the APOLLO MISSION

Motorola's part of the tremendous national effort on the Apollo Program is infinitesimally small. But our pride in being selected is very great.

Since many of those in the electronics industry have never had the opportunity to overview the program, we have prepared this brochure — a graphic narrative of the Apollo Lunar Flight.

We hope you will find it entertaining and informational.

[Source: Motorola, Inc. Legacy Archives. Brochure, circa 1965.]

the company

Motorola is the largest manufacturer in the United States devoted exclusively to electronics. The Motorola Military Electronics Division's Western Center includes over 300,000 square feet of space and over 1000 professional engineering personnel, with the development and production of Aerospace Telecommunications as its major capability. The Telecommunications Laboratory is the largest R&D engineering facility at the Western Center and includes specialized Technical Sections devoted to Data Transmission System Applications, RF Systems, CW Transponders, and Command Systems. Related facilities include Antenna and Microwave, a Radar Systems Laboratory, Advanced Reliability and Components Analysis, and a major Manufacturing facility devoted exclusively to aerospace and related electronics.

experience

Apollo ■ Gemini ■ Ranger ■ Space Ground Link System ■ Thor/Able/Star Probes ■ MSFN & DSN Tracking ■ WSMR Tracking ■ Goddard Range & Range Rate Tracking ■ Venus Probe ■ PMR Tracking ■ Atlas ■ Polaris ■ Sidewinder ■ AMR Tracking ■ MilComSat ■ Regulus ■ Able ■ GAM-87 Skybolt ■ Jupiter ■ Saturn ■ Scout ■ AFMTC Tracking ■ Subroc ■ Bomarc ■ Explorer ■ Hound Dog ■ OGO/EGO ■ Pershing ■ Dyna-Soar ■ DSIF Tracking ■ Centaur ■ Terrier ■ Agena ■ Mars Probe ■ Minuteman ■ Mariner ■ Mercury ■ Lunar Orbiter ■ Advent ■ Midas ■

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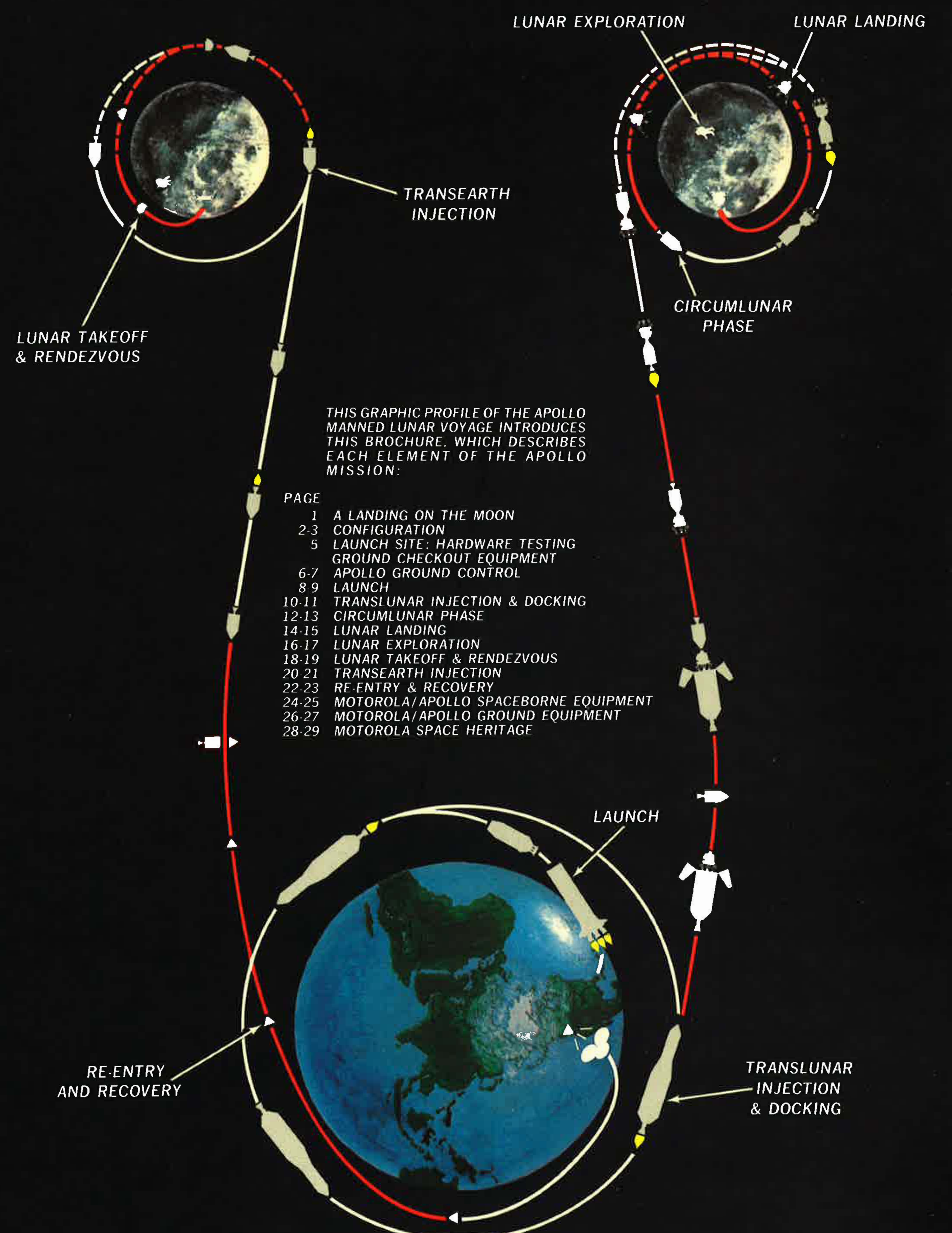
the APOLLO MISSION



THIS GRAPHIC PROFILE OF THE APOLLO MANNED LUNAR VOYAGE INTRODUCES THIS BROCHURE, WHICH DESCRIBES EACH ELEMENT OF THE APOLLO MISSION:

NOTE: BROKEN TRAJECTORY LINES INDICATE LOSS OF COMMUNICATIONS WITH EARTH DURING CLOSE LUNAR ORBIT.

a landing on the moon

Before the end of this decade man will launch his greatest voyage of discovery, a journey whose magnitude and implications for the human race will dwarf any high adventure of the past.

Project Apollo is the most complex undertaking ever contemplated by man; for the first time he will leave his own planet and set foot upon another world, the luminous satellite of earth we call the moon.

More than 5000 of the nation's industrial firms are directly involved in the United States' efforts to place men on the moon. The National Aeronautics and Space Administration estimates that 20,000 companies in all 50 states and 300,000 people eventually will participate. In addition, all of NASA's 10 major centers and most of its 30,000 employees contribute to the effort.[1]

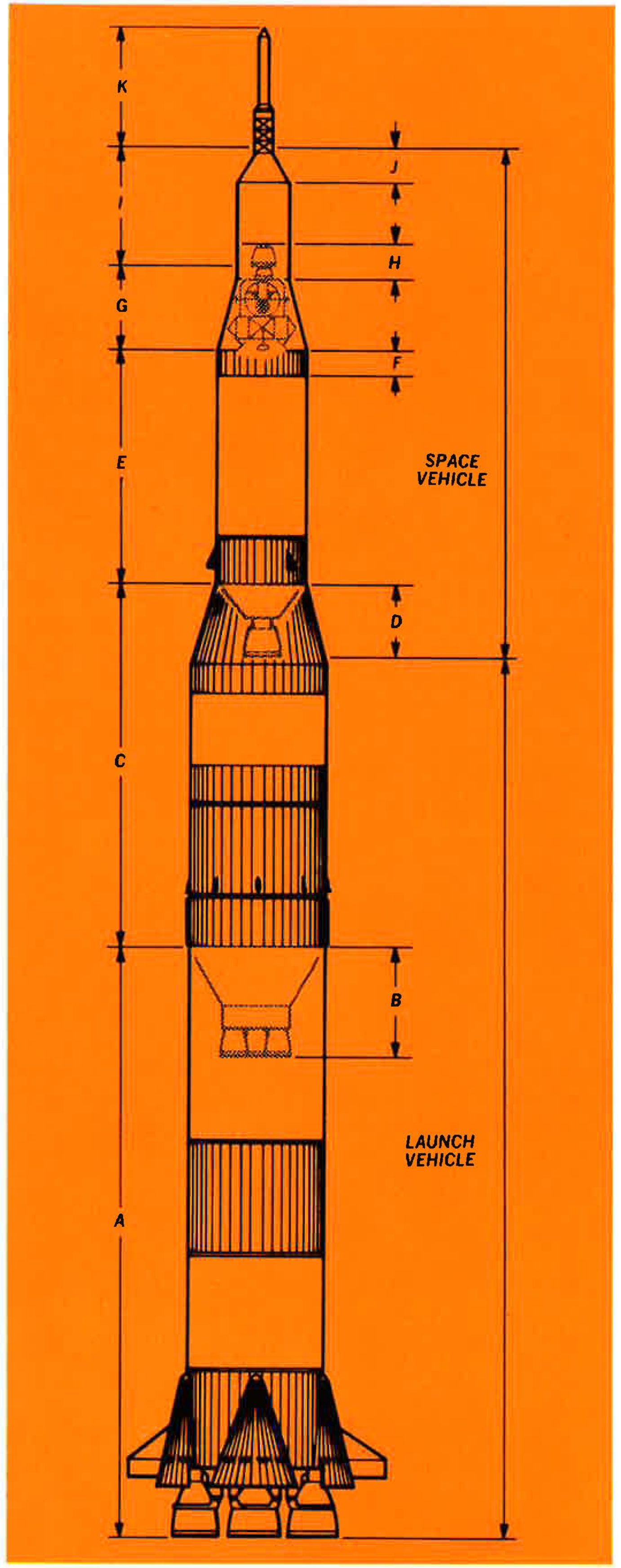
Three Americans will travel through space to the moon in the Apollo spacecraft, which will begin its voyage atop a mighty Saturn V booster rocket. As portions of the rocket and spacecraft complete their functions and are no longer required for the mission, they are jettisoned to reduce dead weight. The command module is the living quarters of the spacecraft, housing the three astronauts during the trip to and from the moon. When in orbit above the moon's pocked face, two of the astronauts will enter the lunar excursion module (LEM), attached to their command module, and descend to the lunar surface. Hours later, after taking photographs and making scientific studies, they will blast off in the LEM to rendezvous and dock with the orbiting command module for the trip home. The LEM will be left behind in moon orbit.

