ground level, this mission was flown to demonstrate the capability of the escape system to propel the command module safely away from a launch vehicle while in the high-dynamic-pressure (transonic) region of the Saturn trajectory.

The launch vehicle was the second in the series of Little Joe II vehicles, which had been developed to accomplish early and economical testing of the launch escape system. The Little Joe II was propelled by seven solid-propellant rocket motors - one Algol sustainer motor, which provided thrust for about 42 seconds, and six Recruit motors, which burned out approximately 1.5 seconds after ignition. The spacecraft consisted of a launch escape system and a boilerplate command and service module (BP-12).

Unacceptable wind conditions had forced a 24-hour postponement of the launch, but the vehicle was successfully launched (fig. 2-6) on May 13, 1964, at 05:59:59.7 a.m. m.s.t. (12:59:59.7 G.m.t). A ground commanded abort signal terminated thrust of the launch vehicle (by rupturing the Algol motor casing), ignited the launch escape and pitch control motors, and separated the command module from the service module. Some structural damage was incurred by the command module aft heat shield because of recontact with the booster at thrust termination. At approximately 44 seconds, the tower jettison motor was ignited and satisfactorily separated the launch escape tower from the command module.

The earth landing sequence was normal until a riser for one of the three main parachutes broke as a result of its rubbing against the structure on the command module upper deck. The parachute separated; however, the command module, supported by the two remaining parachutes, descended at rates of 30 to 26 feet per second instead of the predicted 24 feet per second with three parachutes. The command module landed 22 400 feet down range at 350.3 seconds after attaining an altitude of 29 772 feet above mean sea level. Except for the parachute failure, all test objectives were satisfied.

2.2.3 Mission A-002

Mission A-002 was the third in the series of abort tests to demonstrate that the launch escape system would perform satisfactorily under selected critical abort conditions. The main objective of this mission was to demonstrate the abort capability of the launch escape vehicle in the maximum dynamic pressure region of the Saturn trajectory with conditions approximating the altitude limit at which the Saturn emergency detection system would signal an abort.

The launch vehicle was the third in the Little Joe II series. This vehicle differed from the previous two in that flight controls and instrumentation were incorporated, and the vehicle was powered by two Algol and four Recruit rocket motors. The launch escape system was also changed from previous configurations in that canards (forward control surfaces used to orient and stabilize the escape vehicle in the entry attitude) and a command module boost protective cover were incorporated. The Apollo spacecraft was simulated by a boilerplate command and service module (BP-23). The earth landing system was modified from the previous configuration by the installation of modified dual-drogue parachutes instead of a single-drogue parachute.

The A-002 vehicle was launched on December 8, 1964, at 08:00:00 a.m. m.s.t. (15:00:00 G.m.t.) by igniting all launch vehicle motors simultaneously. Conditions at abort initiation were selected from Saturn boost trajectories, and a nominal test point was used for the maximum dynamic pressure region. A pitchup maneuver and the abort were initiated by using a real-time plot of the dynamic pressure versus Mach number. However, an improper constant was used in the meteorological data input to the real-time data system, resulting in the pitchup maneuver being initiated 2.4 seconds early. Although the planned test point was not achieved, the early pitchup caused a higher maximum dynamic pressure than the design value.

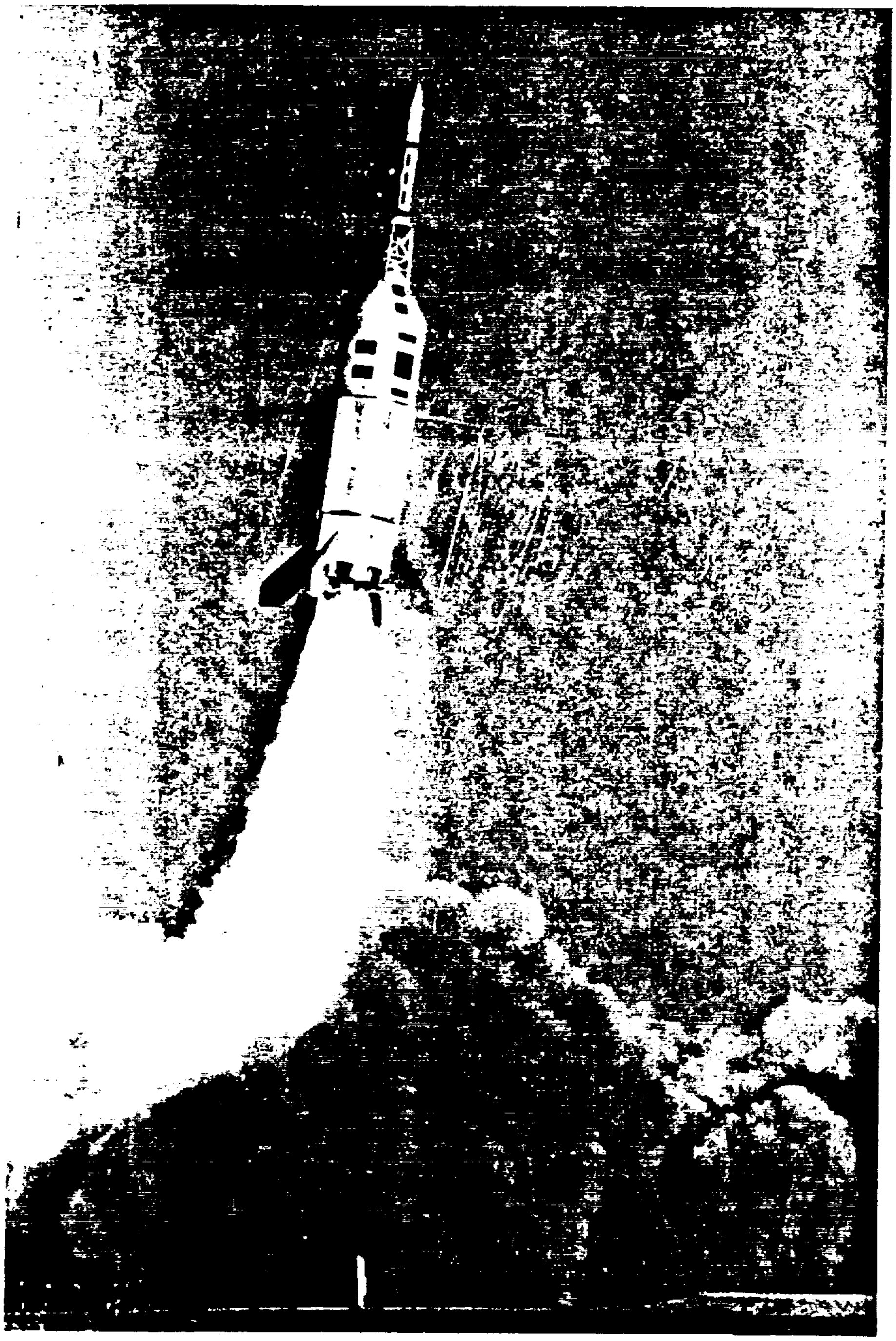

Figure 2-6.- Vehicle lift-off for mission A-001.

Canard deployment took place as expected 11.1 seconds after abort initiation. The launch escape vehicle tumbled four times before stabilizing with the aft heat shield forward. During the first turnaround, the soft portion of the boost protective cover was torn away from the command module. Maximum altitude attained by the launch escape vehicle was 50 360 feet above mean sea level.

