J. Dickinson

News Reference

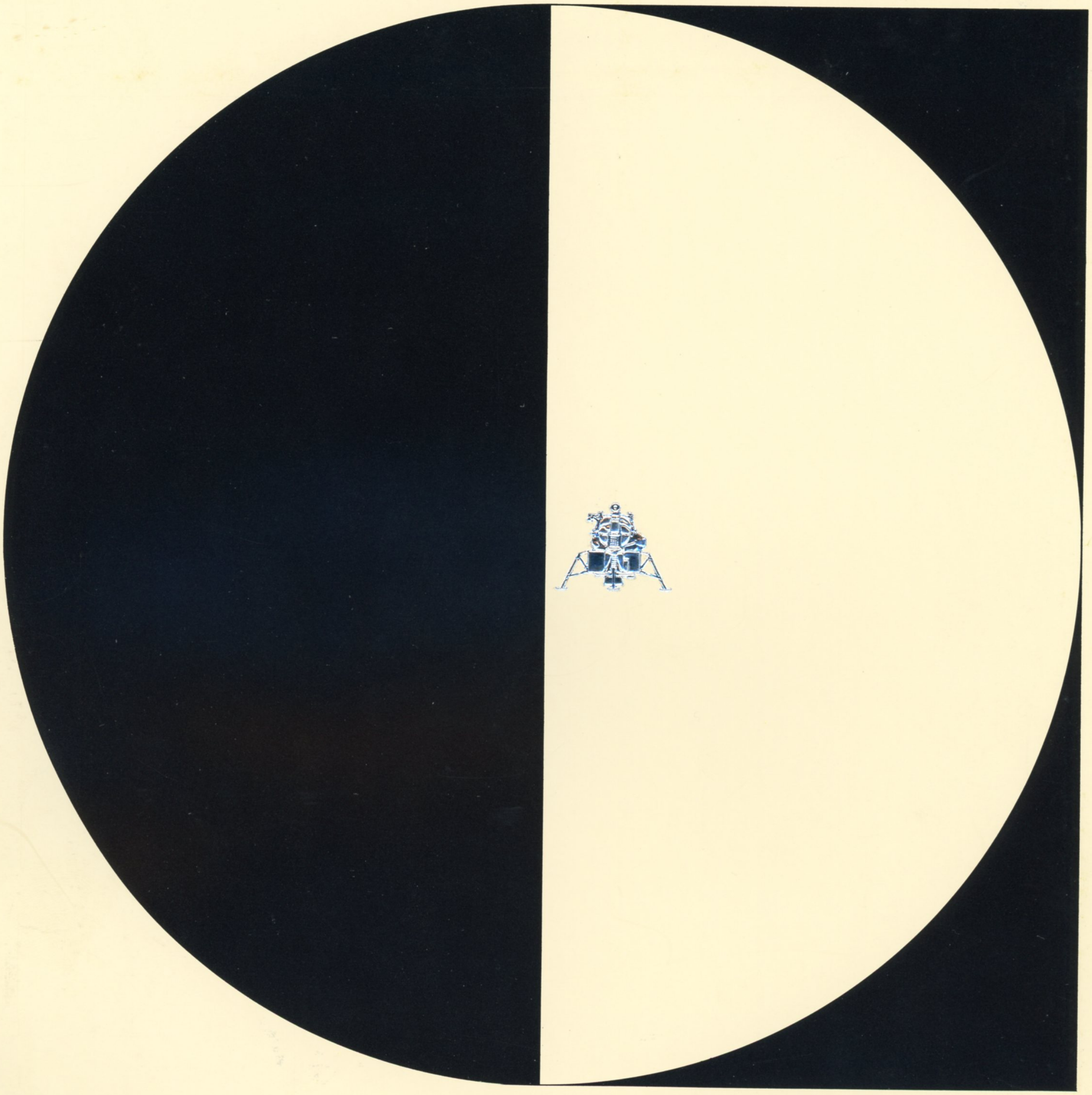
APOLLO 11

RYAN LUNAR LANDING RADAR

News Releases
News Photos
System Description

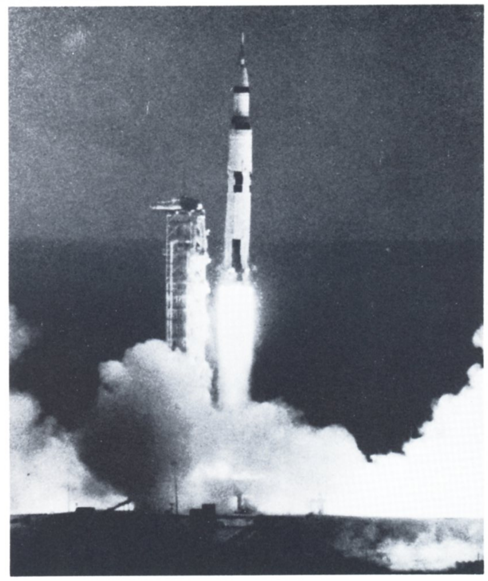
RYAN

RYAN AERONAUTICAL COMPANY ■ LINDBERGH FIELD ■ SAN DIEGO, CALIFORNIA 92112



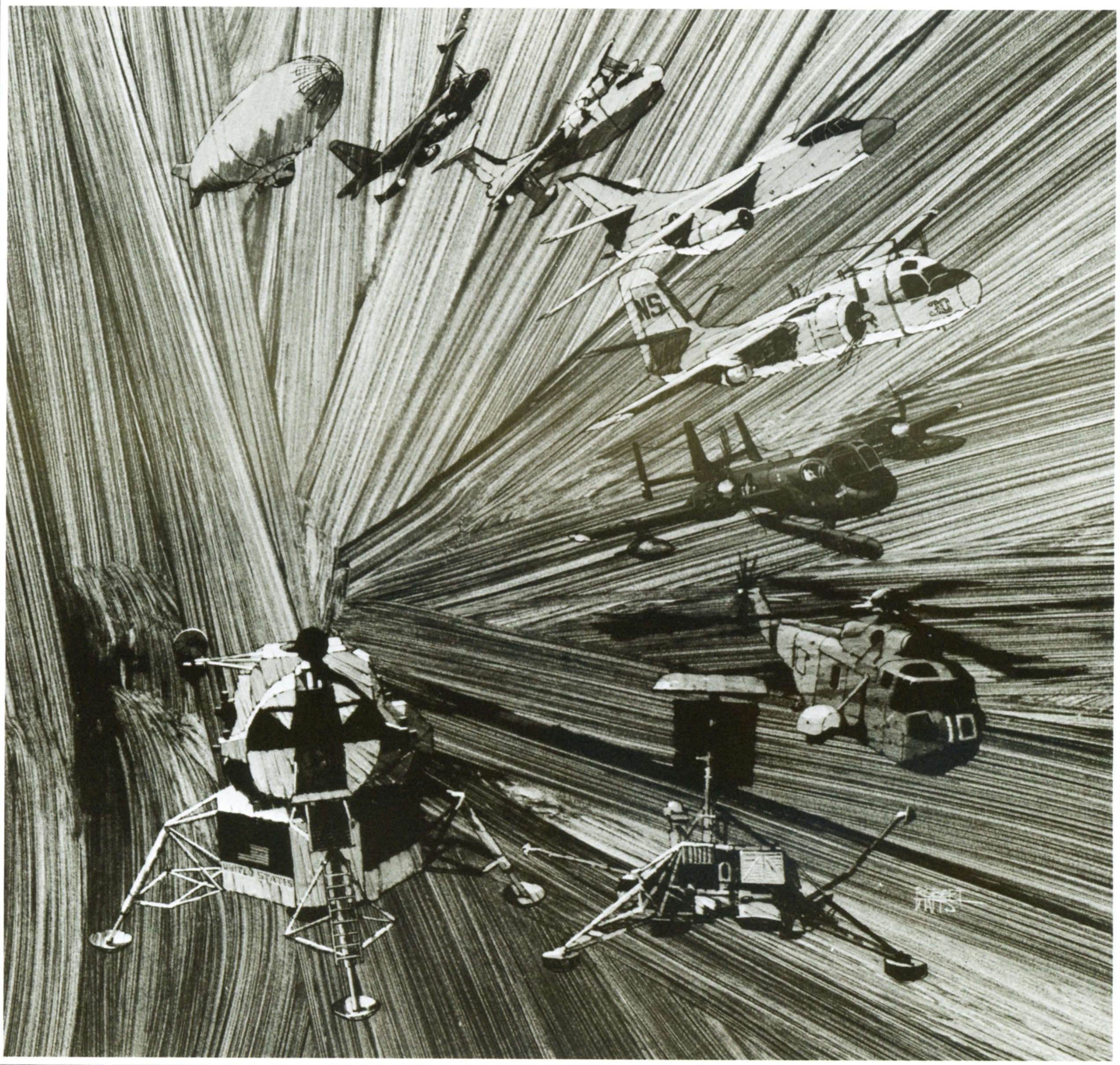
DESCRIPTION OF THE LANDING RADAR FOR THE APOLLO LUNAR MODULE

RYAN AERONAUTICAL COMPANY



CONTENTS

Ryan's Evolving Family of Doppler Navigation Systems. Representative aircraft and systems, from upper left: ZPG-2W Blimp, with AN/APN-125; Lockheed P2V Neptune, with AN/APN-122; Martin P5M Marlin, with AN/APN-122; Douglas A3D Skywarrior, with AN/APN-122; Grumman S2F Tracker, with AN/APN-122; Grumman AO1 Mohawk, with AN/APN-129; Sikorsky SH-3A and SH-3D with AN/APN-130 and AN/APN-182; Hughes Surveyor, with RADVS; Grumman Apollo Lunar Module, with Lunar Landing Radar.



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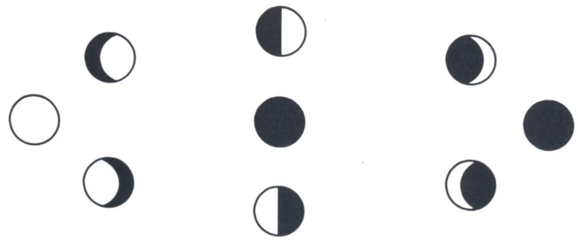

INTRODUCTION

The landing radar for the Apollo Lunar Module is an advanced version of the Radar Altimeter and Doppler Velocity Sensor (RADVS) used on the Surveyor Program. It employs the same principles and proven techniques that the Ryan Aeronautical Company has used for more than 15 years in its evolving family of Doppler navigators and altimeters.

The LM landing radar provides continuous measurement of the LM altitude and velocity relative to the lunar surface, during the descent and landing. This information is integrated with the other LM sensors, computers and control systems to produce a soft, safe landing on the lunar surface. Once landed, the function of the radar has been completed; it remains on the lunar surface as part of the LM descent stage.