American astronauts will experience thousands of man hours of manned earth orbit in various spacecraft before the trip to the moon. This experience and the mastery of rendezvous, the joining together of two space vehicles as they hurtle around the earth at 17,500 miles an hour, will be vital to success.

The future? To quote the late Dr. Hugh Dryden, former Deputy Administrator of NASA, "Apollo, for all its complexity, will be a modest step compared to the magnitude of reaching other planets. A round trip to Venus would require nearly a year and to Mars 1½ years. But it is very likely we will reach Mars and Venus within the next 25 years. Before the year 2000 unmanned probes will have scouted all the planets of the solar system. We have embarked upon a long, long road from which there can be no turning back. The stars beckon us, and a brilliant new era in man's progress unfolds."[2]

This brochure briefly describes the total Apollo manned mission: vehicle configuration, launch site, ground control, and each phase of the program—Launch, Lunar Injection and Docking, Circumlunar, Lunar Landing, Lunar Exploration, Lunar Takeoff and Rendezvous, Transearth Injection, and Reentry and Recovery—are described and illustrated in the pages that follow.

[1] "Footprints on the Moon," by Hugh L. Dryden, Ph.D. **National Geographic**, Vol. 125, No. 3, p. 357 (March 1964). [2] **Ibid.**, pp. 400-401.



configuration

LAUNCH VEHICLE[1]

A. ***S-IC (FIRST STAGE)*** — *initial liftoff; flight data via radar tracking and telemetry, and a command destruct link. MOTOROLA EQUIPMENT OPERATING — Dual MCR-503 Command Destruct Receivers — L-Band ODOP Transponder.*

B. ***S-IC/S-II INTERSTAGE ADAPTER*** — *transmits thrust forces from S-IC (first stage) to S-II (second stage).*

C. ***S-II (SECOND STAGE)*** — *velocity buildup for injection of vehicle into earth orbit; flight data via radar tracking and telemetry, and command destruct link and television viewing of launch from vehicle. MOTOROLA EQUIPMENT OPERATING — Dual MCR-503 Command Destruct Receivers.*

D. ***S-II/S-IVB INTERSTAGE ADAPTER*** — *transmits thrust forces from S-II to S-IVB.*

E. ***S-IVB (THIRD STAGE)*** — *thrust for injection of vehicle into earth orbit and thrust for injection of vehicle into earth-to-moon trajectory; flight data via telemetry and command destruct link. MOTOROLA EQUIPMENT OPERATING — S-Band Transponder.*

F. ***INSTRUMENT UNIT*** — *guidance and control for the three launch vehicle stages; flight data via radar tracking and telemetry, and command link. MOTOROLA EQUIPMENT OPERATING — C-Band Transponder.*[2]

SPACE VEHICLE[1]

G. ***LAUNCH VEHICLE/SERVICE MODULE INTERSTAGE ADAPTER*** — *transmits thrust forces from launch vehicle to service module/command module and houses lunar excursion module.*

H. ***LUNAR EXCURSION MODULE*** — *lunar landing and takeoff: 1) landing stage provides the thrust for lunar descent orbits, deceleration, descent, hovering, and landing; 2) ascent stage provides the thrust for lunar launch and injection into lunar orbit — Unified S-band used to provide radar tracking, telemetry, two-way voice and television to earth ground stations; VHF voice communications and telemetry radar tracking from LEM to command module; VHF voice communications from command module to LEM; two-way voice communications between LEM and astronaut on lunar surface; space suit and biomed telemetry from astronaut to LEM. MOTOROLA EQUIPMENT OPERATING — S-Band Transponder.*

I. ***SERVICE MODULE*** — *thrust for space vehicle mid-course corrections, thrust for deceleration into lunar circular orbit, and thrust for transearth injection and mid-course corrections.*

J. ***COMMAND MODULE*** — *main vehicle for transporting Apollo crew to and from the moon. Provides main control of space vehicle; radar tracking, telemetry, two-way voice, television, command, and up-data via unified S-band (and radar tracking, two-way voice and beacon for recovery). MOTOROLA EQUIPMENT OPERATING — Unified S-Band Transponder with Up-Data Link — Astronaut Helmet Antenna.*

K. ***LAUNCH ESCAPE SYSTEM*** — *provides thrust for abort from liftoff through S-II full thrust buildup.*

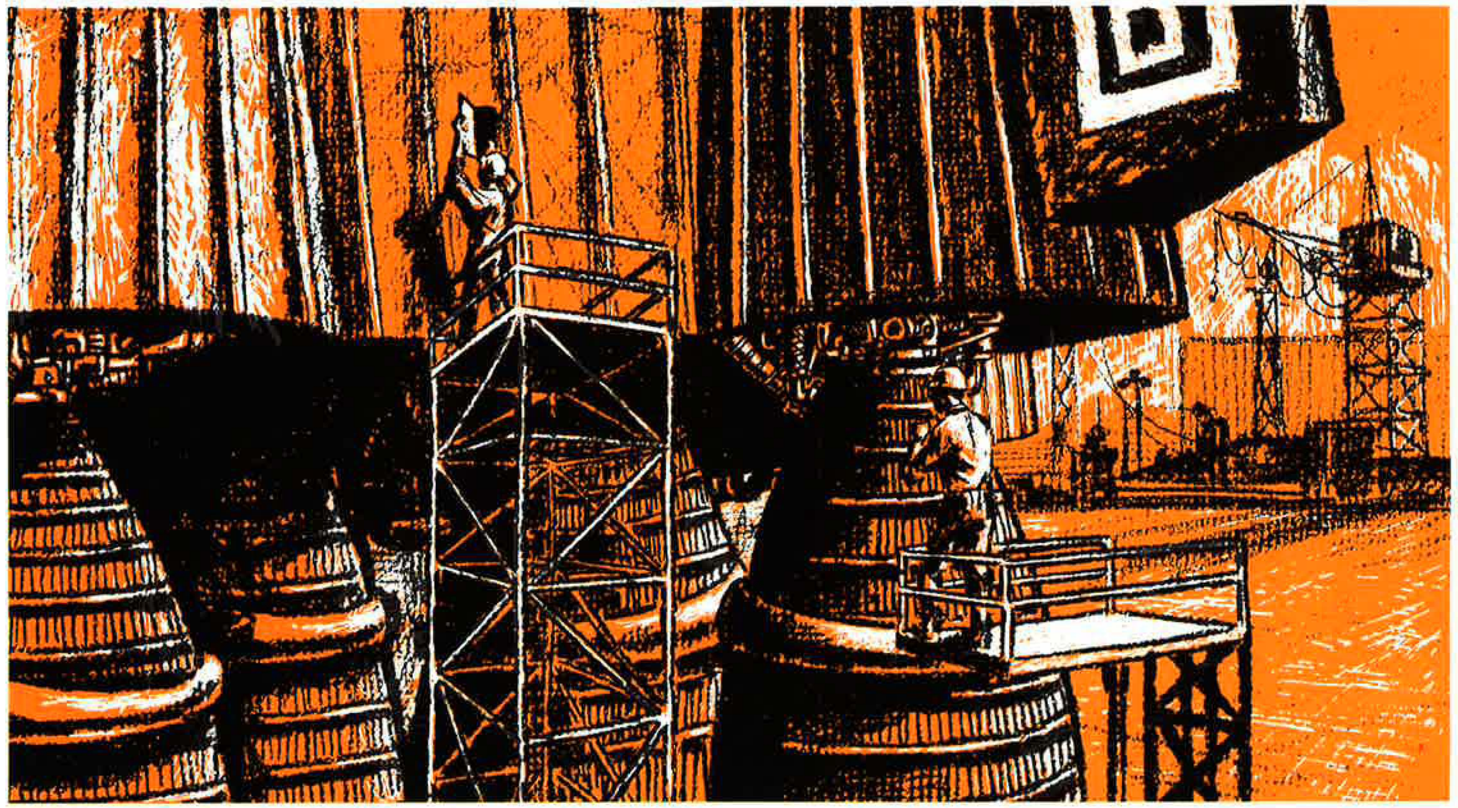
OTHER EQUIPMENT

LAUNCH SITE CHECKOUT EQUIPMENT — *final checkout of spacecraft and launch vehicle prior to launch. MOTOROLA EQUIPMENT OPERATING — Acceptance Checkout Equipment (ACE) Digital Test Command System (DTCS).*

TRACKING AND GROUND CONTROL EQUIPMENT — *transmits signals and receives and processes data from the Apollo Spacecraft during the various phases of the mission from launch to return to earth; the signals include tracking, telemetry, voice, television and command systems, and the necessary point-to-point communications system. MOTOROLA EQUIPMENT OPERATING — Manned Space Flight Net RF Subsystem — Deep Space Net RF Subsystem.*

DEVELOPMENT TEST AND CHECKOUT EQUIPMENT — *rigorous inspections and tests systematically carried out on each individual part, on the units formed by the parts, on the subsystem or system formed by the units, and finally, on the complete spacecraft. MOTOROLA EQUIPMENT OPERATING — Pseudo Random Noise Ranging Test Set — FM Modulator/Demodulator — S-Band Systems Test Set — Doppler Simulator — Spacecraft GOSS Integration Test Set — S-Band FM/PM Test Receivers — S-Band Transponder Test Set.*

[1]"Apollo Communication and Tracking Equipment Functions" **Technical Memorandum ASO-SS-04-64-16,** *p. 4 (1 August 1964).* [2]*Early unmanned Apollo missions only.*



launch site

__TEST AND CHECKOUT EQUIPMENT.__[1] At the Kennedy Space Center facilities, Merrit Island, the Saturn V Launch Vehicle will be put together in a building-block manner with the S-IC stage erected, the S-II stage placed on top, and then the S-IVB stage and instrument unit added before the spacecraft components are put on top. It must be assembled this way because of its weight.

When testing of the individual stages and the spacecraft at Cape Kennedy is completed, the component parts of the overall configuration will be moved into the high bay area of the huge Vehicle Assembly Building. (The largest building in volume in the world; the UN building will fit through one of its doors.) There the Saturn V stages will be mated on a 70-ft platform, the spacecraft components placed on top, and the entire configuration will undergo a final checkout. Then the crawler-transporter will move under the platform, jack itself up under the enormous weight and ease out the 455-foot-high door of the building to start the three-mile journey to the launch pad. As it leaves the building the crawler will move down a five degree ramp to the crawlway with hydraulic jacking cylinders constantly adjusting the level of the platform to within one-tenth of a degree of horizontal.