Baroswitches initiated the earth landing sequence at an altitude of approximately 23 500 feet above mean sea level. All parachutes deployed properly and the command module, supported by the three main parachutes, descended at the planned rate of about 24 feet per second to an earth landing 32 800 feet down range.

The abort conditions obtained were more than adequate in verifying the abort capability in the maximum dynamic pressure region. Only one test objective was not achieved; the boost protective cover was structurally inadequate for the environment experienced during this mission.

2.2.4 Mission A-003

Apollo mission A-003 was the fourth mission to demonstrate the abort capability of the Apollo launch escape system. The purpose of this flight was to demonstrate launch escape vehicle performance at an altitude approximating the upper limit for the canard subsystem.

The launch vehicle was similar to the one used for mission A-002 except that the propulsion system consisted of six Algol motors. The unmanned flight test vehicle consisted of an Apollo boilerplate command and service module (BP-22) and a launch escape system similar to the one used on the previous mission. The command module earth landing system configuration was refined to be more nearly like that of the planned production system, and a forward heat shield jettisoning system was provided.

The test vehicle was launched on May 19, 1965, at 06:01:04 a.m. m.s.t. (13:01:04 G.m.t.). Within 2.5 seconds after lift-off, a launch vehicle malfunction caused the vehicle to go out of control. The resulting roll rate caused the launch vehicle to break up before second-stage ignition, and a low-altitude spacecraft abort was initiated instead of the planned high-altitude abort. The launch escape system canard surfaces deployed and survived the severe environment. The high roll rates (approximately 260° per second at the time of canard deployment) induced by the launch vehicle malfunction stabilized the launch escape vehicle in a tower-forward attitude, which overcame the destabilizing effect of the canards. Postflight simulations verified the ineffectiveness of the canards at the high roll rate, but showed that the canards would be effective at the 20° per second roll rate limit of the Saturn emergency detection system.

All spacecraft systems operated satisfactorily. The command module forward heat shield was protected by the hard portion of the boost protective cover and was jettisoned satisfactorily in an apex-forward attitude at low altitude. The soft portion of the boost protective cover remained intact until tower jettison. At tower jettison, part of the cover stayed with the command module for a short time although the rest of the cover moved away with the tower. The hard portion of the boost protective cover remained intact until ground impact. Both drogue parachutes inflated, even under the severe conditions that existed; that is, command module apex forward and rolling. The command module was effectively stabilized and oriented for deployment of the main parachutes.

Because of the early launch vehicle breakup, the desired altitude of 120 000 feet was not achieved. However, the spacecraft did demonstrate a successful low-altitude (12 400 ft) abort from a rapidly rolling (approximately 335° per second) launch vehicle. The Mach number, dynamic pressure, and altitude at the time of abort were similar to Saturn IB or Saturn V launch trajectory conditions.

2.2.5 Pad Abort Test 2

Apollo Pad Abort Test 2 was the fifth of six unmanned Apollo missions that flight tested the capability of the launch escape system to provide for safe recovery of Apollo crews under critical abort conditions. This flight was the second test of the launch escape system with the abort initiated from the launch pad.

The launch escape system included qualified launch escape and pitch control motors and was equipped with canards to orient the vehicle aft heat shield forward prior to tower jettison and parachute deployment. A boost protective cover was also provided. The spacecraft was BP-23A, a boilerplate command module that had been used on mission A-002 and refurbished to more nearly simulate a Block-I-type command module in mass and other characteristics. The earth landing system was similar to the one used in mission A-003.

The test flight was conducted on June 29, 1965. The vehicle was lifted from Launch Complex 36 by the launch escape motor at 06:00:01 a.m. m.s.t. (13:00:01 G.m.t.). The launch escape and pitch control motors ignited simultaneously, placing the test vehicle into the planned initial trajectory. A moderate roll rate developed at lift-off, which was due to the aerodynamic asymmetry of the vehicle configuration; however, the roll rate did not affect the success of the test.

The canard surfaces deployed and turned the vehicle to the desired orientation for drogue parachute deployment. During the turnaround maneuver, the launch escape tower and forward heat shield were jettisoned as planned. The boost protective cover, which was attached to the launch escape system, protected the conical surface of the command module and remained intact through a canard-induced pitch maneuver. At tower jettison, the soft boost protective cover, as expected, collapsed because of differential pressure during removal from the command module. No recontact or interference between the major components was evident during tower jettison and parachute deployment.

Although one of the pilot parachute steel cable risers was kinked, the earth landing system functioned properly. The drogue parachutes inflated and stabilized the command module for pilot and main parachute deployment, and the rate of descent while on the main parachutes was satisfactory. The maximum altitude achieved was 9258 feet above mean sea level, approximately 650 feet higher than predicted. The command module landed about 7600 feet from the launch site, some 2000 feet farther than planned.

Four glass samples had been mounted on the command module in the general area planned for the rendezvous and crew windows. No soot appeared on the samples, but an oily film was found on the exposed surfaces of three of the four samples. This film, however, was not expected to cause excessive degradation to the horizon scan or ground orientation ability during an abort. The test was highly successful and all planned objectives were fulfilled.

2.2.6 Mission A-004

Mission A-004 was the final test of the Apollo launch escape vehicle and the first flight of a Block I production-type spacecraft. The mission was unmanned and was conducted to demonstrate that (1) the launch escape vehicle would satisfactorily orient and stabilize itself in the proper attitude after being subjected to a high rate of tumbling during the powered phase of an abort and (2) the escape vehicle would maintain its structural integrity under test conditions in which the command module structure was loaded to the design limit.

The launch vehicle was the fifth and final Little Joe II flown. The propulsion system consisted of four Algol and five Recruit rocket motors. The attitude control system was similar to the one used on mission A-003 except that the reaction control system was deleted and the vehicle was provided with the capability of responding to a radio-transmitted pitchup command. The pitch-up maneuver was required to help initiate tumbling of the launch escape vehicle. The spacecraft for this mission consisted of a modified Block I command and service module and a modified Block I launch escape system (airframe 002). The center of gravity and thrust vector were changed to assure that power-on tumbling would be attained after abort initiation. The earth landing system was essentially the same as that used during Pad Abort Test 2.

The vehicle was launched on January 20, 1966, at 08:17:01 a.m. m.s.t. (15:17:01 G.m.t.) after several postponements due to technical difficulties and adverse weather conditions. The pitchup maneuver was commanded from the ground when telemetry showed that the desired altitude and velocity conditions had been reached. The planned abort was automatically initiated 2.9 seconds later. The launch escape vehicle tumbled immediately after abort initiation. Pitch and yaw rates reached peak values of 160° per second, and roll rates reached a peak of minus 70° per second. The launch escape system canard surfaces deployed at the proper time and stabilized the command module with the aft heat shield forward after the escape vehicle had tumbled about four times. Tower jettison and operation of the earth landing systems were normal, and the command module landed about 113 620 feet form the launch pad after having reached a maximum altitude of 78 180 feet above mean sea level.

All systems performed satisfactorily, and the dynamic loads and structural response values were within the design limits and predicted values. Although a structural loading value of primary interest was not achieved (local differential pressure between the interior and exterior of the command module wall), all test objectives were satisfied.