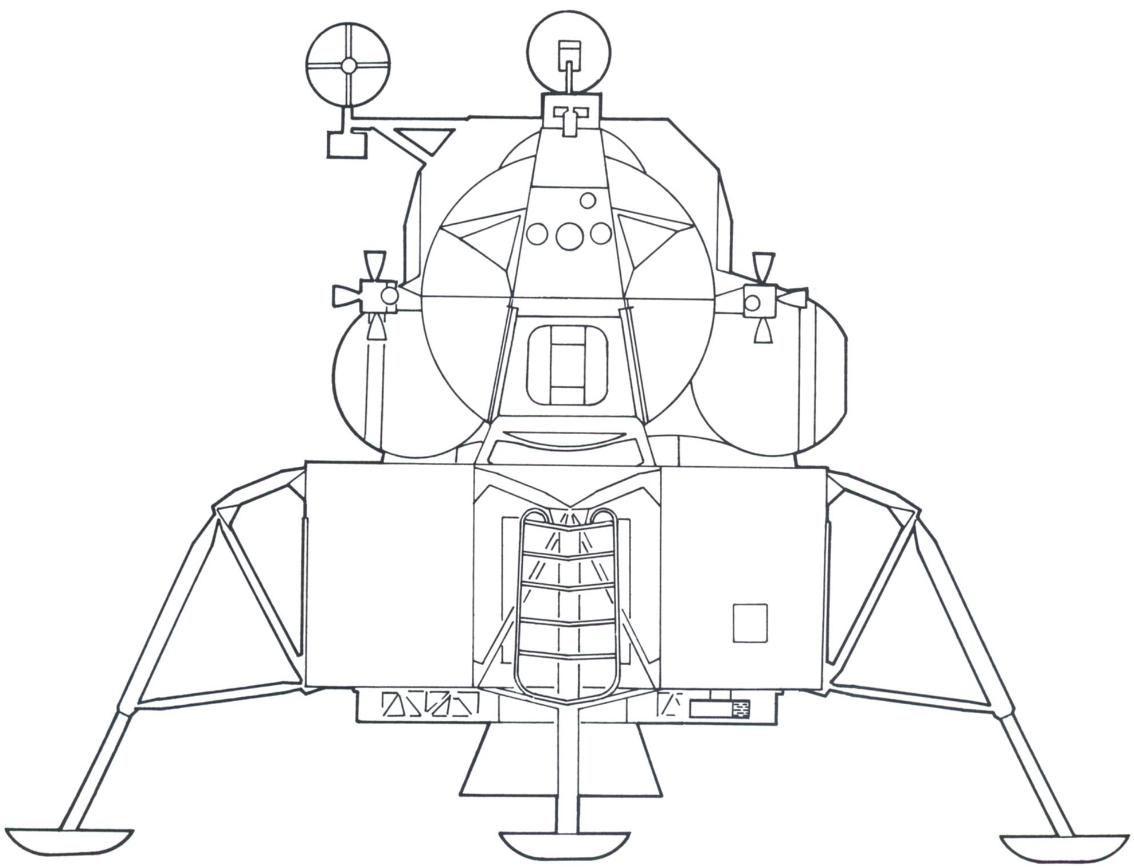

FIGURE 1 LUNAR MODULE

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THE MISSION

A simplified representation of the Apollo Mission is given in Figure 2. Illustrated are the earth launch; injection into earth orbit; injection into translunar flight; injection into lunar orbit and the descent to the lunar surface. After the exploration of the surface by the astronauts, a subsequent launch of the LM ascent stage from the lunar surface and injection into lunar orbit is depicted. This is followed by rendezvous with the Command and Service Module, and the return to Earth.

Since the landing radar is used only during the lunar descent, just this portion of the total mission will be treated.

OPERATIONAL DESCRIPTION

The function of the landing radar is to make continuous, accurate measurement of the velocity of the LM and the range to the lunar surface. Orthogonal components of velocity are provided in an antenna coordinate system for use by the astronauts and the LM Guidance Computer (LGC).

TYPICAL LUNAR DESCENT

A typical descent trajectory is depicted in Figure 3.

Powered descent begins with engine turn-on at the pericynthion of the LM orbit, nominally at 50,000 feet altitude and about 5500 fps velocity. The landing radar is turned on about this time. Range acquisition occurs at about 35,000 feet. The velocity sensor acquires at a nominal altitude of 18,500 feet. Velocity at this time is approximately 1200 fps. Attitude, altitude, and velocity details on a typical descent are given in Table 1, "Typical Descent Profile."