The crawler is powered by two 2750-horsepower diesel engines and will move to the pad at a speed of about one mile per hour. Total weight of the crawler and the Saturn V configuration will be about 9,000 tons.

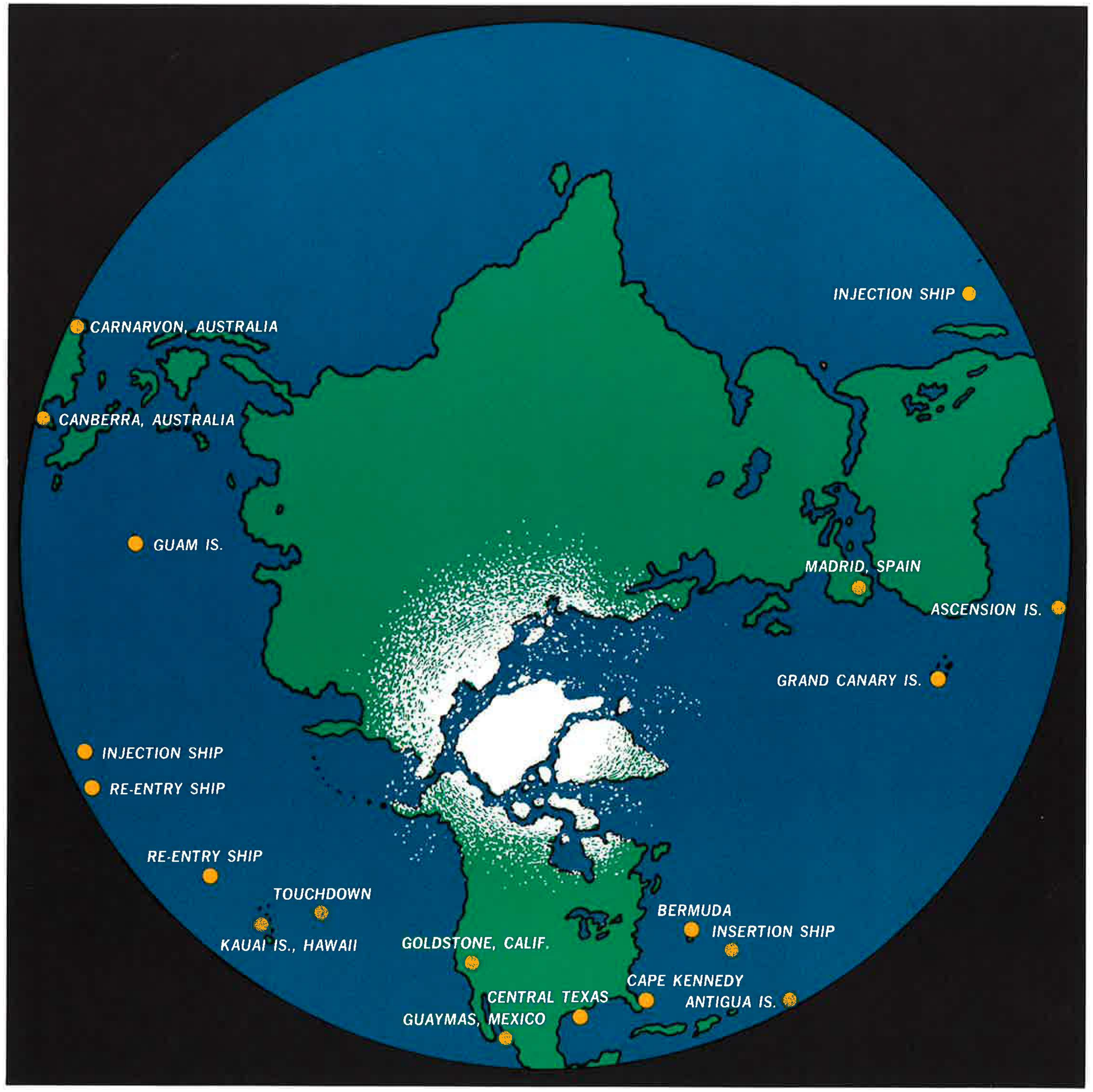
__HARDWARE TESTING.__[2] Every item of hardware in the Apollo spacecraft — beginning with nuts and bolts and continuing to the finished product — is subjected to rigorous inspections and tests. This phase of preparation for an eventual lunar landing flight is conducted to protect the astronauts on board and to insure success of the mission.

Tests are systematically carried out on each individual part, on the units formed by the parts, on the subsystem or system formed by the units, and finally on the complete spacecraft. Each subsystem and system is tested in its actual position in the spacecraft under various simulated launch, space, and reentry conditions, and finally in its interaction with other systems.

This activity includes x-ray and chemical tests; structural, static, and dynamic load tests; vibration tests, functional tests, and environmental tests.

Each component is tested far beyond the required safety level, and in many cases to the point of breakdown to determine performance margins. Since the systems are complex, failures must be anticipated and, in some instances, complete backup subsystems are provided, separate from the regular subsystems, to provide redundancy.

[1] *Information obtained from "Apollo Program,"* **MSFC Fact Sheet 292** *(June 1965).* [2] **Ibid.**



apollo ground control

The Apollo flights will be controlled, from launch, from the Mission Control Center at Houston through use of a world-wide communications network. A centralized group of flight control personnel will maintain contact with Apollo spacecraft through the Manned Space Flight Network, which includes the Deep Space and Near Earth remote sites. These networks are complexes of ships, aircraft, and remote land stations used for transmitting signals to and receiving and processing data from manned space flight spacecraft during the various phases of the Apollo Mission from launch to return to earth. They include tracking, telemetry, television and command systems, and the necessary point-to-point communications system.[1]

MANNED SPACE FLIGHT NETWORK

Near Earth Stations

Cape Kennedy	Carnarvon, Australia	Insertion Ship
Bermuda	Guam Island	Injection Ships
Antigua Island	Kauai Island, Hawaii	Re-entry Ships
Ascension Island	Guaymas, Mexico	Re-entry Ships
Grand Canary Island	Corpus Christi	Instrumented Aircraft

Deep Space Stations

Goldstone, California ■ Canberra, Australia ■ Madrid, Spain

Near earth stations will utilize 30-ft dish antennas, while the three deep space sites will have redundant 85-ft dishes. Several tracking ships will be used during the lunar missions, and, during the S-IVB injection thrust, aircraft also will be used to recover voice and telemetry and to provide an automatic flight relay to the flight control team.

The near earth stations will serve as the information link to the Apollo spacecraft from lift off to separation from the S-IVB stage. During this time, the critical maneuvers of the command and service modules' separation, transposition, and docking with the LEM also will have been completed. Approximately one hour after the spacecraft has been injected into its translunar trajectory, the deep space network (a dual unified S-band system for telemetry, voice, ranging, up data, and television) will establish the communications link through the remainder of the mission until the spacecraft reaches about the same distance on the return trip. Then, the near earth stations will again become the primary link.[2]

[1] **Hearings before the Subcommittee on Manned Space Flight of the Committee on Science and Astronautics,** *U.S. House of Representatives, 89th Congress, Part 2, Figure 60 (facing page 63), U.S. Government Printing Office: Washington (1965).* [2] *"Apollo Program,"* **op. cit.**

launch

Following the most comprehensive and extensive checkout and countdown ever performed at Cape Kennedy, the 33-story high Saturn V booster and launch vehicle is ignited, the hold down is released, and powered flight begins with a programmed gravity turn. The powerful five F-1 rockets of the S-IC produce 1.5 million pounds of thrust each for a total of 7.5 million pounds of thrust to propel the 6 million pound vehicle spaceward; burn out is at 206,000 feet at an approximate speed of 5,000 mph.[1] During this brief three-minute lift-off, vehicle communications, command, and control systems are linked to the Atlantic Missile Range Instrumentation Facilities at Cape Kennedy and the Near Earth Stations:[2]

- S-IC: VHF telemetry, ODOP tracking, and command destruct.
- S-II: VHF telemetry, VHF television, and command destruct.
- S-IVB/IU: VHF telemetry, Azusa tracking, and command destruct.
- Apollo interstage adapter (LEM): Unified S-band telemetry, and ranging (not active during launch phase).
- Command module: Unified S-band (voice, telemetry, ranging, and up data), and VHF voice.

The S-IC is jettisoned at burnout, and the S-II second stage ignited; its five J-2 engines develop 1 million pounds of thrust to impart a velocity of 22,000 feet per second. The launch escape tower to propel the astronauts to safety in case of booster malfunction is jettisoned following the S-II stage thrust buildup and vehicle stabilization. When the S-II stage cuts off it is jettisoned also, and the S-IVB third stage ignited.

The single 200,000-pound thrust J2 engine of the S-IVB burns briefly to insert the Apollo spacecraft into a normally circular parking orbit about 100 nautical miles above the earth; it has taken about 12 minutes to reach orbit from launch. The orbit may last up to five hours.

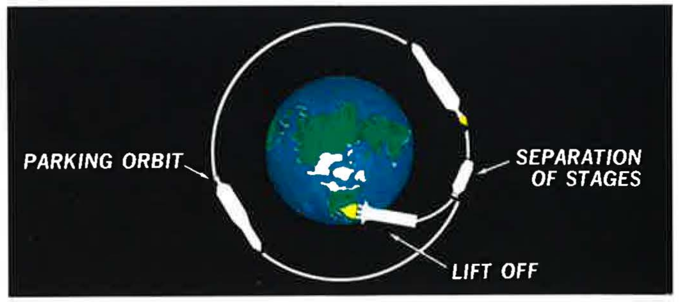
Mission Control at Houston monitors the flight at all times. Crew and equipment are checked out during the parking orbit prior to buildup of escape velocity and injection into a trajectory toward the moon.