2.3 UNMANNED APOLLO/SATURN FLIGHTS

The six flights of the unmanned Apollo/Saturn series were conducted to qualify all launch vehicle systems (Saturn IB and Saturn V) and all spacecraft systems (command and service module and lunar module) for manned flight. Each flight built on the knowledge and experience gained from the previous flights, with the last two flights serving as final flight verification of all systems. In addition, these flights provided the final verification of the ground support hardware, launch checkout and countdown procedures, the communications network (Manned Space Flight Network), and the ground support personnel.

The first planned manned flight was originally scheduled for launch after the third unmanned flight of this series; however, the first manned flight was not accomplished until six unmanned flights had been completed.

2.3.1 Mission AS-201

Mission AS-201 was the second flight test of a production-type Apollo Block I spacecraft (airframe 009) and was the first flight test of the Saturn IB launch vehicle. Objectives of this unmanned suborbital flight were to demonstrate the compatibility and structural integrity of the spacecraft/Saturn IB combination and to evaluate the spacecraft heat shield performance during a high-heat-rate entry.

The Saturn IB consisted of two stages, an S-IB first stage and an S-IVB second stage with an instrument unit. The spacecraft consisted of a command module, a service module, an adapter, and a launch escape system. The vehicle is shown in figure 2-7 as it was undergoing the countdown demonstration test approximately 3 weeks before launch. The spacecraft differed from the standard Block I configuration in several respects. Fuel cells, crew equipment, suit loop, cabin postlanding ventilation system, cryogenic storage tanks, and the guidance and navigation system were not installed. In addition, a partial emergency detection system was flown, and the radiators for the environmental control system and the electrical power system were inoperative.

Mission AS-201 was launched from Cape Kennedy Launch Complex 34 at 11:12:01 a.m. e.s.t. (16:12:01 G.m.t.), February 26, 1966. The command module landed safely in the primary landing area near Ascension Island approximately 37 minutes later and was recovered as planned. The sequence of mission events is given in reference 2-4.

The launch was normal except that S-IVB cutoff and S-IVB/command and service module separation occurred 10 seconds later than predicted. Also, because of the delay in S-IVB cutoff, the mission control programmer was activated 10 seconds later than planned, and subsequent event times reflected this 10-second delay. In general, all spacecraft systems performed as expected except for the service module reaction control system. An oxidizer isolation valve failed to open, preventing operation of one of the service module reaction control system engine assemblies. Also, a negative yaw engine in another assembly was inoperative. However, the system successfully provided spacecraft attitude and rate control, adequate translation for the S-IVB/command and service module separation, and ullage for the two service propulsion system maneuvers.

The AS-201 mission was the first flight test of the service propulsion system. Although the reaction control system failure resulted in only 25 to 45 percent of the ullage velocity increment expected, the first ignition of the service propulsion system was successful and performance was near normal for the first 80 seconds of the 184-second firing. However, at engine cutoff, the

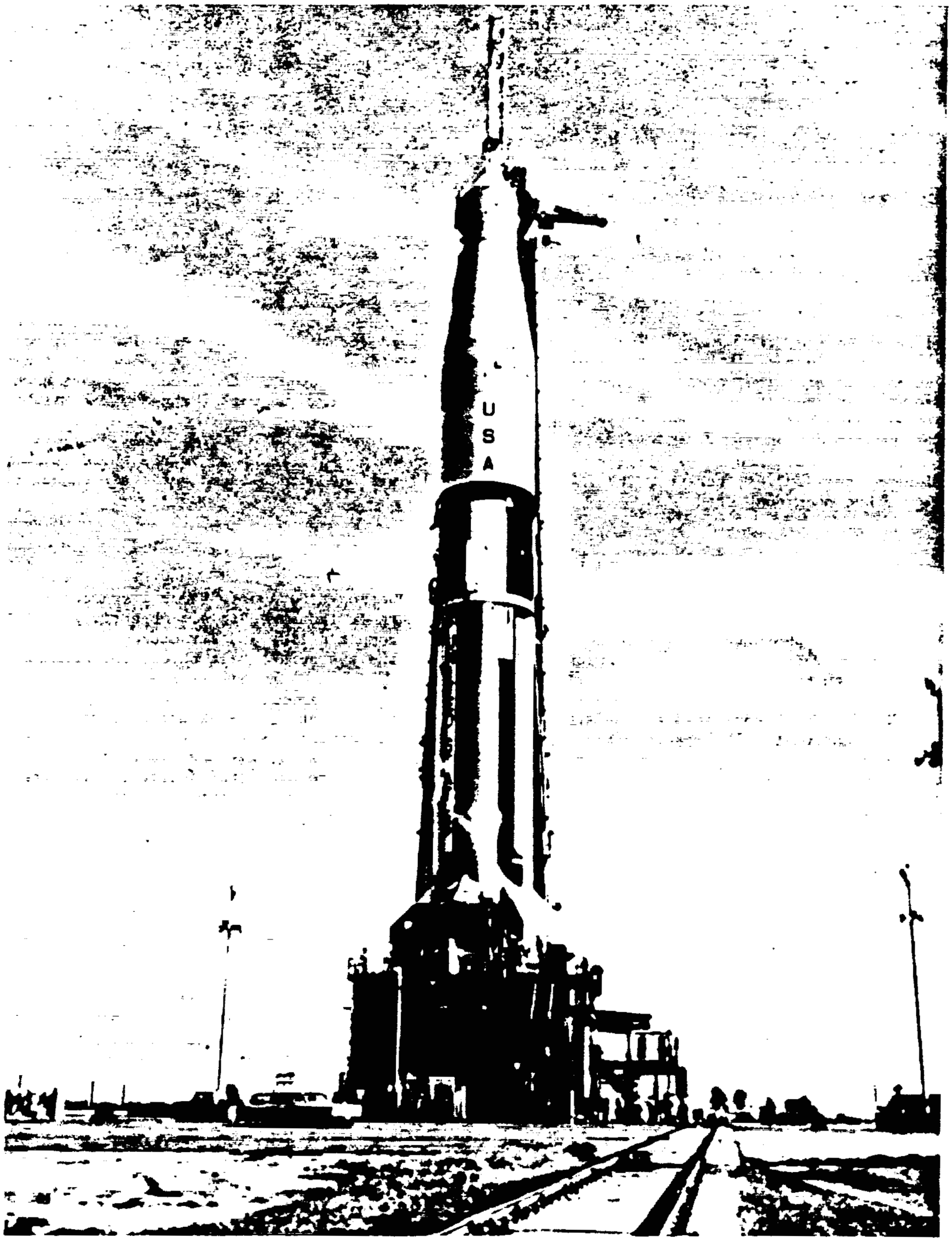

Figure 2-7.- Apollo/Saturn vehicle undergoing countdown demonstration test for mission AS-201.

chamber pressure had decayed to approximately 70 percent of normal. The second firing, planned for a 10-second duration, was erratic with chamber pressure oscillations that ranged from 12 to 70 percent of normal. The subnormal performance of the service propulsion system was attributed to helium ingestion.

Spacecraft communications blackout began at 1580 seconds and lasted until 1695 seconds. Entry was initiated with a space-fixed velocity of 26 481 feet per second. The command module was subjected to a maximum entry heating rate of 164 Btu/sq ft/sec at 1631.7 seconds and a maximum deceleration of 14.3g at 1639.7 seconds. The command module structure and heat shields performed adequately in the entry environment.