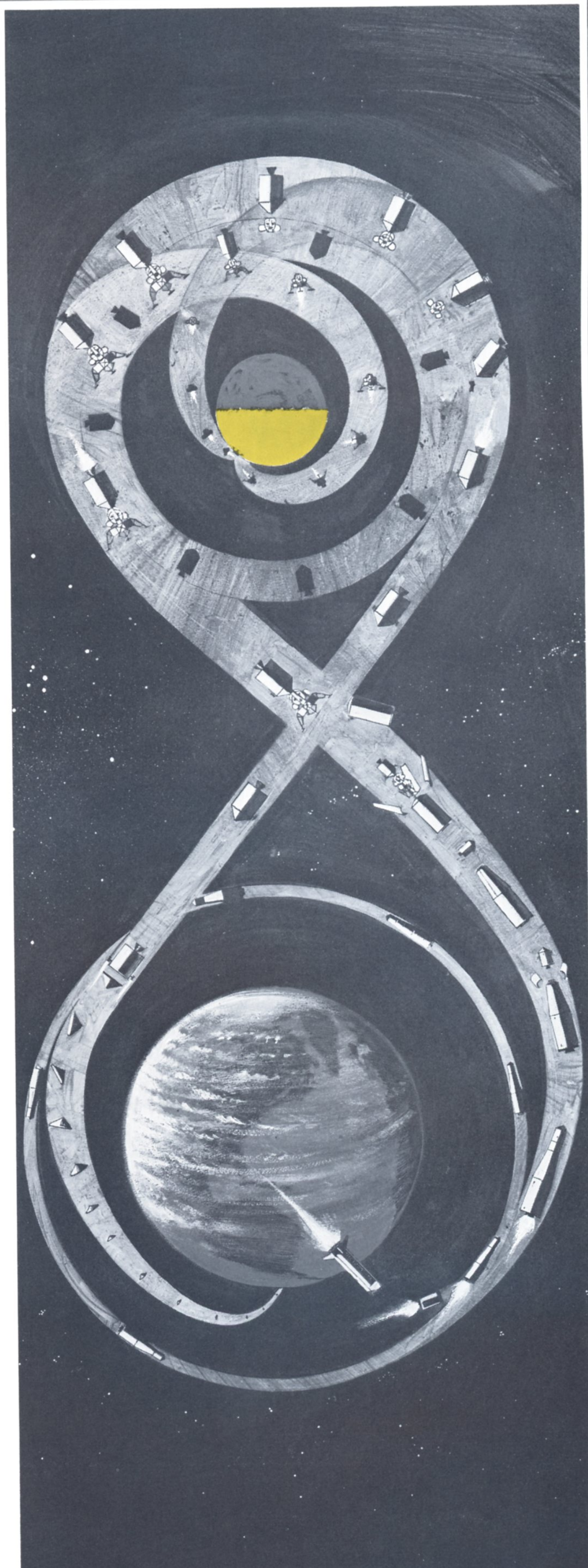

FIGURE 2 REPRESENTATION OF APOLLO MISSION

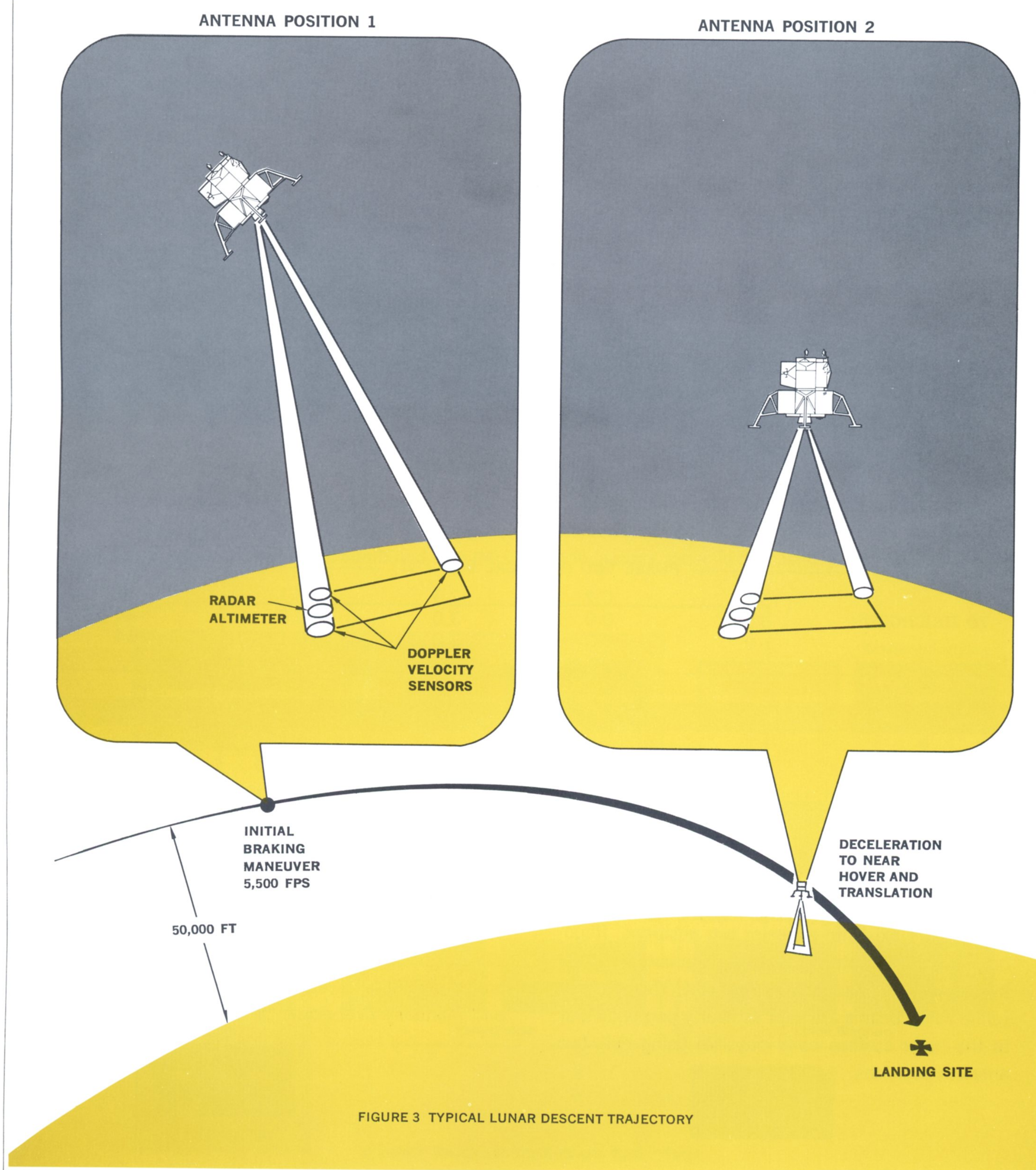

FIGURE 3 TYPICAL LUNAR DESCENT TRAJECTORY

TABLE I / TYPICAL DESCENT PROFILE

	TIME TO GO	HORIZONTAL VELOCITY	VERTICAL VELOCITY	LOCAL PITCH	ALTITUDE
	SECONDS	FPS	FPS	DEGREES FROM VERTICAL	FEET
PHASE ZERO					
TO VERTICAL DESCENT ↓	330	2329	119	71.8	25,900
	309	2066	119	71.2	23,500
	290	1797	116	69.6	21,200
	274	1523	103	67.1	19,000
	243	1069	84.1	60.5	15,600
	227	949	93.0	57.5	14,200
	203	780	99.1	53.0	11,900
	184	651	98.4	49.3	9,900
	164	532	93.5	45.5	7,980
PHASE ONE					
	154	499	91.3	44.4	7,420
	145	449	90.8	42.5	6,510
	122	353	83.7	38.6	4,750
	102	265	70.5	34.7	3,200
	82	187	54.0	30.7	1,950
	62	120	36.5	26.5	1,050
	42	65.7	20.7	21.5	483
	22	26.3	8.9	15.6	196
	17	17.6	6.5	13.5	150
	7	6.4	3.8	9.8	100
	3	3.1	3.2	8.5	86
	1	1.6	3.0	8.0	80
PHASE TWO (VERTICAL DESCENT)					
TO TOUCHDOWN ↓	20	0.2	2.9	7.1	74
	10	0.0	3.0	0.8	44
	0	0.0	3.0	0.1	14
TOUCHDOWN					

It can be seen that, since a large variation in vehicle attitude occurs, action must be taken to keep the landing radar beams aimed at the lunar surface. This is accomplished by a positioning pedestal which can rotate the antenna assembly of the landing radar about the Y axis into either of two positions. Repositioning of the antenna may be done automatically by the LGC, or manually by the pilot. Thus the antenna radar beams are kept as nearly perpendicular to the lunar surface as is possible using only two antenna positions.

Upon descending to an altitude of between 500 to 100 feet, the descent rate of the LM is slowed to a near hover. The spacecraft slowdown allows for pilot assessment of the landing site and, if desired, permits a manually controlled translational maneuver to a more preferred spot. The complete lunar descent can be automatically controlled by the LGC and the auxiliary systems or it may be interrupted and manually over-ridden at any time.