At this point, computers at the Mission Control Center in Houston calculate trajectory and orbit and determine the precise moment when the S-IVB must be fired to put the Apollo spacecraft on an accurate course — not where the moon is at the moment, but to where it will be 70 hours later. This complex problem must take into account the speed of the earth at 67,000 miles an hour relative to the sun, the speed of the moon at 2300 miles an hour relative to the earth, and the average speed of the craft, about 3300 miles an hour en route to the target.[3]

[1] "Apollo Mission" op. cit. [2] TM ASO-SS-08-64-16, op. cit. p. 9. [3] Dryden, op. cit., p. 385.

motorola equipment participating

ACE(DCTS) ■ GROUND CHECKOUT EQUIPMENT ■ C-BAND BEACON ■ MCR-503 COMMAND RECEIVERS ■ L-BAND ODOP TRANSPONDER ■ MSFN RF SUBSYSTEM



Following the ground computer calculations for the translunar injection firing (following one to three parking orbits about the earth), the information is transmitted from the Mission Control Center at Houston to the spacecraft. The spacecraft computer then determines the orbit and translunar injection firing program. This is confirmed with Mission Control; the orbit evaluation and firing program are continuously updated during the second and third orbits, as Mission Control must provide concurrence to continue the mission. Only then can S-IVB be re-ignited for the second burn to propel the spacecraft to the necessary escape velocity of 25,000 miles per hour. This activity will be controlled either by Cape Kennedy or the command astronaut.[1]

Once out of its orbit around the earth and after correct translunar trajectory has been confirmed by Mission Control, the interstage adapter surrounding the LEM is retracted and the command and service module separates from the rest of the vehicle — moving approximately 100 feet forward. With the skill of long practice, the astronauts use the reaction jets to maneuver the command and service modules in a 180-degree turn and back to the rest of the spacecraft. The command module docks nose first with the LEM, freeing the service module engine for later use. The union is accomplished at the access hatch, which will permit two astronauts to move into the LEM from the command module during the Circumlunar Phase. The spacecraft may stay with the S-IVB for stabilization for a period; however, prior to lunar orbit, the S-IVB and the interstage adapter are jettisoned into a separate trajectory through the use of reaction jets.[2]

The astronauts then settle down to an established routine of work, rest and household chores. They will talk to earth and continually monitor equipment. At intervals one man takes star sightings with a specially designed sextant and feeds the information to the spacecraft computer, which is linked to an inertial guidance system that monitors the spacecraft trajectory. Several times, the astronauts reorient Apollo and fire the service module engines briefly to make necessary course corrections.[3]

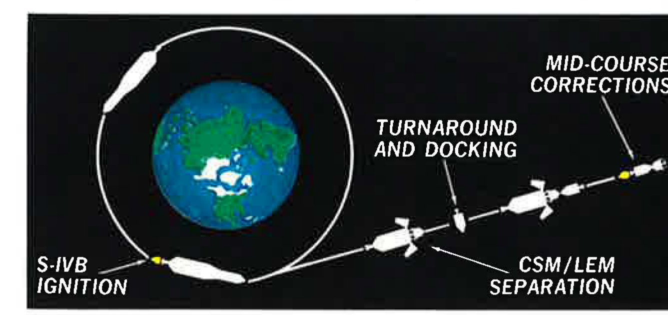
During the lunar injection and docking phase the following communications, command, and control systems will be in operation. They will be connected to the near earth stations through their range capability, and then picked up by the MSFN.[4]

S-IVB/IU Interstage Adapter: Unified S-band (telemetry, up data).
Command and Service Module: Unified S-band (voice, telemetry, ranging, and up data).

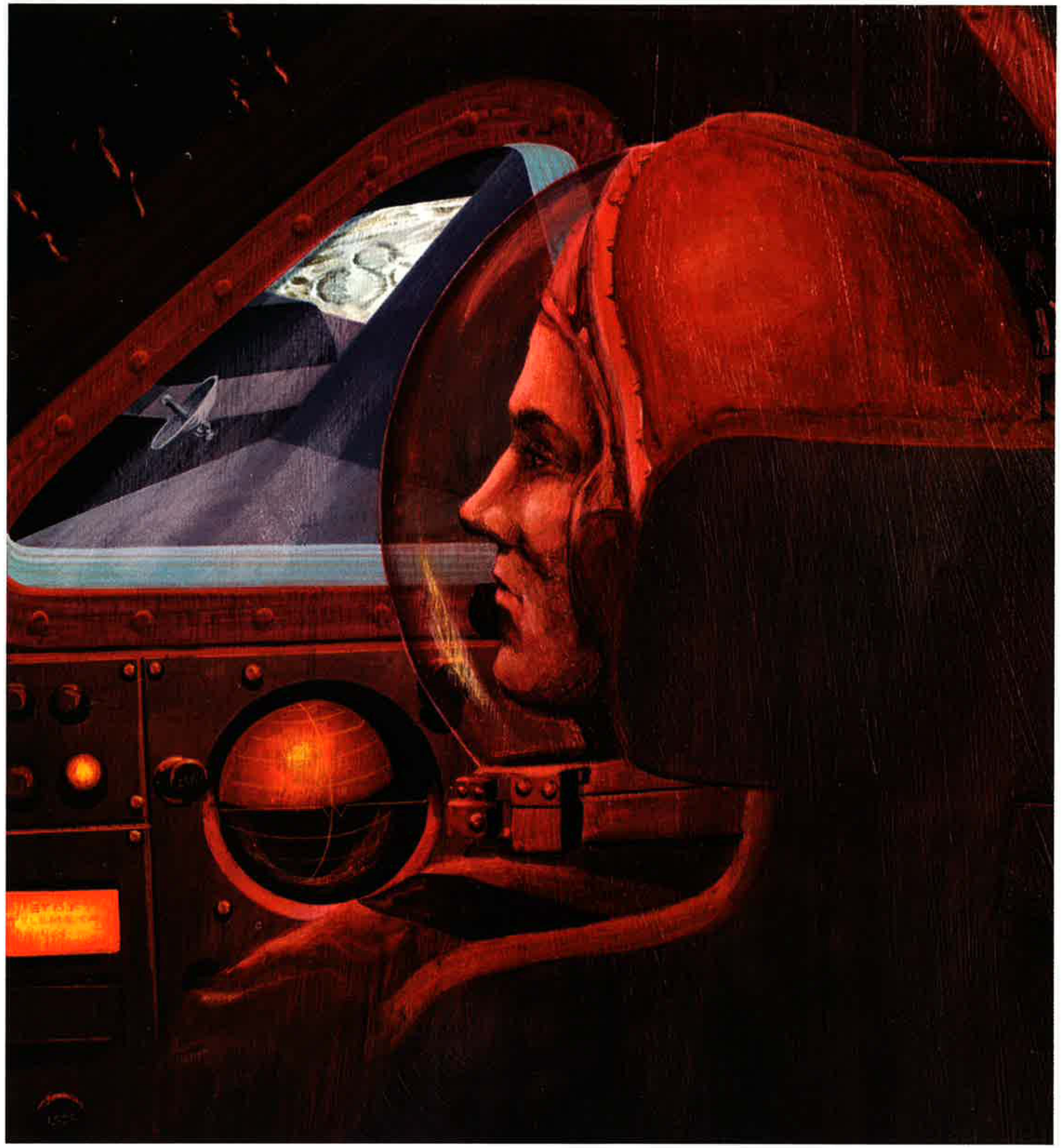
[1]Hearings, op. cit., *Figure 60.* [2]*"Apollo Program,"* op. cit. [3]*Dryden*, op. cit., *p. 385.* [4]Hearings, op. cit., *Figure 60.*

motorola equipment participating

MSFN RF SUBSYSTEM ■ SATURN S-IVB S-BAND TRANSPONDER ■ DSN RF SUBSYSTEM



translunar injection & docking



the circumlunar phase

"Like an automobile coasting uphill, Apollo has been losing speed. At 220,000 miles from home, it reaches a point where the moon's gravity wins the tug-a-war with earth's. Once past the invisible crest, the spaceship accelerates toward the moon."[1]

Initial conditions are calculated for entering a lunar parking orbit; and the spacecraft is oriented for the retro maneuver to the lunar orbit. The service module engine is ignited and the spacecraft begins a powered flight retro maneuver to brake the plunge and enter a circular orbit approximately 80 nautical miles above the lunar surface.[2] *The spacecraft with LEM attached will orbit at least once to establish the orbit ephemeris; further optical measurements are then made for calculation of lunar parking orbit parameters.*[3]

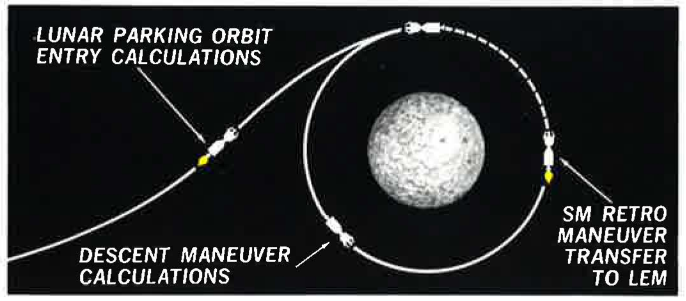
Following a final equipment checkout, two of the three crewmen wiggle through a hatch into the LEM. The LEM will receive a thorough checkout and initial conditions for the separation and descent maneuver will be calculated. Following separation, the command and service modules continue to orbit around the moon, with one astronaut aboard maintaining voice and telemetry contact with LEM via VHF link.[4]

The Unified S-Band System provides continuous voice, telemetry, ranging and television coverage for the command module and LEM to the earth, except when they are masked by the moon.[5]

[1]Dryden, **op. cit.**, *p. 385.* [2]*"Apollo Mission,"* **op. cit.** [3]**Hearings, op. cit.,** *Figure 60.* [4]*Dryden,* **op. cit.,** *p. 385.* [5]**Hearings, op. cit.,** *Figure 60.*

motorola equipment participating

DSN RF SUBSYSTEM ■ SATURN S-IVB S-BAND TRANSPONDER ■ CSM S-BAND TRANSPONDER ■ CSM UP DATA LINK



lunar landing

It is time for the climactic phase, the descent to the moon. The LEM separates from the command and service modules and assumes its descent attitude approximately 500 feet from the command and service module, cruising for approximately one hour to check out communications channels between the two vehicles.[1] The LEM landing stage is ignited and the lunar landing craft is thrust out of the circular orbit into an elliptical orbit known as the Hohmann transfer ellipse. The LEM then circles the moon in a race with the command module; every two hours they pass one another as their orbits cross. Should anything go amiss at this stage, the two spacecraft rendezvous and return to earth.[2]

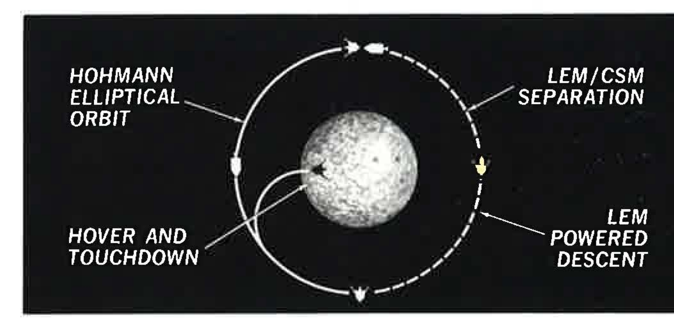
Equipment and systems are checked out, and as the LEM approaches the low part of its orbit (50,000-ft. altitude), the command astronaut fires the descent engine. The LEM will be in a coasting mode when it is about 10 miles above the lunar surface; a burn of the descent engine will be made to bring the LEM down to a hover point several hundred feet above the surface.[3] For a successful reunion with the command module, the LEM must touch down within five degrees of the moon's equator. A voice link is maintained open between the CM and the LEM during this phase.