Loss of power to both command module reaction control systems at 1649 seconds resulted in an uncontrolled rolling entry (in excess of 26° per second) instead of the planned lifting entry. Power was returned to reaction control system A at 2121 seconds, and the required depletion burning of the command module reaction control system propellants was accomplished.

Forward heat shield jettison, drogue parachute deployment, and main parachute deployment occurred as planned. The command module landed in the Atlantic Ocean near Ascension Island at 2239.7 seconds and remained in an upright attitude. The landing time was 30.8 seconds earlier than the preflight-predicted time. Touchdown was 45 miles up range (northwest) of the recovery ship U.S.S. *Boxer*. One of the main parachutes failed to disengage after landing and was cut loose by a recovery force swimmer. The spacecraft was taken aboard the recovery ship at 02:20 p.m. e.s.t., 3 hours 8 minutes after lift-off. While all primary objectives were accomplished, the subnormal performance of some systems necessitated further investigation and improvements for future flights.

2.3.2 Mission AS-203

Mission AS-203 was an unmanned, research and developmental test of the Saturn IB vehicle. Major objectives of the flight were to (1) evaluate the S-IVB stage liquid hydrogen venting, (2) evaluate the S-IVB engine chilldown and recirculation systems, and (3) determine fluid dynamics of the S-IVB tanks. The data obtained were directly applicable to the Saturn V program. The S-IVB was to be used as the third stage of the Saturn V on lunar missions. A second firing of the S-IVB engine was necessary to insert an Apollo spacecraft into a translunar trajectory. Therefore, the test was conducted to simulate Saturn V third-stage engine restart in earth orbit.

The vehicle was the second Saturn IB launched. The general configuration was similar to that of mission AS-201 except that an aerodynamic fairing (nose cone) was installed in place of the spacecraft (fig. 2-8). Telemetry and recoverable 16-mm cameras (ejected during launch) were provided to furnish data on vehicle performance. In addition, two television cameras were mounted on the forward bulkhead of the S-IVB liquid hydrogen tank to aid in determining the amount of propellant sloshing.

Mission AS-203 was launched from Cape Kennedy Launch Complex 37B at 09:53:17 a.m. e.s.t. (14:53:17 G.m.t.) on July 5, 1966. The launch was delayed 1 hour and 53 minutes because of a loss of signal from one of the television cameras. The S-IVB stage, instrument unit, and nose cone were inserted into an orbit that was close to the planned 100-mile circular orbit.

Satisfactory system operation was demonstrated on the first of four orbits in which the systems were planned to be active, and all mission objectives were achieved. The simulated S-IVB engine firing duration was very close to the predicted time even though the chilldown valve failed to close after engine ignition. Data were gathered on S-IVB stage behavior in other Saturn V modes during the next three orbits. At the beginning of the fifth orbit, while a test was being performed, pressure in the liquid hydrogen tank built up to a level in excess of the design value, bursting the rank and resulting in premature destruction of the stage. However, all mission objectives had been accomplished.

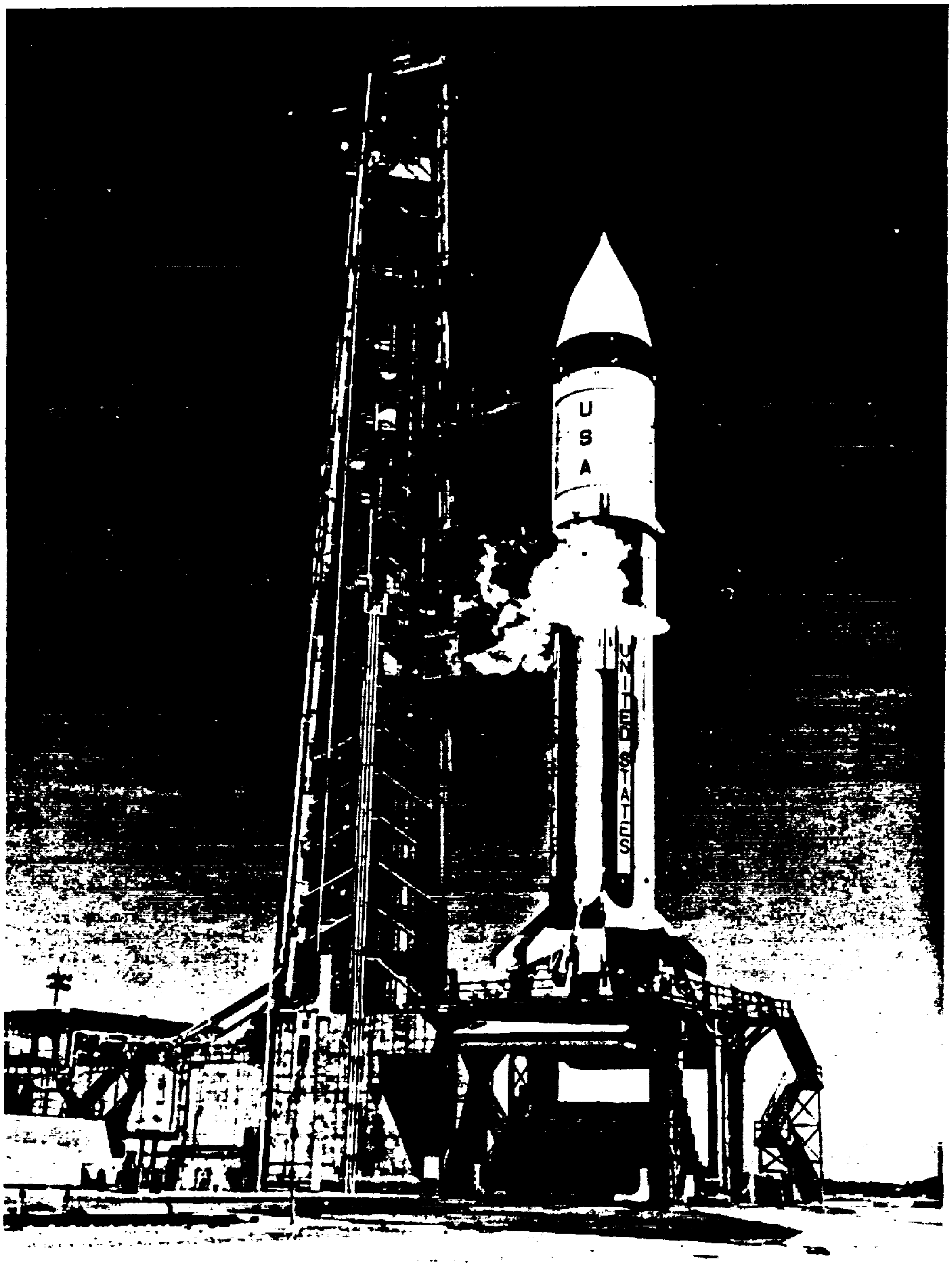

Figure 2-8.- Space vehicle for mission AS-203 during prelaunch countdown.