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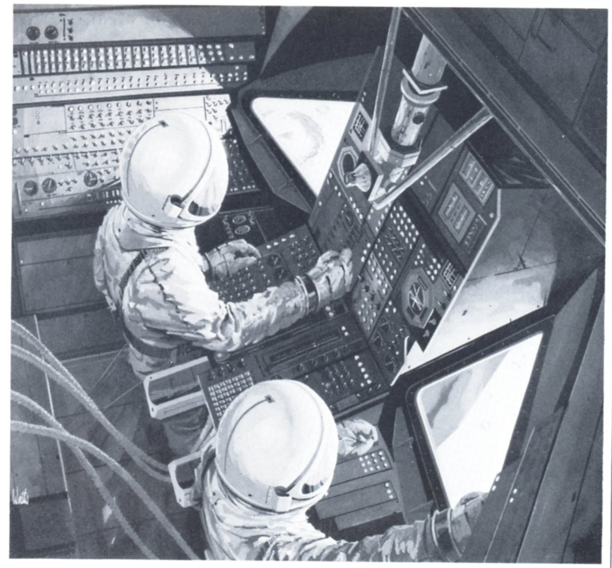
THE LANDING RADAR

LANDING RADAR INTEGRATION INTO THE LM SYSTEM



Integration and function of the landing radar with other LM subsystems is shown in simple form in Figure 4. The measured outputs of velocity and range are provided to the digital computer in the Navigation and Guidance System and also to the displays and controls in the cockpit. Additional status and condition signals are provided which are discussed in the section entitled "Pilot Displays and Controls" and the functional description paragraphs.

Another subsystem, called the Inertial Measuring Unit (IMU) also provides velocity and altitude inputs to the LGC and the pilot's displays. The IMU has attitude-sensing gyros and velocity-sensing accelerometers.

The landing radar provides the first direct contact with the lunar surface, sensing range and velocity relative to the surface. Its data is combined with IMU data with variable weighting, programmed so as to result in the best accuracy. Errors in IMU data tend to increase with time. Landing radar errors, on the other hand, are determined primarily by velocity and altitude, tending to decrease as velocity and altitude decrease. Therefore, weighting of radar data in the LGC is initially low and increases as the descent progresses.

As radar data begins to be used, it acts to cancel the effects of the accumulated errors in the IMU; the landing radar is thus said to "update" the IMU.

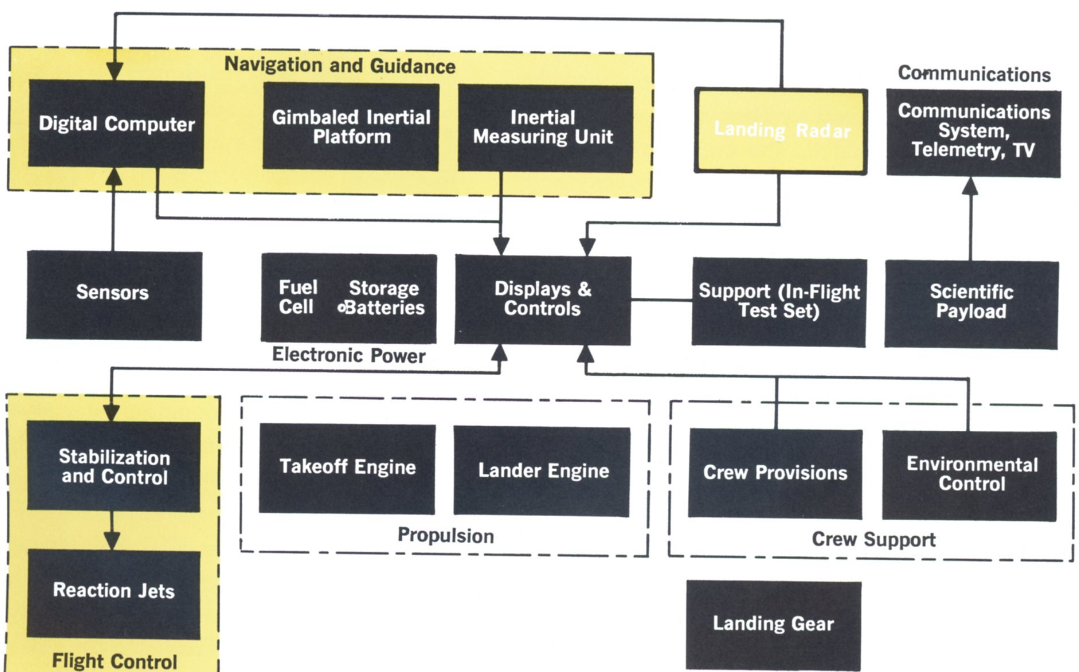
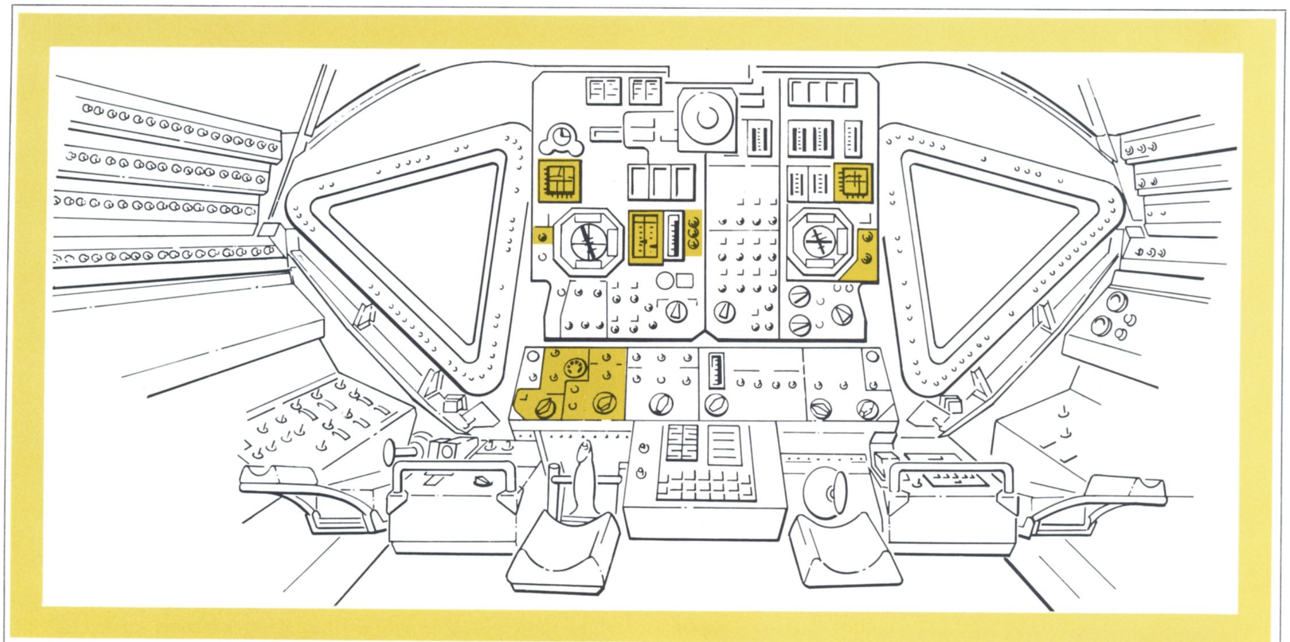


FIGURE 4 MAJOR LM SYSTEMS AND SUBSYSTEMS

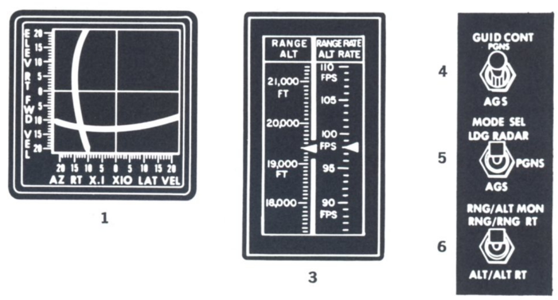


PILOT DISPLAYS AND CONTROLS

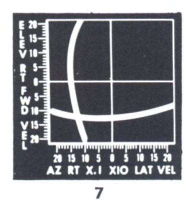
Figure 5 depicts the cockpit controls and displays for both the LM commander and systems engineer. The controls and displays which relate to the landing radar are identified by differential shading. The displays and controls for the landing radar and the rendezvous radar have been combined to reduce weight and panel space.

The landing radar is turned "on" or "off" by the use of the circuit breaker located to the left of the command pilot's head. The forward, lateral and vertical velocities and altitude are read out visually by the commander and systems engineer on the instruments as indicated. The cross pointers provide indication of forward and lateral velocity and the tape displays provide indication of range and vertical velocity. These same instruments may alternately be used to read the rendezvous radar outputs of elevation, azimuth and range rates and range, respectively, when the radar mode selecting switch is moved from the Landing Radar Position to the Rendezvous Radar Position.