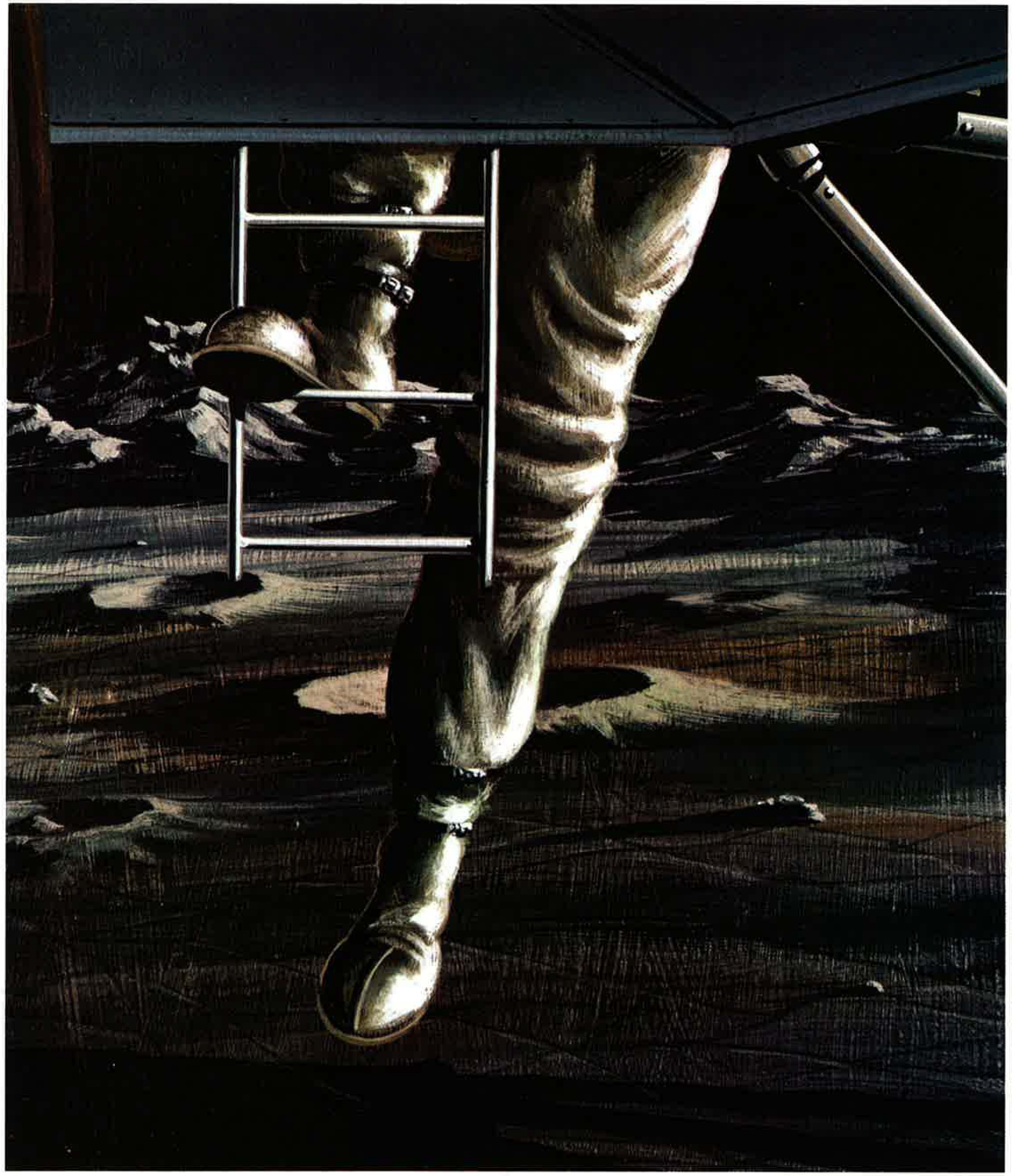
While the craft hovers, the surface is viewed intently, as only two minutes of fuel is available to select a landing site or return to the mother ship.[4] On the selection of safe terrain, the pilot will manually control the LEM descent to final touchdown in a torrent of flame and dust, the propulsion providing a braking force and the landing gear absorbing the shock. The landing takes about ten minutes, ending a journey of from two and a half to three and a half days.

motorola equipment participating

LEM S-BAND TRANSPONDER ■ CSM S-BAND TRANSPONDER ■ CSM UP DATA LINK ■ DSN RF SUBSYSTEM

[1]**TM ASD-SS-08-64-16, op. cit.** [2]*Dryden,* **op. cit.,** *p. 385.* [3]*"Apollo Program,"* **op. cit.** [4]*Dryden,* **op. cit.,** *p. 385.*





lunar exploration

After touchdown, when the dust and debris have settled, the crew members will check all the systems to make sure there has been no damage during the lunar landing. They will determine if there is any factor which might hinder the LEM in performing a successful ascent. The crew will then prepare for the astronauts to leave the LEM and perform the lunar exploration. These preparations will include surveying the surrounding lunar landscape, checking the LEM hatches, and performing a final check on the portable life support systems. All equipment in the LEM not required for the lunar stay will be turned off.[1]

The cabin of the LEM is depressurized briefly, for an astronaut to leave the spacecraft. He will be equipped with camera, scientific equipment, and a life-support backpack on his space suit that includes VHF equipment for communication with the other astronauts in the LEM and the orbiting command module. (One astronaut may remain in the spacecraft for safety reasons.)

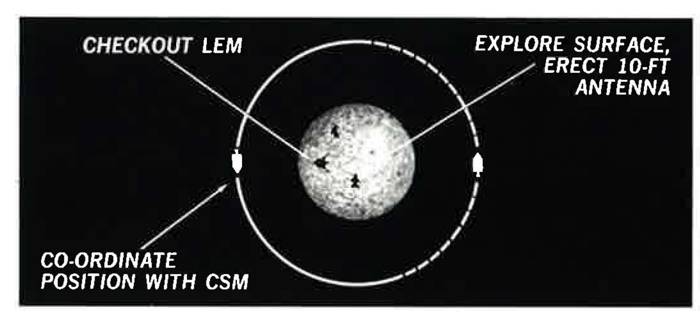
As Dr. Dryden described it, "the astronaut will step down from the LEM into the lunar dust and stand in awed immobility: overhead will hang a huge luminous blue globe wearing vast veils of brilliant white. As seen from the moon, the earth, nearly four times the diameter of its neighbor world, glows with a much greater brilliance than that of the loveliest full moon ever observed by man. An eerie twilight will bathe the ancient rocks and craters of the desolate lunar plain."[2]

The exploring astronaut will first check the exterior of the vehicle and a television system used to send pictures back to earth. He will make photographs, take notes, collect rock samples, and place instruments and a ten-foot antenna that will relay information back to earth after he leaves. He will move easily in the gravitational field of the moon, only one/sixth that of earth. "The sensation is one of buoyance, like that of a man standing chest deep in calm water. All too soon his allotted time ends. He will then return to LEM and give his partner a chance to explore."[3]

The portable life support system must be replenished after about three hours, and the life support stores on board will permit only two or three refills for each astronaut.

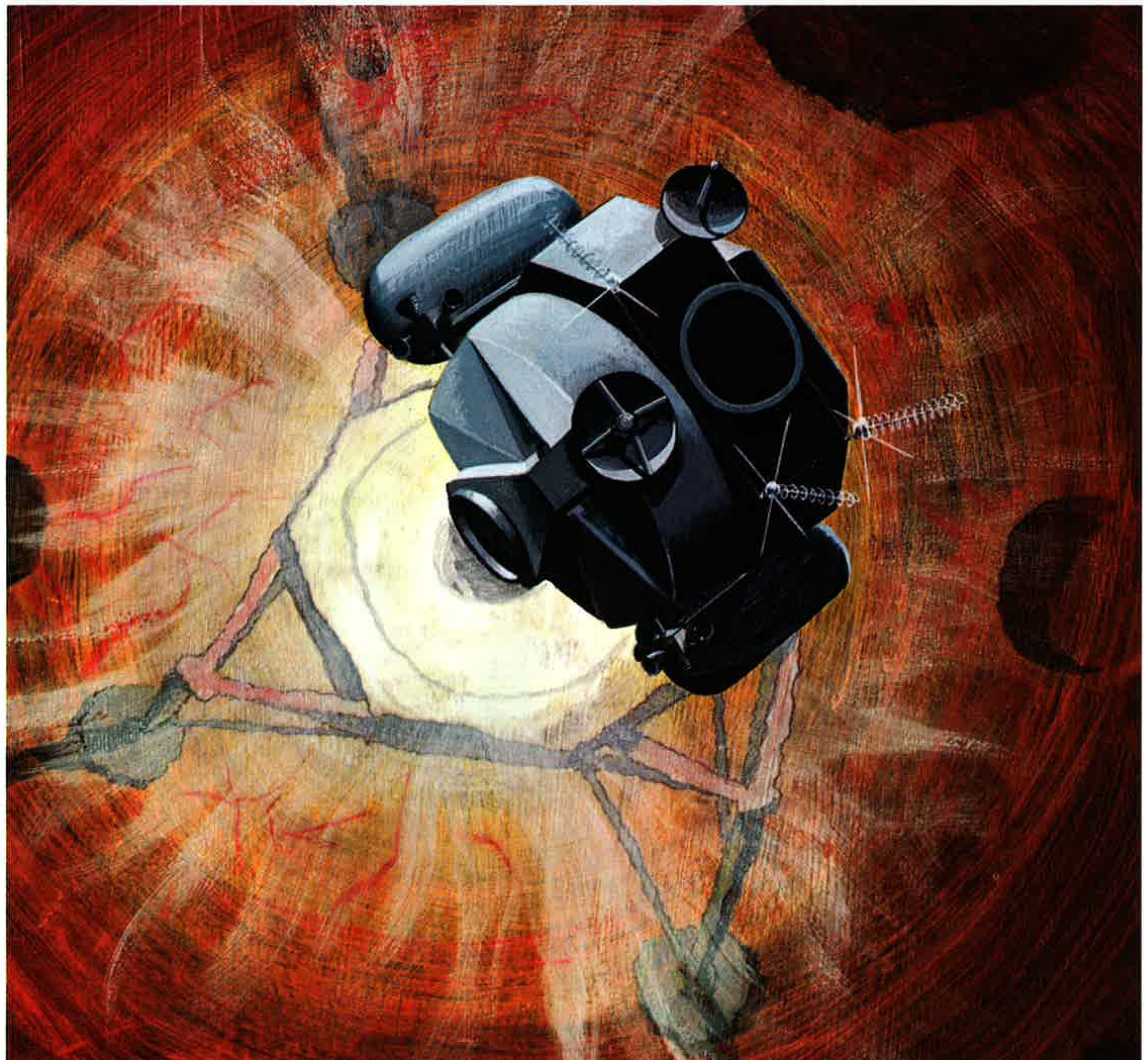
motorola equipment participating

LEM S-BAND TRANSPONDER ■ CSM S-BAND TRANSPONDER ■ CSM UP DATA LINK ■ DSN RF SUBSYSTEM ■ ASTRONAUT BORNE LUNAR EXPLORATION ANTENNA