2.3.3 Mission AS-202

Mission AS-202 was an unmanned suborbital flight to further evaluate the Saturn IB launch vehicle and the Apollo command and service module before committing them to manned flight. The launch vehicle was the third Saturn IB and the spacecraft was the third production-type Block I command and service module (airframe 011). The mission objectives were (1) to obtain further launch vehicle and spacecraft information on structural integrity and compatibility, flight loads, stage separation, subsystem operation, and emergency detection system operation and (2) to evaluate the command module heat shield at high heat loads during entry at approximately 28 000 feet per second.

The Saturn IB was similar to the previous two launch vehicles. The spacecraft consisted of an adapter, the command and service module, and a launch escape system. The spacecraft systems and equipment were generally like those of the AS-201 mission spacecraft except that the fuel cells and cryogenic reactants, the guidance and navigation system, the S-band communications equipment, and the service propulsion system propellant gaging equipment were being flown for the first time. Also, the environmental control system and electrical power system radiators were operative on this mission and a closed-loop emergency detection system was provided.

The spacecraft was launched from Cape Kennedy Launch Complex 34 at 12:55:32 p.m. e.s.t. (17:55:32 G.m.t.), August 25, 1966. The spacecraft timing sequence was initiated by the S-IVB stage separation command, which was 13.8 seconds early due to higher-than-expected performance of the launch vehicle. Consequently, the flight events occurred earlier than planned (ref. 2-5). The spacecraft landed in the Pacific Ocean near Wake Island.

All mission objectives were accomplished, including the performance assessment of the systems being flown for the first time. Performance of these systems is discussed in the following paragraphs.

Fuel cell power plant electrical performance was normal, and current distribution between the cells and auxiliary batteries followed the expected ratios. The condenser exit temperatures on the two active fuel cells approached the maximum limit during the flight. The problem was attributed to entrapped air in the secondary coolant loop. Servicing procedures were changed for later spacecraft to eliminate this problem.

The cryogenic system performance was satisfactory. Pressurization, temperature, and flowrate response to fuel cell reactant gas demands were as expected.

The guidance and navigation system performed normally. Attitude control, navigation thrust vector and differential velocity control, and entry targeting were satisfactory. The command module, however, landed approximately 200 miles short of the planned point because the preflight prediction of the trim lift-to-drag ratio was not sufficiently accurate. The guidance and navigation system responded properly in attempting to correct for the undershoot condition.

The S-band communications equipment performed satisfactorily. Simulated downvoice and upvoice (via tone signals), down-link telemetry, and ranging modes were proper. Minor signal reception and station handover problems, not associated with the airborne equipment, were encountered.

The propellant gaging equipment for the service propulsion system functioned normally. Appreciable biases were noted but were explainable on the basis of preflight loading conditions and dynamic flow effects.

The environmental control system radiators provided proper heat rejection and compensated for a malfunction of the water evaporator. Erratic evaporator cooling was attributed to excess water which froze and plugged the overboard vent. Prelaunch servicing procedures were changed for later spacecraft.

The emergency detection system operated properly in the closed-loop mode. The automatic abort circuit was properly enabled at lift-off and deactivated by the launch vehicle sequencer prior to staging.

2.3.4 Apollo 4 Mission

The Apollo 4 mission was the fourth unmanned flight test of a production type Block I Apollo spacecraft and the initial flight of the three-stage Saturn V, the launch vehicle that was to be used for lunar missions. The first and second stages of the Saturn V (the S-IC and S-II stages) had not been flown previously. The third stage (the S-IVB) had been used as the second stage of the Saturn IB. The instrument unit configuration was basically the same configuration flight tested during the Saturn IB development series. Figure 2-9 shows the vehicle and mobile launcher as they were being positioned on the launch pad.

The mission had a number of important objectives applicable to both the launch vehicle and spacecraft. The principal objectives were (1) to demonstrate the structural and thermal integrity and compatibility of the Saturn V and the Apollo spacecraft, (2) to verify operation of the launch vehicle propulsion, guidance and control, and electrical systems, (3) to demonstrate separation of the launch vehicle stages, (4) to verify the adequacy of the thermal protection system developed for the Block II command module under lunar return conditions, and (5) to demonstrate a service propulsion system engine no-ullage start.

The Apollo 4 spacecraft (airframe 017) included a launch escape system, a command and service module, and a spacecraft/lunar module adapter. A lunar module test article was installed in the adapter. The command module was equipped with the lunar-mission-type thermal protection system that was to be tested and had other modifications applicable to the Block II spacecraft. As on previous unmanned flights, the command module contained a mission control programmer to actuate functions that would normally be performed by the crew.

The space vehicle was launched from Kennedy Space Center Launch Complex 39A (the first use of this facility) at 07:00:01 a.m. e.s.t. (12:00:01 G.m.t.) on November 9, 1967. Detailed flight events are given in reference 2-6.

The launch phase was normal. All planned events occurred within allowable limits, and structural loading was well within the capability of the vehicle. Measurements telemetered from the command module indicated that qualification vibration levels were not exceeded and verified the adequacy of thermal prediction techniques.

The spacecraft was inserted into a circular orbit by the S-IVB stage after approximately 11 minutes of powered flight. Near the end of the second revolution, the S-IVB engine was successfully reignited to place the spacecraft into a simulated translunar trajectory. At the completion of the maneuver, the command and service module was separated from the S-IVB stage, and the service propulsion system engine was fired for approximately 15 seconds to demonstrate the capability of starting the engine in zero gravity without performing a reaction control system ullage maneuver. There were no adverse effects, and the maneuver raised the apogee of the spacecraft trajectory from 9292 miles to 9769 miles. A few seconds after service propulsion system engine cutoff, the spacecraft was oriented to an attitude in which the side hatch was pointed directly toward the sun. This attitude was maintained for approximately 4-1/2 hours to obtain thermal data.

After approximately 8 hours and 10 minutes of flight, a second service propulsion system maneuver was performed to accelerate the spacecraft to a velocity representative of severe lunar return entry conditions. Shortly afterward, the command module was separated from the service module and oriented to the entry attitude.

The inertial velocity at atmospheric entry, which occurs at an altitude of 400 000 feet, was approximately 36 000 feet per second, about 210 feet per second greater than predicted. This overspeed was caused by a longer-than-planned firing of the service propulsion system. Because of the change in entry conditions, the peak deceleration force was 7.3g rather than the predicted 8.3g.

The guidance and control system performed satisfactorily in guiding the spacecraft to the desired landing point. Although the landing was about 5 miles short of the target point, it was within the accuracy predicted before the mission. The forward heat shield and one of the main parachutes were recovered along with the command module by the primary recovery ship, the U.S.S. *Bennington*. Postflight inspection of the command module indicated that the thermal protection system withstood the lunar return entry environment satisfactorily.