A separate radar test panel is also shown in Figure 5. This panel provides a means of operationally testing the landing radar, or alternatively, the rendezvous radar. To test the landing radar transmitted microwave power, the switch must be placed in the Landing Radar Position and the test monitor switch used to select either the velocity sensor transmitter



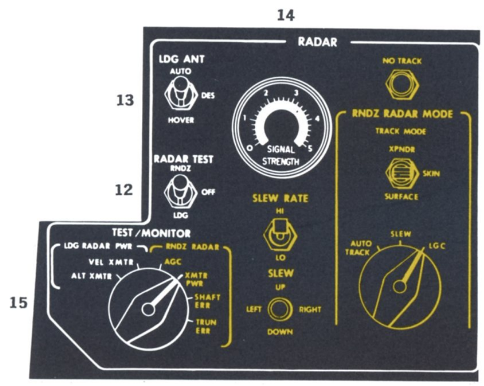
COMMANDER
1. LOS RATE, HORIZONTAL VELOCITY INDICATOR
2. LANDING RADAR/LGC RATE/ERROR MONITOR
3. ALTITUDE RANGE INDICATOR
4. GUIDANCE CONTOL SWITCH
5. MODE SELECTION SWITCH
6. ALTITUDE/RANGE MONITOR SWITCH



SYSTEMS ENGINEER
7. LOS RATE, HORIZONTAL VELOCITY INDICATOR
8. LANDING RADAR/LGC RATE/ERROR MONITOR
9. ATTITUDE MONITOR SWITCH

10. LANDING RADAR HEATER
11. LANDING RADAR ON/OFF

FIGURE 5 COCKPIT CONTROLS AND DISPLAYS



12. RADAR TEST SWITCH
13. LANDING ANTENNA SWITCH
14. SIGNAL STRENGTH METER
15. TEST/MONITOR SWITCH

or the altimeter transmitter. Indication of transmitter power is provided by the signal strength meter. Placing the radar test switch in the Landing Radar Position injects simulated velocity and altitude signals into the landing radar. These signals correspond to the specific velocities and ranges as described in Table 1.

Tests of the landing radar positioning pedestal are accomplished by placing the selector switch in either the descent or hover position. The actual position of the antenna is available to the pilot by interrogation of the LM Guidance Computer. For normal operation and descent, this landing antenna switch is placed in the auto position.

FUNCTIONAL DESCRIPTION

The landing radar accurately measures the velocity and range of the spacecraft relative to the lunar surface by means of a three beam Doppler velocity sensor and a single beam altimeter. The measured velocity and range information is processed and made available to the LGC in a serial binary form. It is also provided to the pilot's displays in the form of pulse trains and dc analog voltages which are then converted to the visual displays described in the preceding paragraph. A simplified functional block diagram of the landing radar is provided in Figure 6. An abbreviated Table of Characteristics is given in Table 2.

The landing radar is composed of two assemblies, the antenna assembly and the electronic assembly. (These are depicted by the large shaded areas on Figure 6.) The antenna assembly contains the three beam continuous wave (CW) velocity sensor, receiver and transmitter. It also contains the single beam frequency modulated continuous wave (FM/CW) altimeter receiver and transmitter. The velocity sensor and altimeter beam geometry is illustrated in Figure 7. The beam angles remain fixed in the antenna coordinates but rotate during the tilt maneuver with respect to the LM coordinate system. The transformation from antenna to spacecraft coordinates is performed in the LGC.

The landing radar measures the Doppler shifts along the three velocity beams and the range along the altimeter beam. Then, by appropriate coordinate transformation, the desired velocities and range in antenna coordinates are obtained. Equation (1) illustrates this typical operation for velocity along the antenna axis (V_{xa}).

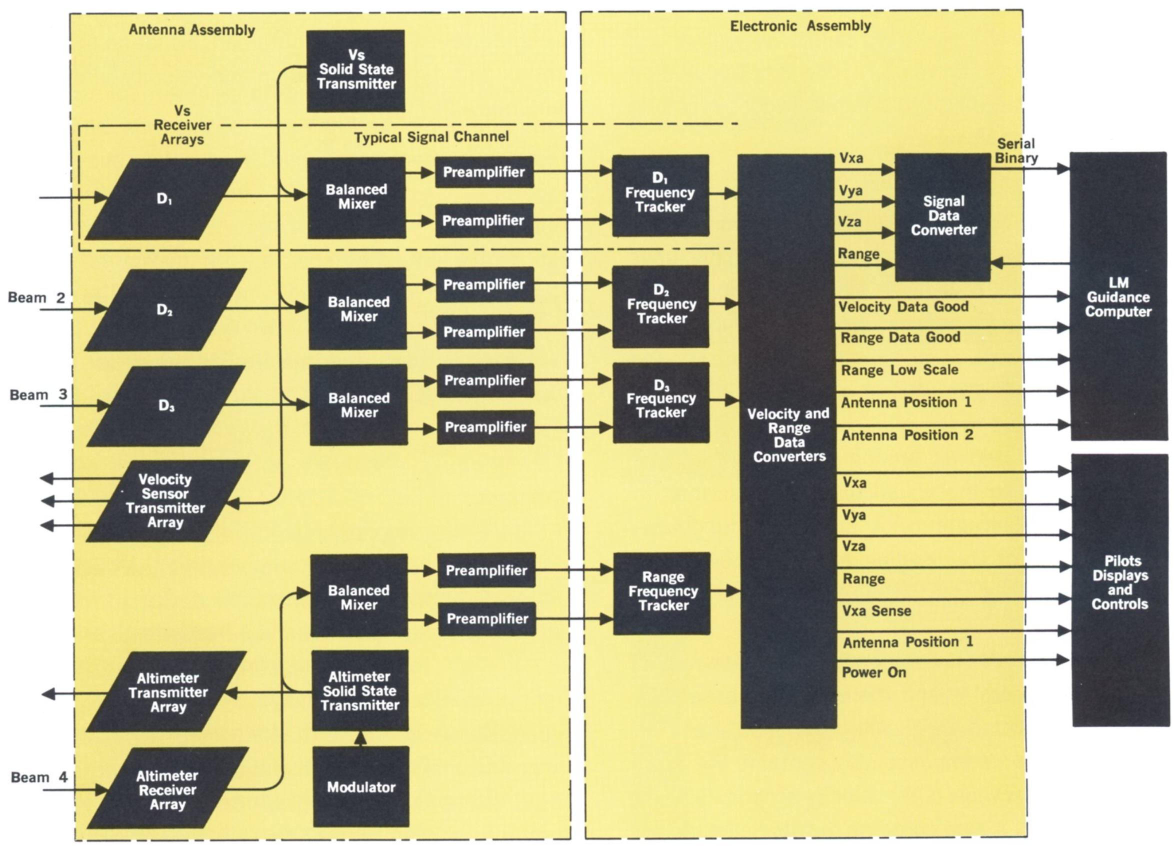
$$(1) \qquad V_{xa} = - \frac{\lambda}{2 \cos \Lambda \cos \xi} \quad \frac{(D_1 + D_3)}{2}$$