[1]*"Apollo Mission,"* **op. cit.** [2]*Dryden,* **op. cit.,** *p. 385-386.* [3]**Ibid.**

lunar takeoff & rendezvous



When lunar exploration and the many assigned tasks are completed, the two astronauts will check out the LEM and begin a countdown for the complex launch and rendezvous maneuver. The orbit parameters of the command and service modules are determined by tracking with an X-band radar, and the ascent trajectory parameters are confined over the VHF link with the command module and over the unified S-band link with Mission Control on earth. The LEM receives its final checkout and the ascent engine is ignited at just the right moment for intercept. The four-legged LEM descent stage and landing gear serves as the launch pad and is left behind.[1]

The LEM is thrust up out of the moon's comparatively weak gravitational pull into the alien sky. It is planned that the LEM will ascend to about 50,000 feet. It will stay in a parking orbit at that height until the proper time to again fire the ascent engine, on a trajectory to place it within rendezvous range of the command and service module. The terminal rendezvous phase will begin when the two spacecraft are about 20 miles apart. When the LEM closes to about 500 feet from the spacecraft, the pilot will manually bring the LEM into the correct docking attitude and adjust the rate of closure until the docking is complete. At this time, the pressure in the LEM and command module will be stabilized; the returning astronauts will turn off the LEM systems, transfer the scientific samples into the command module, and prepare for the return to earth.[2] The LEM is left attached until after transearth pre-injection checkout of the command and service module.

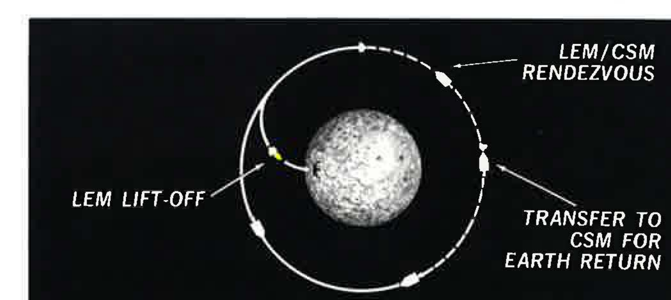
The LEM launch stage is then jettisoned and will remain in lunar orbit. The spacecraft is then ready for its quarter million mile flight back to earth.

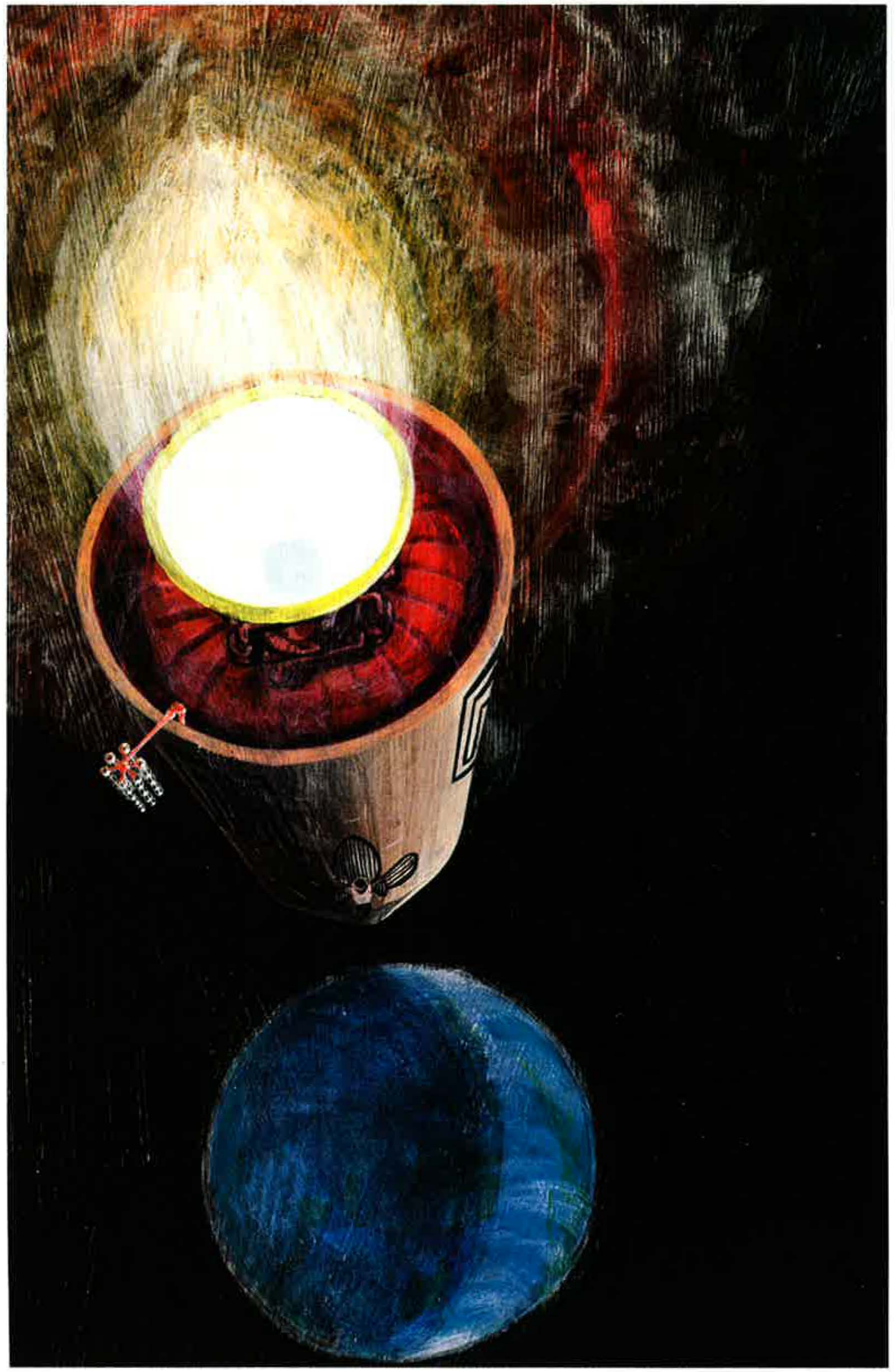
Continuous voice, telemetry, ranging, up data, and television contact is maintained via unified S-band between Apollo and the Manned Space Flight Net on earth.[3]

[1]Dryden, op. cit., p. 386. [2]"Apollo Program," op. cit. [3]Hearings, op. cit., Figure 60.

motorola equipment participating

LEM S-BAND TRANSPONDER ■ CSM S-BAND TRANSPONDER ■ CSM UP DATA LINK ■ DSN RF SUBSYSTEM





transearth injection

The 70-hour journey home for the three astronauts begins with a crew and equipment checkout while still in lunar orbit. The required transearth trajectory insertion maneuver is confirmed with Mission Control on earth via S-band. The service module engine will be fired for approximately 100 seconds to give the spacecraft the necessary speed to leave the lunar orbit and enter a transearth trajectory.

As on the outward journey, painstaking midcourse corrections are made by firing the service module engine: the data for each correction will be confirmed with Mission Control via the unified S-band system.[1]

The correct spacecraft attitude for firing must be assumed, the service module engine ignited, and the correction made. Each time the engine is shut down, there must be a further checkout of all systems. Periodic voice reports and telemetry data via the unified S-band link are used to monitor status and assess flight capabilities.

In the words of Dr. Dryden, "The survival of the astronauts depends upon hitting a tiny corridor of the earth's atmosphere only 300 miles wide and 40 miles deep. If the spacecraft angle of descent is too shallow, Apollo will skip out of the atmosphere and hurtle into space. If the angle is too steep, abrupt decelleration in the thickening air will crush them at up to 350 g's. The accuracy requirement is equivalent to shooting the nap off a tennis ball — but not hitting the ball — from a distance of 100 yards."[2]

[1]Hearings, op. cit., Figure 60. [2]Dryden, op. cit., p. 386.

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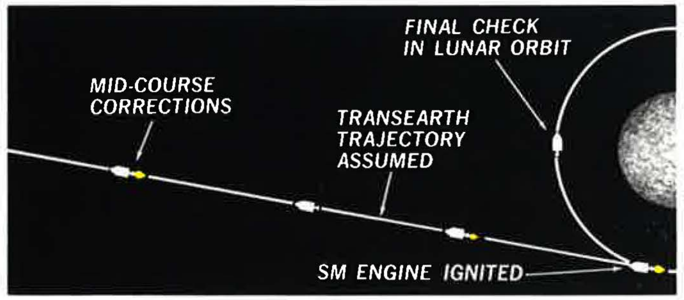
CSM S-BAND TRANSPONDER ■ CSM UP DATA LINK ■ DSN RF SUBSYSTEM



reentry & recovery

Following the final midcourse correction, the spacecraft receives re-entry parameters from Mission Control to determine correct separation parameters for the service module. The spacecraft is maneuvered to the separation attitude and the service module jettisoned approximately 30 minutes before reaching the re-entry point, leaving only the tiny command module remaining of the 3000-ton giant that had left the earth a week earlier.

With the three astronauts buckled tightly in their seats, the command module then assumes the re-entry attitude just above 400,000 feet over the earth. The increased pull of earth's gravity will result in an increase in speed to about 25,000 miles per hour as the command module approaches the atmosphere.