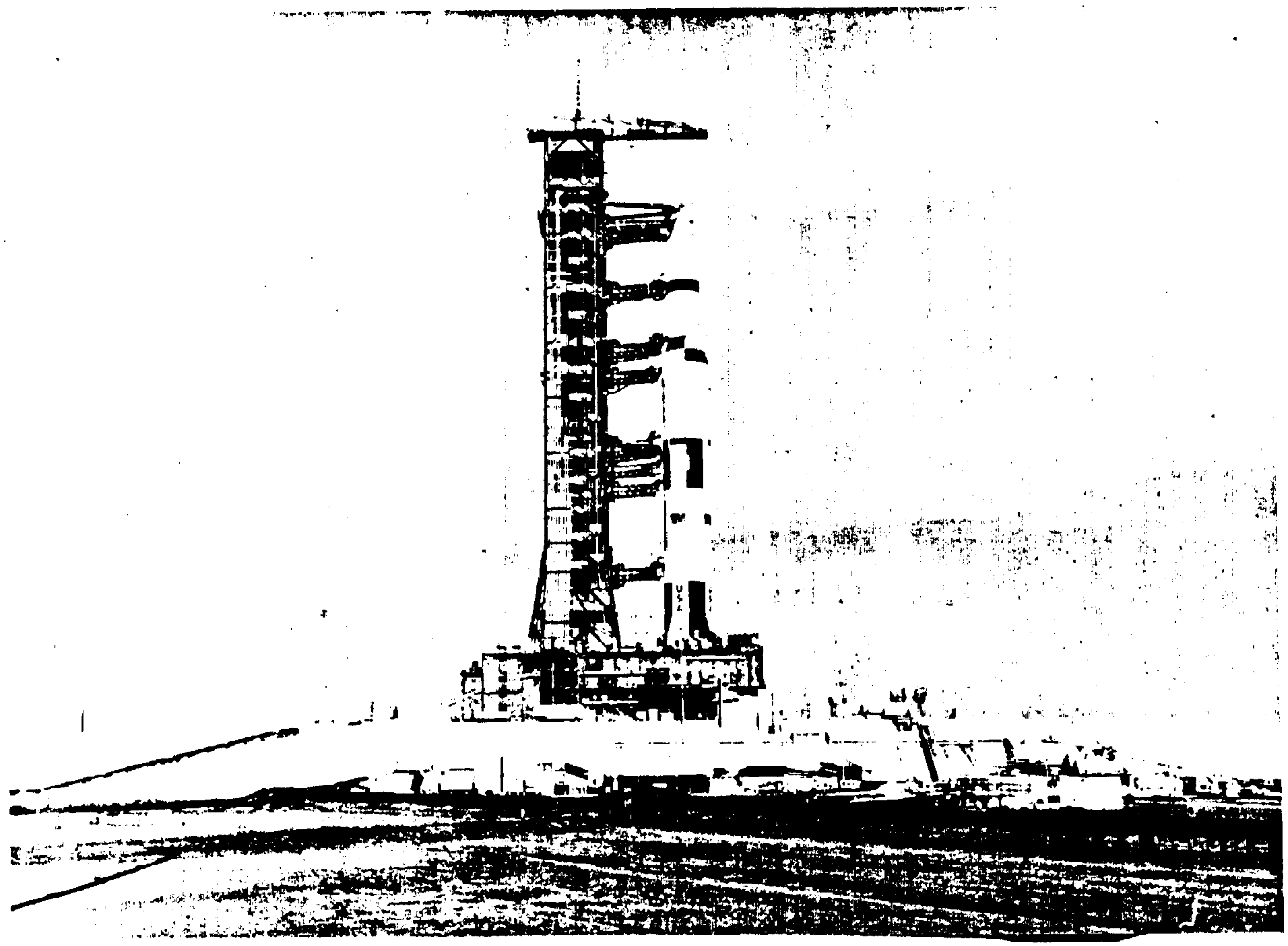

Figure 2-9.- Apollo 4 space vehicle on Launch Complex 39A.

2.3.5 Apollo 5 Mission

The Apollo 5 mission was the first flight of a lunar module and the fourth flight test of the Saturn IB launch vehicle. The space vehicle consisted of an S-IB stage, an S-IVB stage, an instrument unit, an adapter, the lunar module, and a nose cone. Primary objectives of the mission were to verify the lunar module ascent and descent propulsion systems and the abort staging function for manned flight. These objectives were satisfied.

Lift-off from Cape Kennedy Launch Complex 37B (fig. 2-10) was initiated at 05:48:08 p.m. e.s.t. (22:48:08 G.m.t.) on January 22, 1968. (The detailed sequence of mission events is given in reference 2-7.) The lunar module and S-IVB stage were inserted into earth orbit after 10 minutes and 3 seconds of powered flight. Lunar module loads and measured vibrations were within the design capability of the structure during powered flight. Spacecraft cooling began after S-IVB stage cutoff, and the equipment temperatures were properly regulated by the coolant system for the remainder of the mission. The lunar module was separated from the S-IVB stage by using the reaction control system engines. Separation disturbances were small. The lunar module was maneuvered to a cold-soak attitude which was maintained by the guidance system until early in the third revolution. A minimal reaction control system engine duty cycle was required to maintain the desired attitude.

Midway through the third revolution, the first descent engine firing was initiated. The planned duration of this firing was 38 seconds; however, after only 4 seconds, the guidance system shut down the engine. Both the guidance system and the propulsion system operated properly, and the premature shutdown resulted from an incorrect definition of the engine thrust buildup characteristics as used in the guidance system software.

After the premature shutdown, a planned alternate mission that provided minimum mission requirements was selected. At approximately 6 hours and 10 minutes into the flight, the automatic sequencer within the onboard mission programmer initiated the sequencing for the second and third descent engine firings, the abort staging, and the first ascent engine firing. Attitude rate control was maintained with the backup control system. The descent engine gimbaled properly and responded smoothly to the commands to full throttle. The thermal aspects of the supercritical helium pressurization system could not be adequately evaluated because of the short duration of the three descent engine firings. During abort staging, all system operations and vehicle dynamics were satisfactory for manned flight.

After the first ascent stage engine firing, the primary guidance and control system was reselected to control the spacecraft attitudes and rates. Because the primary system had been passive during the abort staging sequence, the computer program did not reflect the change of mass resulting from staging. Therefore, computations of reaction control system engine firing times were based on the mass of a two-stage vehicle and resulted in an extremely high propellant usage by the reaction control system engines, eventually causing propellant depletion. Because of excessive reaction control system engine activity, the engine cluster red-line upper limit was exceeded; however, no detrimental effects were evident.

The reaction control system was later subjected to abnormal operating conditions because of low manifold pressures after propellant depletion. Continued operation under these abnormal conditions resulted in three malfunctions within the system, but none had an appreciable effect on the mission.

The second firing of the ascent engine, initiated by the automatic sequencer, began at 7 hours 44 minutes 13 seconds into the mission and continued until thrust decay 5 minutes and 47 seconds later. During the initial portion of the firing, attitude rate control was maintained by using propellants from the ascent propulsion system tanks through interconnect valves to the reaction control system engines. However, the sequencer automatically closed the interconnect valves and switched the system over to the already depleted tanks. With the resultant loss of rate control, the vehicle began tumbling while the ascent engine was firing. All tracking was lost within 2 minutes after ascent stage engine thrust decay. The lunar module had been in a retrograde orientation during the controlled portion of the firing, and trajectory simulations indicated that the lunar module entered over the Pacific Ocean soon after the ascent stage engine firing. The predicted point of impact was approximately 400 miles west of the coast of Central America. The duration of the flight was approximately 8 hours.