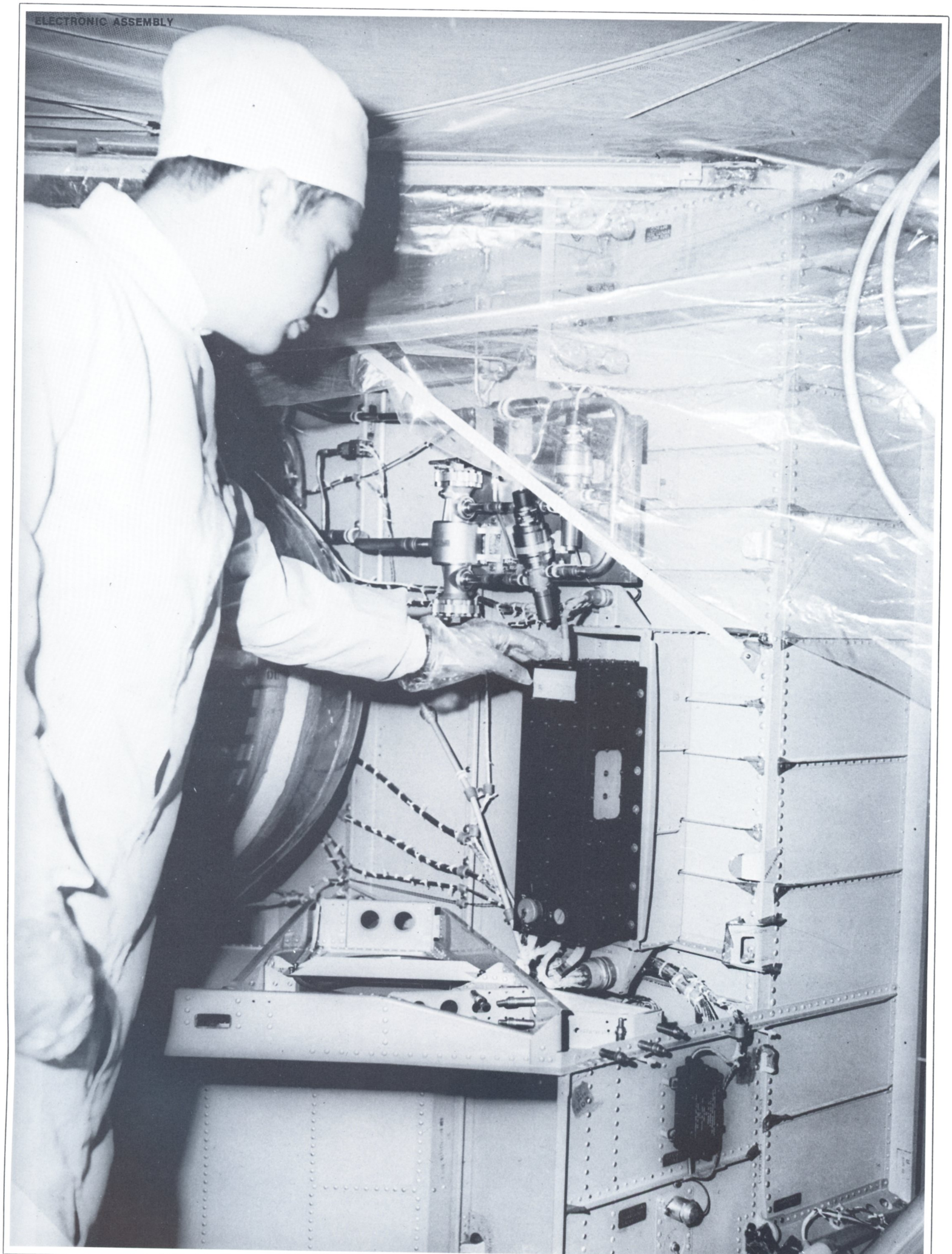
Range is measured in a similar manner as shown in Equation (2).

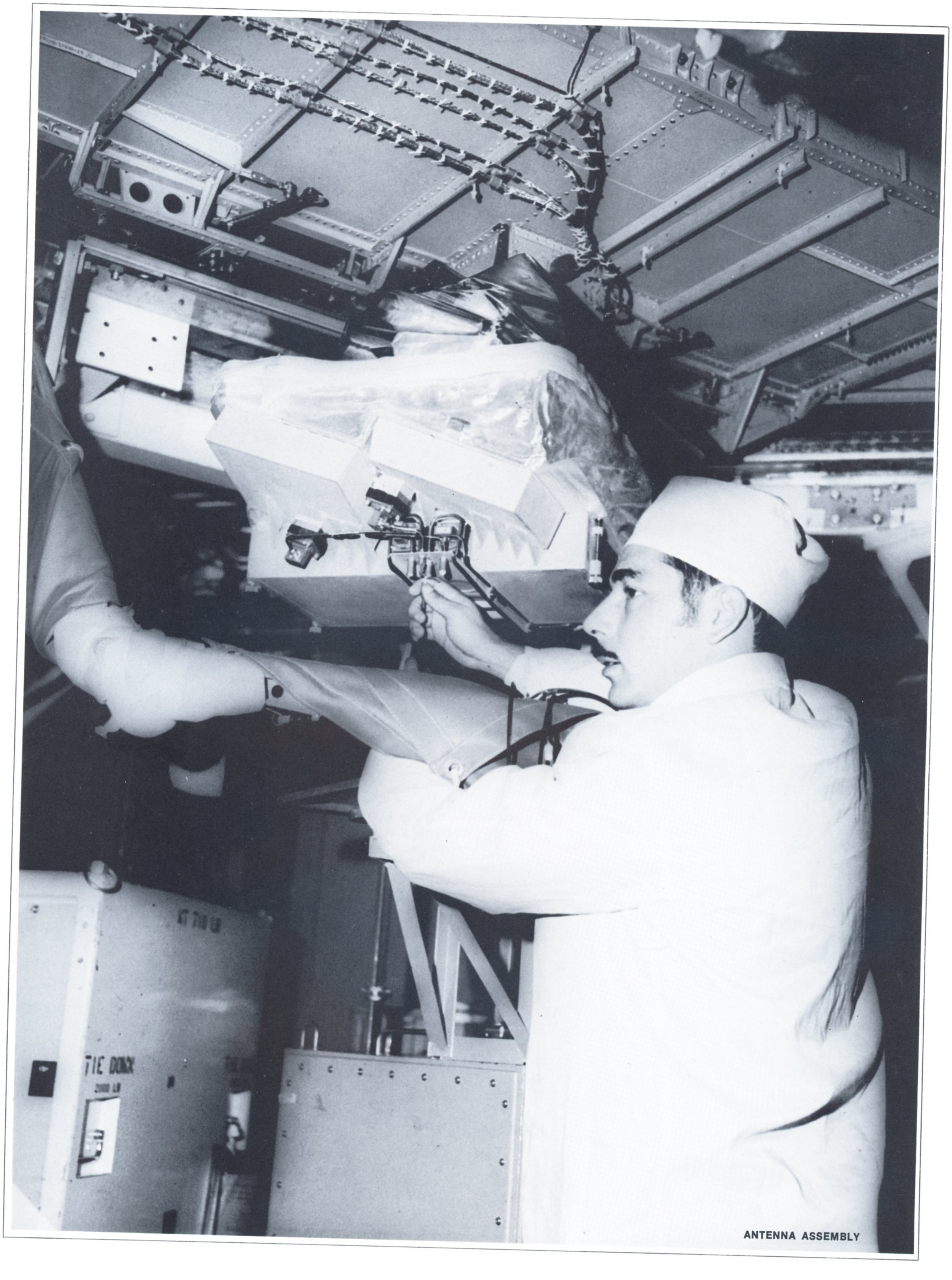
$$(2) \qquad R = \frac{c}{2S} \quad [f_a - K(D_1 + D_2)]$$

Where:

- R = range to lunar surface
- c = electromagnetic propagation velocity
- S = altimeter transmitter deviation rate
- f_a = altimeter received frequency, including range and Doppler components
- K = scaling constant
- D_1 = Doppler shift along beam 1
- D_2 = Doppler shift along beam 2
- D_3 = Doppler shift along beam 3
- λ = electromagnetic radiation wavelength
- Λ = antenna beam angle
- ξ = antenna beam angle


Antenna Assembly
Electronic Assembly
Vs Solid State Transmitter
Vs Receiver Arrays
Typical Signal Channel
D1
Balanced Mixer
Preamplifier
Preamplifier
D1 Frequency Tracker
Beam 2
D2
Balanced Mixer
Preamplifier
Preamplifier
D2 Frequency Tracker
Beam 3
D3
Balanced Mixer
Preamplifier
Preamplifier
D3 Frequency Tracker
Velocity Sensor Transmitter Array
Balanced Mixer
Preamplifier
Preamplifier
Range Frequency Tracker
Altimeter Transmitter Array
Altimeter Solid State Transmitter
Beam 4
Altimeter Receiver Array
Modulator
Velocity and Range Data Converters
Vxa
Vya
Vza
Range
Signal Data Converter
Serial Binary
LM Guidance Computer
Velocity Data Good
Range Data Good
Range Low Scale
Antenna Position 1
Antenna Position 2
Vxa
Vya
Vza
Range
Vxa Sense
Antenna Position 1
Power On
Pilots Displays and Controls


ELECTRONIC ASSEMBLY



ANTENNA ASSEMBLY

PRINCIPLES OF OPERATION

The basic principles of operation of the velocity sensor are illustrated in the single channel of signal processing associated with beam 1 on Figure 7. The received energy is shown incident on the velocity sensor receiving array (D 1). This received energy is mixed immediately with a portion of the transmitter energy. This process of direct radio frequency to audio frequency conversion produces Doppler frequencies proportional to the component of total spacecraft velocity along that beam. In order to determine whether the velocity is increasing or decreasing along that beam, the radar divides each Doppler signal in quadrature pairs. A subsequent recombination of the quadrature pair and signal sideband comparison yields velocity sense.