The first part of the re-entry phase is a dive into the atmosphere using aerodynamic lift to achieve a zero altitude rate. The second part is a suborbital skip out of the atmosphere or a constant altitude, depending on the CM guidance calculated trajectory. The third part is the final entry into the atmosphere.[2]

Scoring a bull's eye on the narrow corridor, communications are blacked out, and the reaction control jets are used to maneuver the command module so that its blunt reentry shield is toward the direction of flight.

Flame envelopes the blunt heat shield as its surface vaporizes at 5000°F. Through the viewing ports, the three astronauts will see glowing ablation vapors in the wake of their ship. Flaming pieces of the specially designed heat shield will melt and stream away; and converging gasses form a golden trail. Between the capsule's heat shield and the shock wave immediately ahead of the spacecraft, temperatures will reach a maximum of 100,000°F, nearly ten times the temperature of the sun's surface.[3]

Apollo's shape and offset center of gravity give the spacecraft some lift in the atmosphere, and throughout the fiery re-entry the commander will maneuver with his attitude jets to control the lift and thereby the range of the atmospheric portion of the flight. This maneuvering will bring Apollo near the landing site. The forward heat shield will be jettisoned at 50,000 feet and atmospheric drag will slow the command module enough to allow deployment of drogue chutes at 25,000 feet. At about 15,000 feet three parachutes will deploy, fill with air and gently bring the command module with its valuable cargo back to the surface of the earth.[4]

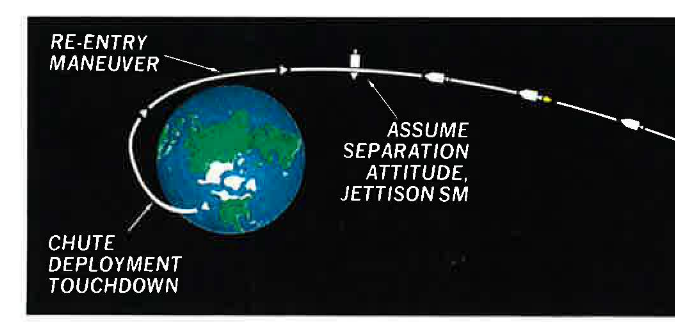
At this point recovery forces will go into action and locate the astronauts and the spacecraft.

All that remains is further evaluation of the scientific data obtained. But the Apollo Mission will have demonstrated the ultimate in human endeavor: thousands of people working together for millions of hours to further man's understanding of himself and his universe.

[1]*"Apollo Program,"* **op. cit.** [2]**TM ASD-SS-08-64-16, op. cit.,** *p. 76.* [3] *Dryden,* **op. cit.,** *p. 401.* [4]*"Apollo Program,"* **op. cit.**

motorola equipment participating

CSM S-BAND TRANSPONDER ■ MSFN RF SUBSYSTEM



motorola/apollo
spaceborne equipment

***Command Module S-Band Transponder* — This unified S-band transponder will provide the only RF link connecting the Apollo spacecraft to earth for all deep space portions of the manned lunar mission. This high-reliability equipment receives and recovers up link voice and command subcarriers, ranging, and coherent carrier information; it transmits coherent carrier, turnaround ranging, and telemetry and voice subcarrier signals. A separate wideband FM transmitter provides down link television and alternate telemetry capability.**

Command Module Up Data Link — The latest in a Motorola heritage of ultrahigh reliability digital command systems, this equipment detects, decodes, and transfers data to on-board subsystems; it also controls external and internal relays. Digital data, transmitted to the up-data link over unified S-band, is required for performance of complex spacecraft operations: 1) During various mission phases, the guidance computer requires current information from the ground for complex guidance and navigational equations. 2) Spacecraft central timing equipment requires periodic updating to accurately initiate and control critical spacecraft operations. 3) Relay control is essential for numerous on/off and alarm functions.

Command Destruct Receivers (MCR-503) for Saturn S-IC Booster and S-II Second Stage — Dual MCR-503 units will be used for command destruct functions in both the S-IC and S-II stages of the Saturn V. This receiver was developed and built to NASA specifications for use on the Saturn Program, and provides a significant advance in aerospace command instrumentation. The latest silicon semiconductors are utilized throughout for greatly improved high temperature performance, well in excess of 100°C. A compression packaging method enables the unit to withstand high vibration and shock levels without sacrificing size and weight. The MCR-503 is a solid-state, crystal controlled, double conversion, superheterodyne FM receiver with a coaxial low-pass filter, two tuneable bandpass filter stages, low-noise RF amplifier, a passive bandpass IF filter, and dual audio outputs.

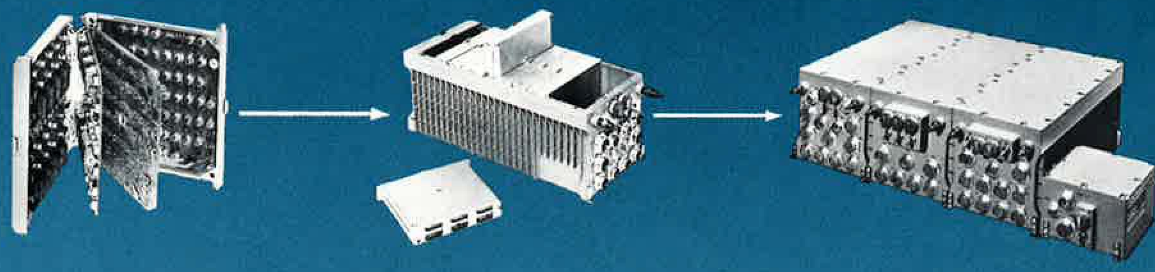
LEM C-Band Radar Transponder (AN/DPN-66) — This general purpose superheterodyne C-band radar transponder was designed by Motorola to the rigid specifications of the Air Force Missile Test Center for use under the severe environmental conditions experienced in long-range missiles. The transponder, located in the LEM, will be utilized for C-band radar tracking in the earlier pre-lunar missions only.

Saturn S-IVB/IU S-Band Transponder — This command and communications transponder is a phase-coherent receiver/transmitter that provides the communications link between the Manned Space Flight Net and Deep Space Net stations and the instrumentation unit of the Saturn V launch vehicle located on the S-IVB third stage. The transponder receives and demodulates command updata for the guidance computer. It transmits PCM mission control measurements to the ground, and it also coherently retransmits the PRN range code received from the ground.

L-Band ODOP Transponder — This offset Doppler transponder is used on the S-IC Saturn booster for ranging and tracking. It represents an advanced design of the Motorola developed high reliability range transponder that performed flawlessly throughout numerous lunar missions. The transponder provides phase-coherent reception and retransmission of an L-band carrier by the transponding ratio of 96/89. The all solid state receiver has a tracking loop bandwidth of 600 cps for maximum stability in the launch environment; carrier threshold sensitivity is −131 dbm. A preselection filter is included to provide suppression of the image frequency response.

Astronaut-Borne Lunar Exploration Antenna — This dual frequency transmission line spiral antenna has been developed for the Apollo space suit communication system. With a pattern equivalent to a short monopole, the antenna has a linear vertical polarization. The VSWR is 1.5:1 at both 260 and 300 Mc. The antenna is potted or foamed in place to prevent vibration and shock and is provided with a protective fiberglass cover, assuring a structure of adequate protection in all Apollo Mission environments.

LEM S-Band Transponder — This transponder provides the Lunar Excursion Module with up link voice, digital commands, and pseudo-random noise (prn) turnaround information; the down-link provides phase-coherent prn ranging, telemetry, voice, emergency keying, television, or biomedical data transmission between the LEM and the earth. The transponder consists of a phase-lock receiver, phase modulator, frequency modulator, and an RF power amplifier plus frequency multiplier chain, all powered by a dc/dc converter. Except for input and output switching, signal processing circuits, and the frequency multiplier, the transponder is redundant, comprised of two receiver/transmitters, either of which may be selected for operation while the other is at standby.