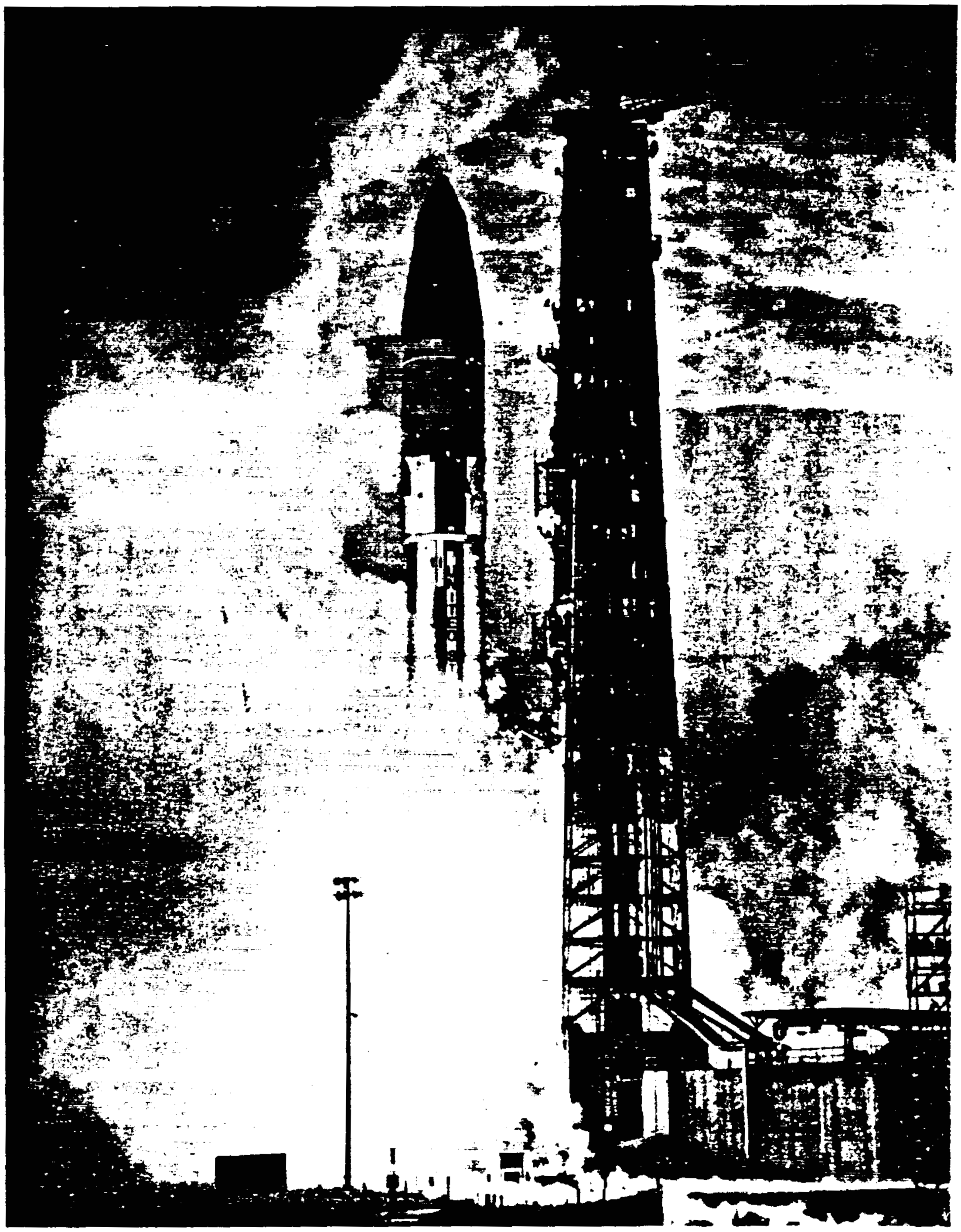

Figure 2-10.- Lift-off of space vehicle for Apollo 5 mission.

The overall performance of the lunar module was good and met all requirements for manned orbital flight. All operational systems were successfully verified, and the abort staging sequence was demonstrated.

2.3.6 Apollo 6 Mission

The Apollo 6 mission was accomplished on April 4, 1968. This was the second mission in which a Saturn V launch vehicle was used with an unmanned Block I command and service module and a lunar module test article.

The space vehicle was launched from Kennedy Space Center Launch Complex 39A at 07:00:01 a.m. e.s.t. (12:00:01 G.m.t.). Lift-off was normal but a major structural anomaly in the spacecraft/launch vehicle adapter occurred during first-stage boost. Approximately 2 minutes 13 seconds after lift-off, abrupt changes were indicated by strain, vibration, and acceleration measurements in the S-IVB, instrument unit, adapter, lunar module test article, and command and service module. The anomaly was apparently caused by 5-hertz oscillations induced by the launch vehicle; these oscillations exceeded the spacecraft design criteria. Photographic coverage from ground and aircraft cameras revealed material coming from the area of the adapter. (Sec. 4.4.2 of this report and ref. 2-8 contain additional information concerning this anomaly.)

After second-stage ignition, the boost phase was normal until two engines in the S-II stage shut down early. The firing time of the remaining three S-II stage engines was extended approximately 1 minute in an attempt to attain the desired velocity. The S-IVB stage firing was also longer than planned. At termination of the S-IVB thrust, the orbit had a 198-mile apogee and a 96-mile perigee, instead of the planned 100-mile near-circular orbit.

An attempt to reignite the S-IVB engine for a simulated translunar injection firing was unsuccessful. A ground command to the command and service module implemented a preplanned alternate mission that consisted of a long-duration firing (442 seconds) of the service propulsion system engine. This firing was executed under onboard guidance computer control and the onboard programmed apogee of 12 000 miles was attained. After the service propulsion system engine firing, the command and service module was aligned to a preset cold-soak attitude. The preflight-planned second firing of the service propulsion system engine was inhibited by ground command.

Atmospheric entry at 400 000 feet occurred at an inertial velocity of 32 830 feet per second and a flight-path angle of minus 5.85 degrees. The entry parameters were lower than predicted because of the S-IVB failure to reignite. The landing was about 36 miles up range of the targeted landing point as a result of the abnormal launch and insertion trajectory. This was the first mission in which the command module assumed the stable II (inverted) flotation attitude after landing. The command module was returned to the stable I (upright) attitude by the uprighting system. The mission duration was 9 hours 57 minutes 20 seconds.

The overall performance of the command and service module was satisfactory and none of the system anomalies precluded satisfactory completion of the mission. The most significant spacecraft anomaly was the aforementioned structural anomaly.

The abnormal occurrences during the boost phase subjected the command and service module to adverse environments that would normally not be seen during a flight test program. The alternate mission flown was the more difficult to accomplish of the two alternatives, which were (1) to attempt to complete the planned trajectory and obtain new evaluation data points or (2) to abort the mission and recover the spacecraft. The manner in which the command and service module performed during the alternate mission, after the adverse initial conditions, demonstrated the versatility of the systems.

The single primary spacecraft objective, demonstration of the performance of the emergency detection system operating in a closed-loop mode, was achieved. The secondary spacecraft objectives that were satisfied included demonstration of (1) effective operation of mission support facilities during the launch, orbital, and recovery phases of the mission, (2) successful operation of the service propulsion system (including a no-ullage start), and (3) proper operation of selected spacecraft systems (including electrical power, communications, guidance and control, and environmental control). The secondary spacecraft objectives that were partially satisfied included (1) demonstration of the adequacy of the Block II command module heat shield for entry at lunar return conditions (not fully satisfied because of failure to achieve the high velocity planned for entry), (2) demonstration of the structural and thermal integrity and compatibility of launch vehicle and spacecraft, and (3) confirmation of launch loads and dynamic characteristics. Reference 2-9 provides details on spacecraft performance.