The quadrature outputs of this beam are applied to audio preamplifiers which in turn provide the amplified signals to the frequency trackers in the electronic assembly.

The frequency trackers are designed to search for the Doppler signals within a specific expected range of frequencies. The initial sweep search period is nominally six seconds. A narrow band tracking filter is used to select the true signal from the noise background.

Once acquired, the Doppler signal is tracked with a high order of accuracy. The tracker then provides an output frequency corresponding to the frequency at the center of power of the received Doppler signal spectrum.

Each beam tracker provides this Doppler signal to the velocity and range data converters along with a dc step voltage to indicate acquisition and authentication of a true lunar return signal.

The converter then provides the indicated coordinate transformation and data form conversion.

The measurement of range is accomplished in an analogous manner, the only difference being that some compensation for the Doppler shift along the range beam is required. This is provided quite simply in the velocity and range data converters by subtracting an appropriately scaled velocity or Doppler shift obtained by summing the Dopplers along beams 1 and 2.

The measured range and the velocities are finally held ready in the signal data converter of the landing radar for readout when interrogated by the LGC. The LGC reads out the velocity and range data one at a time in a cyclic manner. The readout or sampling time is nominally 80 milliseconds. Radar status signals are sent to the LGC and the pilot displays. These include indications of range data good, velocity data good, antenna position and range scale factor. The change in range scale factor is made at 2500 feet.

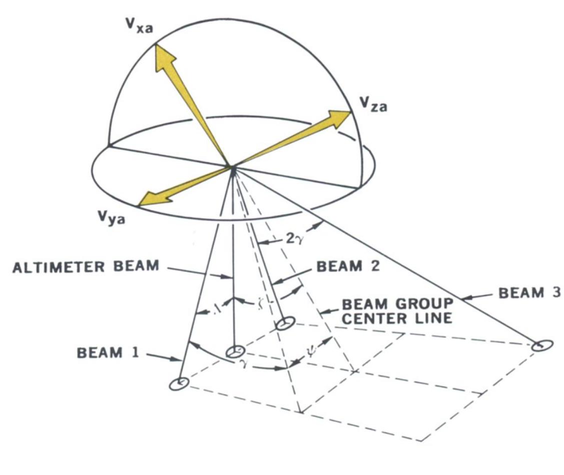


FIGURE 7 LM RADAR ANTENNA BEAM GEOMETRY

PHYSICAL DESCRIPTION

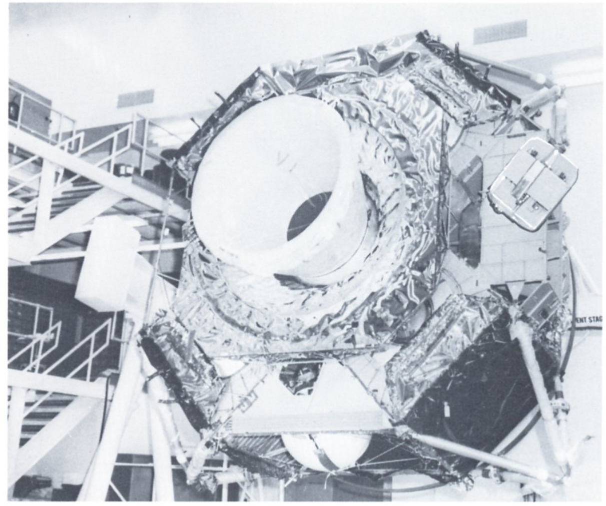
The landing radar is composed of two assemblies as shown in the following photographs. The antenna assembly is located external to the descent stage on the underside of the spacecraft adjacent to the retro-rocket skirts. It is capable of being positioned upon command in either of two positions as depicted in Figure 4. Thermal finishes and protective coatings are applied to the antenna assembly to control temperature during all phases of the Apollo mission. Vacuum deposited aluminum is used in conjunction with selected thermal paint patterns to carefully control the ratio of thermal energy absorptance to emittance.

The antenna assembly contains a three beam, continuous wave velocity sensor receiver-transmitter and a single beam, frequency modulated continuous wave altimeter receiver-transmitter. The transmitting and receiving antennas are planar arrays. The velocity sensor and altimeter transmitting arrays are mechanically interlaced into a common aperture. The beam angles are fixed in the antenna coordinate system.

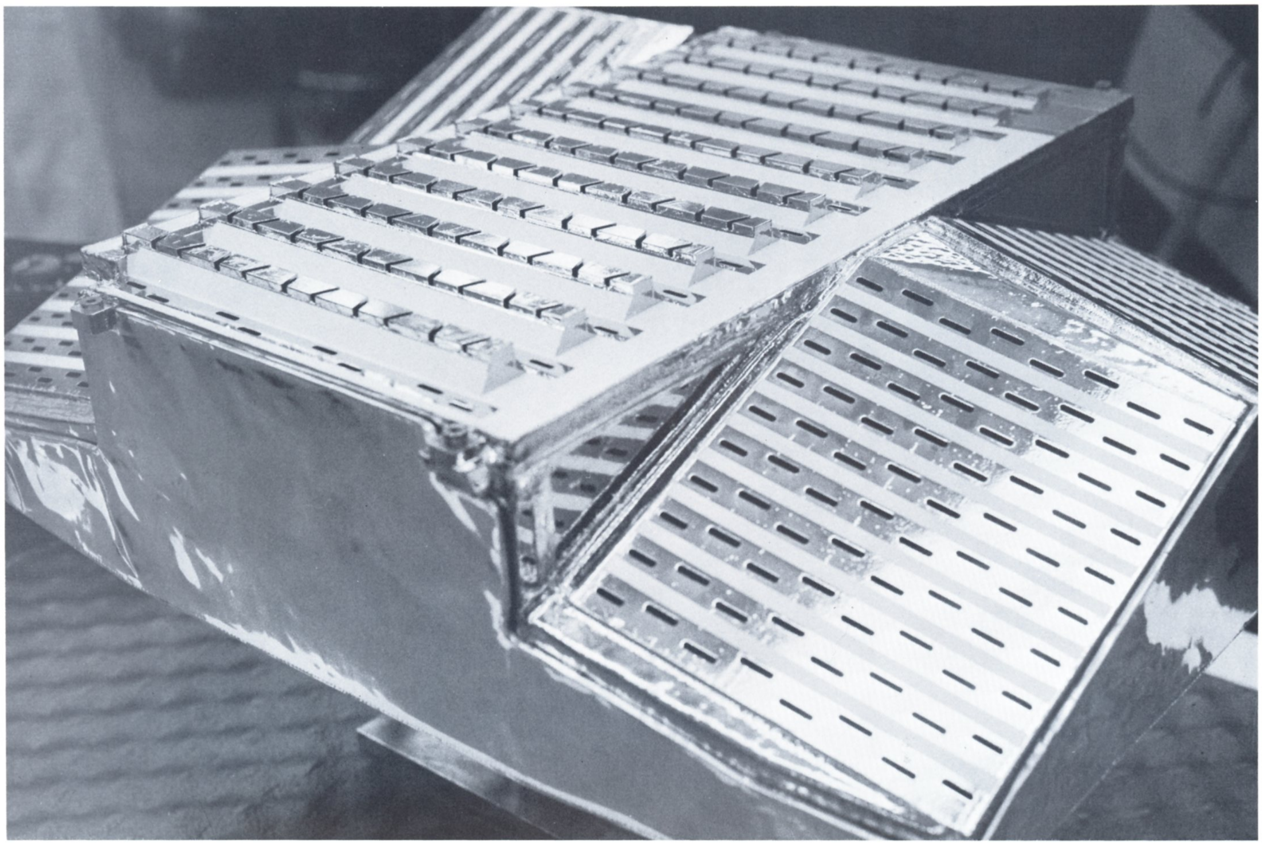
The electronic assembly is mounted within the descent stage and, as such, is exposed to a less severe thermal environment than the antenna assembly.