ACE Digital Test Command System

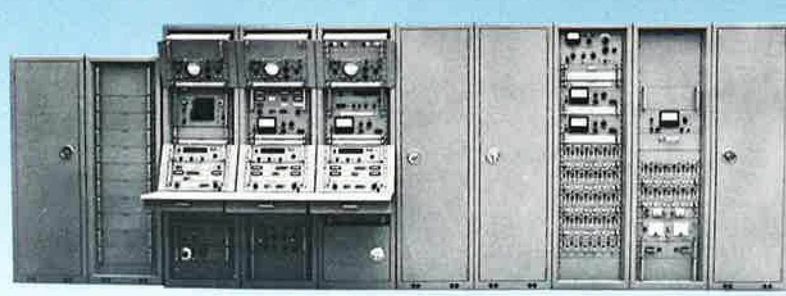
Pseudo Random Noise Ranging Test Set

S-Band FM/PM Test Receivers

Deep Space Net RF Subsystem

FM Modulator/Demodulator

Spacecraft GOSS Integration Test Set



Manned Space Flight Net RF Subsystem

motorola/apollo
ground equipment

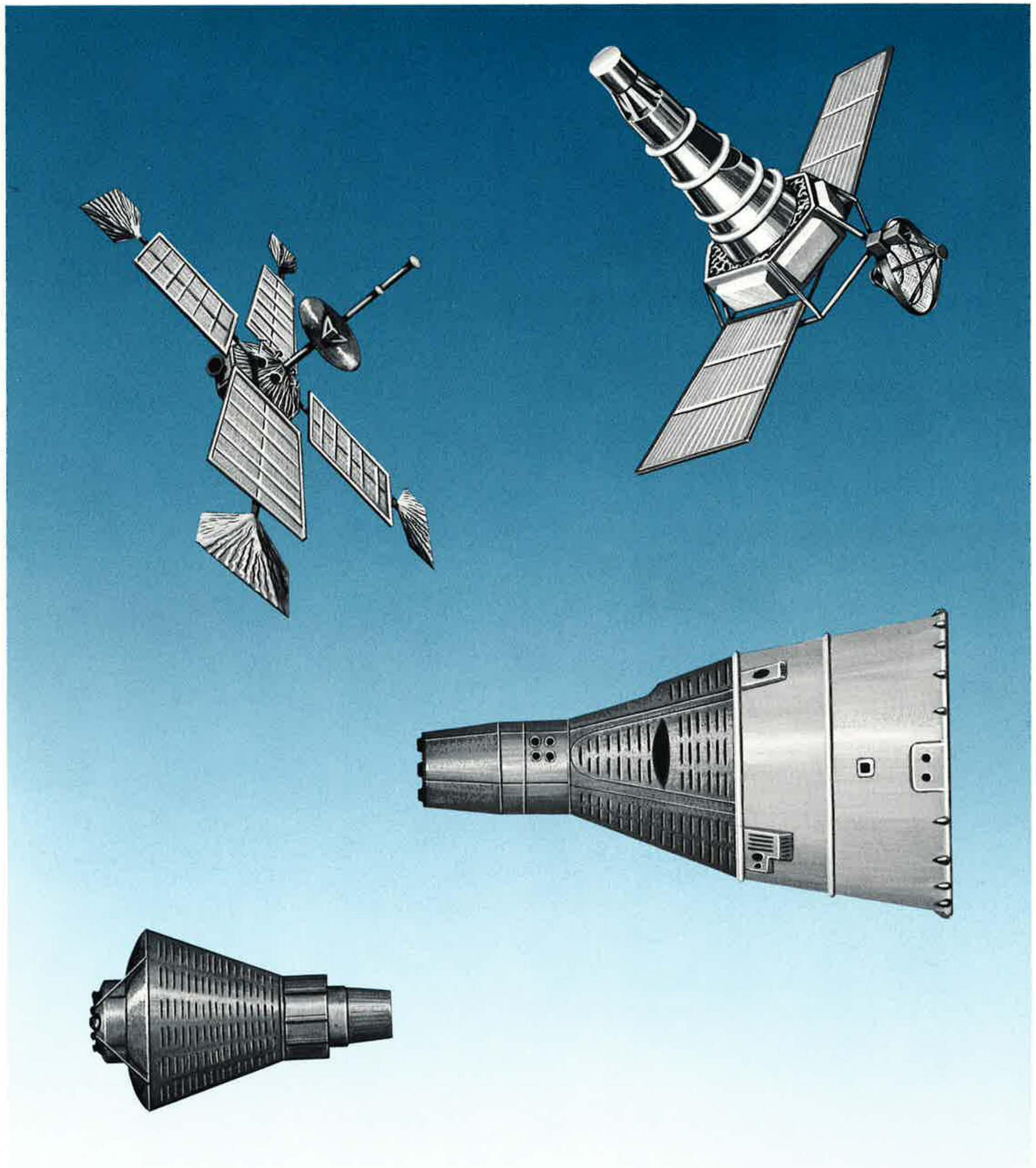
Manned Space Flight Net RF Subsystem *— The MSFN RF S-Band Receiver Exciter Subsystem is the heart of ground based communication system to be used for the Project Apollo Manned Lunar Landing Program. It provides two-way phase coherent precision tracking and communications: it receives telemetry, voice and ranging, and such wideband information as television on S-band frequencies simultaneously; it also transmits command, voice, and ranging to the spacecraft. This capability will accommodate operation with the LEM, the command module, or the Saturn S-IVB booster. The system measures radial velocity and range to the spacecraft. Because of the multi-frequency capability, various antenna configurations, and the low noise amplifiers and receivers, all phases of the Apollo Mission can be supported with the one basic receiving and transmitting subsystem.*

Deep Space Net RF Subsystem *— The DSN RF S-Band Receiver Exciter Subsystem is the earth based portion of a two-way phase-coherent precision tracking and communications system primarily for deep space applications. The system has already been used in the Mariner Venus and Mariner Mars probes in which tracking distances in excess of 175 million miles have been achieved. It will also provide command, telemetry, and position tracking for the Apollo Mission. It measures angle, radial velocity, and range to the spacecraft as well as providing an efficient and reliable two-way communication capability. Further it provides a dual-channel reception capability and can be operated in various configurations of antennas, low noise amplifiers, and receivers for acquisition and tracking and/or listening modes.*

ACE Digital Test Command System *— ACE is the Acceptance Checkout Equipment used at the Cape Kennedy launch site for final compatibility testing of Apollo Spacecraft Systems prior to launch. Motorola is supplying the Digital Test Command System, part of the up link portion that processes digital command messages to produce and channel test stimuli to various spacecraft systems under test. A carry-on system is located on board the command module during the test phase prior to launch; another system is located in the spacecraft test area and connected to the service module; a third system is located at the base test area and provides remote control of various service equipment. Each DTCS is expected to use about 8 000 Motorola MECL integrated circuits, selected for their fast switching rates and reserve margin.*

Other Prelaunch Checkout Equipment *— In addition to the ACE DTCS, Motorola expects to supply prelaunch checkout equipment for a significant portion of the spaceborne equipment delivered for the manned lunar mission. Bench maintenance equipment developed (described below) will be the keystone for design of the final prelaunch test and checkout equipment for the manned flight.*

Development Test and Checkout Equipment *— Motorola has continually supplied bench test and checkout equipment for all its space equipment. The equipment illustrated is only representative of that produced for the Apollo Program.*



motorola space heritage

***Ranger* — *This significant lunar photographic program was an important predecessor to the Apollo mission. Motorola equipment on the Ranger series of probes that impacted the moon included a flight data encoder and an L-band transponder. The encoder is a transistorized time and frequency shared telemetry data multiplexing system used to condition and combine a large number and variety of engineering and scientific measurements for applications to a ratio transmission link. The L-band transponder transmitted spacecraft operational and scientific telemetry information, providing a coherent carrier frequency translation for range rate measurements and receiving earth-to-vehicle commands.*

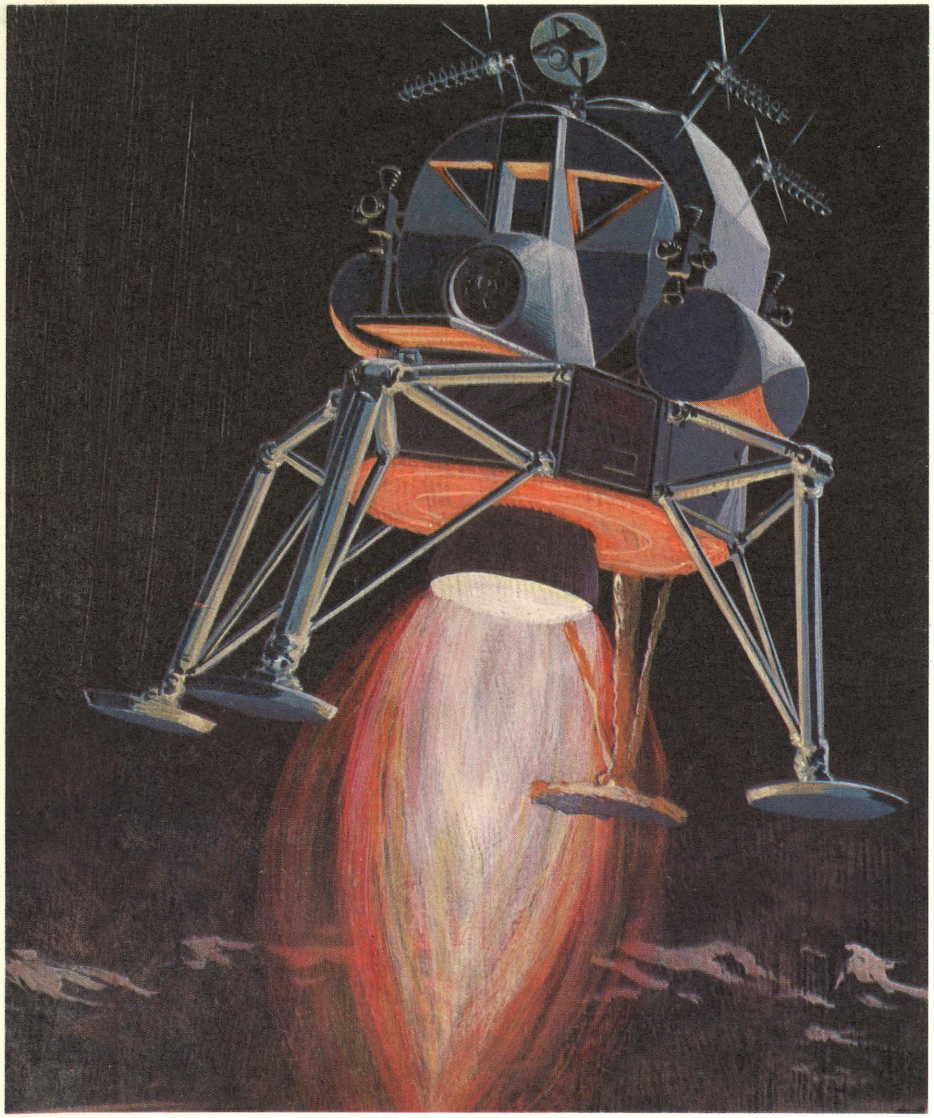
***Mariner* — *The Mariner Venus and Mars probes are a significant stepping-stone to man's conquest of space. Motorola/Mariner equipment included a series of L- and S-band transponders and the vital digital command system. The L-band transponder maintained two-way control over a range in excess of 54 million miles for the Venus probe. The S-band unit provided Mariner II and Mariner IV had a calculated MTBF in excess of 26,000 hours. The digital command system had a measured MTBF of greater than 50,000 hours, and operated successfully for 122 days in space: command functions were used to activate the encounter mode on the Venus probe, then successfully locked and used to reactivate the cruise mode.*

***Gemini* — *For the Gemini two-man orbital flights, Motorola provided the space digital command system that provided up link information for immediate accomplishment of activities, fed to other spacecraft systems, or stored for later use. The Gemini equipment had an MTBF of 16,800 hours; reliability was a crucial requirement, since commands and messages for many functions flowed through the command system.*

***Mercury* — *For the first manned space mission, Motorola provided the command receiver used for remote control functions including: initiation of the escape tower rockets, initiation of retro-rockets for reentry, and capsule clock and instrumentation calibration. The unit contains 20 decoder channels that can be actuated in combination of one to five channels simultaneously.*

BIBLIOGRAPHY

1. *"Apollo Communication and Tracking Equipment Functions,"* **Technical Memorandum ASD-SS-08-64-16,** *p. 4, (1 August 1964).* 2. *"Footprints on the Moon," Hugh L. Dryden, Ph.D.,* **National Geographic,** *Vol. 125, No. 3, p. 357 (March 1964).* 3. *"Saturn V Apollo LOR Mode Typical Mission Profile,"* **Marshall Space Flight Center Drawing E-R 500f** *(December 15, 1964).* 4. *"Apollo Program,"* **MSFC Fact Sheet 292** *(June 1965).* 5. **Hearings Before the Subcommittee on Manned Space Flight of the Committee on Science and Astronautics,** *U.S. House of Representatives, 89th Congress, Part 2, Figure 60 (facing page 63), U.S. Government Printing Office, Washington, D. C. (1965).*



motorola

and the apollo mission

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