2.4 MANNED APOLLO/SATURN FLIGHTS

The manned flights of the Apollo program were to be initiated with the AS-204 mission; however, a fire in the command module during preflight checkout on the launch pad resulted in the death of the three crewmen and an 18-month delay of the first manned mission. The manned phase included two earth orbital missions, two lunar orbital missions, and seven lunar landing missions, one of which was aborted. The six successful lunar landing missions allowed approximately 838 pounds (380 kilograms) of lunar material to be returned to earth. In addition, these missions and the lunar orbital missions provided a wealth of scientific data about the moon and its environment for analysis by scientists throughout the world.

2.4.1 Apollo I Mission

On January 27, 1967, tragedy struck the Apollo program when a flash fire occurred in command module 012 during a launch pad test of the Apollo/Saturn space vehicle being prepared for the first manned flight, the AS-204 mission. Three astronauts, Lt. Col. Virgil I. Grissom, a veteran of Mercury and Gemini missions; Lt. Col. Edward H. White, the astronaut who had performed the first United States extravehicular activity during the Gemini program; and Roger B. Chaffee, an astronaut preparing for his first space flight, died in this tragic accident.

A seven-man board, under the direction of the NASA Langley Research Center Director, Dr. Floyd L. Thompson, conducted a comprehensive investigation to pinpoint the cause of the fire. The final report (ref. 2-10), completed in April 1967, was subsequently submitted to the NASA Administrator. The report presented the results of the investigation and made specific recommendations that led to major design and engineering modifications, and revisions to test planning, test descipline, manufacturing processes and procedures, and quality control. With these changes, the overall safety of the command and service module and the lunar module was increased substantially. The AS-204 mission was redesignated Apollo I in honor of the crew.

2.4.2 Apollo 7 Mission

Apollo 7, the first manned mission in the Apollo program was an earth orbital mission. The command and service module was the first Block II configuration spacecraft flown, and the launch vehicle was a Saturn IB. Flight crewmen for the Apollo 7 mission were Walter M. Schirra, Jr., Commander; Donn S. Eisele, Command Module Pilot; and R. Walter Cunningham, Lunar Module Pilot. The primary objectives of this flight were to demonstrate command and service module/crew performance, crew/space vehicle/mission support facilities performance, and the command and service module rendezvous capability.

The spacecraft was launched at 11:02:45 a.m. e.d.t. (15:02:45 G.m.t.) on October 11, 1968, from Cape Kennedy Launch Complex 34 (fig. 2-11). The launch phase was normal, and the spacecraft was inserted into a 123- by 153-mile earth orbit. The crew performed a manual takeover of attitude control from the launch vehicle S-IVB stage during the second orbital revolution, and the control system responded properly. The command and service module was separated from the S-IVB stage approximately 3 hours after launch; the separation was followed by spacecraft transposition, simulated docking, and stationkeeping with the S-IVB.

A phasing maneuver was performed using the service module reaction control system to establish the conditions required for rendezvous with the S-IVB stage on the following day. The maneuver was intended to place the spacecraft approximately 75 miles ahead of the S-IVB. However, the S-IVB orbit decayed more rapidly than anticipated during the six revolutions after the phasing maneuver, and a second phasing maneuver was performed to obtain the desired conditions.

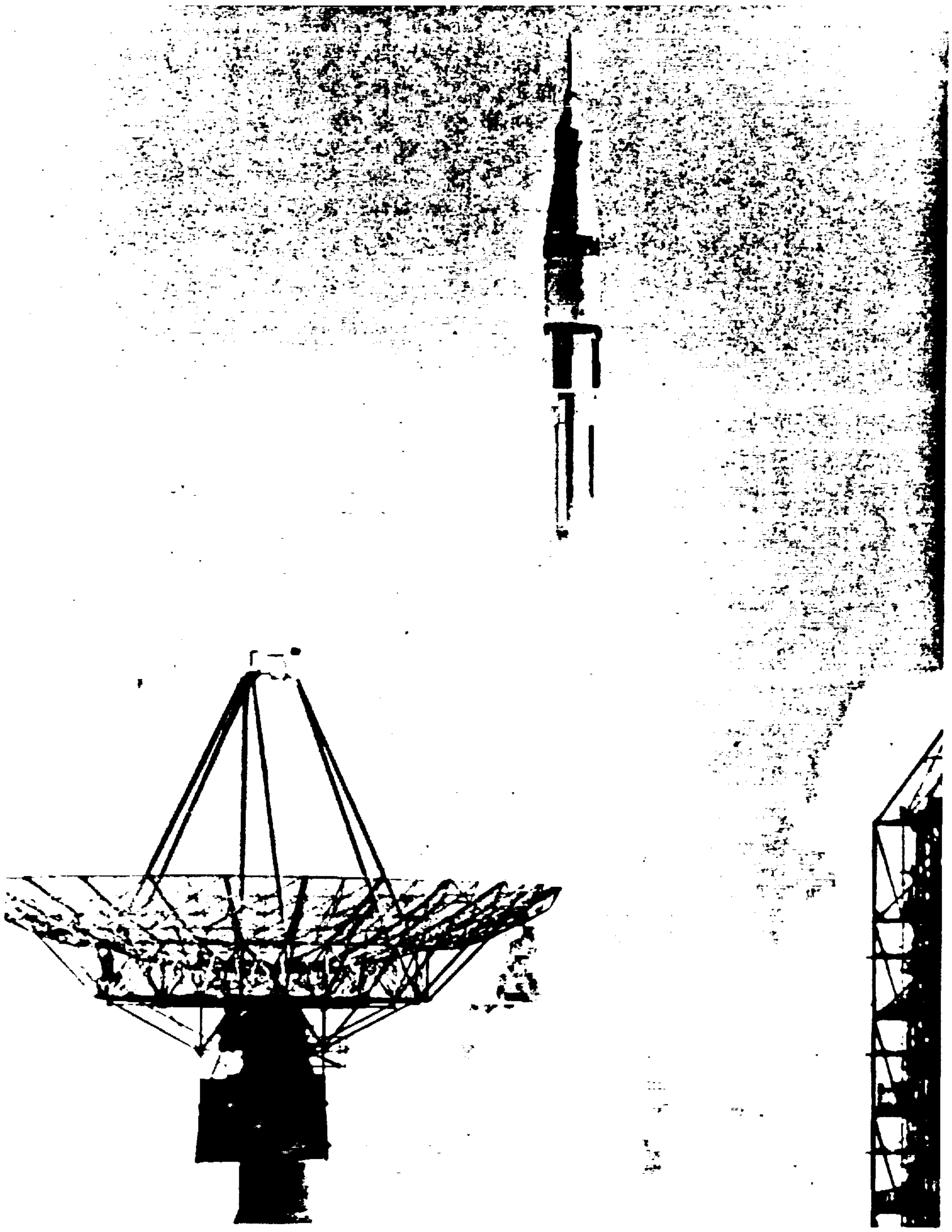

Figure 2-11.- Lift-off of space vehicle for Apollo 7 mission.