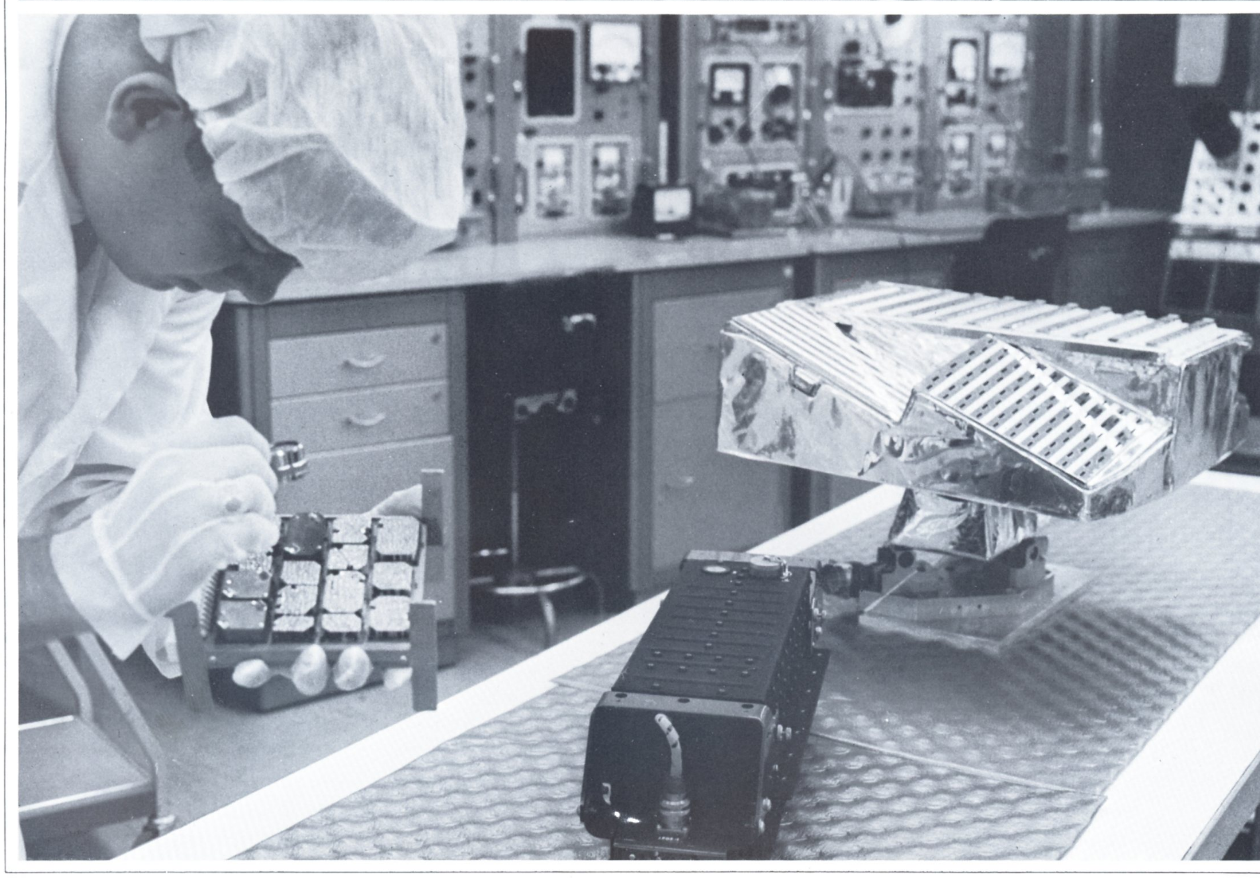
SPECIAL FEATURES

The following are among the special features designed into the landing radar to enhance its capabilities:



Lunar Module Landing Radar: the magnesium planar array antennas, thermally coated with vacuum deposited aluminum, fixed in a honeycomb fiberglass shell, which in turn, is faced with thin aluminum foil; and the electronic assembly, a magnesium case sprayed with black epoxy, the densely packaged electronic components within.





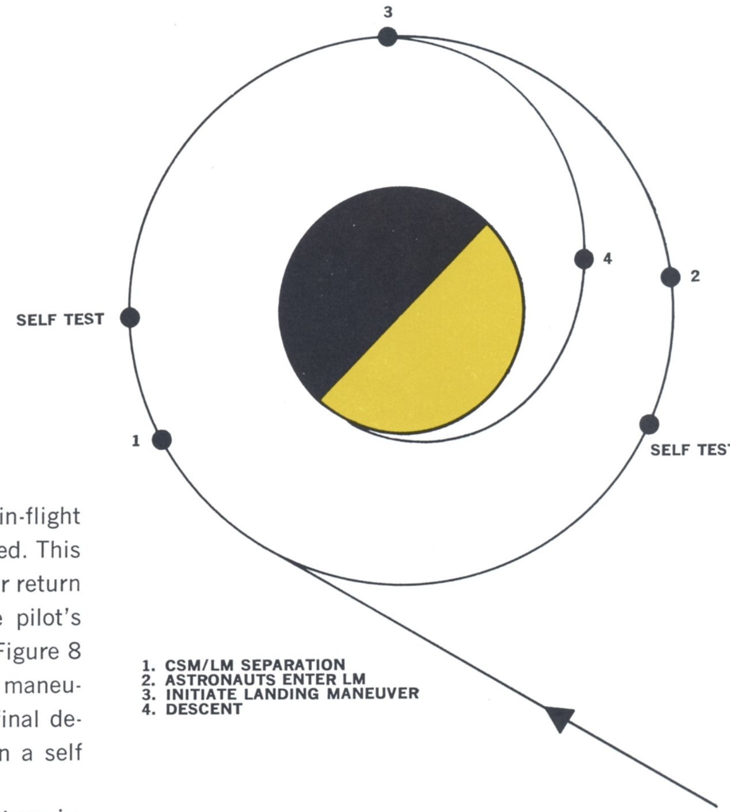


FIGURE 8. TYPICAL LUNAR DESCENT, RADAR SELF TESTS

BUILT IN SELF TEST The ability to perform in-flight landing radar self tests has been incorporated. This test can be performed without an actual lunar return signal. The control for this test is on the pilot's control panel and is initiated at his option. Figure 8 depicts the expected lunar orbit and descent maneuver. It indicates two typical times prior to final descent when the landing radar may be given a self test.

The implementation of the self test feature involves the generation of a test frequency within the electronic assembly and the injection of this frequency into the preamplifiers. The landing radar then operates as though this were a valid signal. It produces normal outputs to the LGC and to the pilot's displays. For a satisfactory self test, these indications must be within a specific tolerance of a predetermined fixed velocity and range. These self test values are given in Table 2.

THERMAL CONTROL Figure 9 depicts the location of the landing radar assemblies on the LM. The electronic assembly is located inside the descent stage, while the antenna assembly is mounted externally on the underside of the descent stage. No auxiliary cooling or heat sinks are provided to either unit. During the descent and braking maneuvers, the antenna assembly is also exposed to re-radiation from the lunar surface and radiation from the engine skirt and exhaust plume. The landing radar design is such as to maintain all parts (resistors, transistors, etc.) temperatures within a specific range during the full mission.

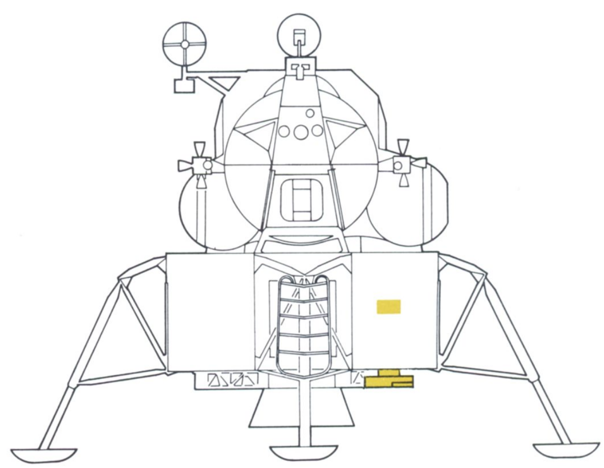


FIGURE 9. LANDING RADAR ASSEMBLY LOCATIONS

VACUUM DEPOSIT ALUMINUM FOR THERMAL CONTROL

"SPURIOUS SIGNAL" RF VIEW FACTOR TEST

The thermal design accommodates the worst possible combination of flight conditions. Careful attention has been paid to the finishes of external surfaces and internal surfaces of the antenna assembly to provide the optimum ratio of absorptance to emittance. This maintains the antenna assembly parts below the maximum allowable temperature during the worst case high temperature exposure (full solar exposure and radiation during the entire mission). A heater has been integrated in the electronic portion of the antenna assembly to prevent the temperature from falling below the minimum allowed, in the event of total flight exposure to deep space instead of solar radiation.

SOLID STATE TRANSMITTERS

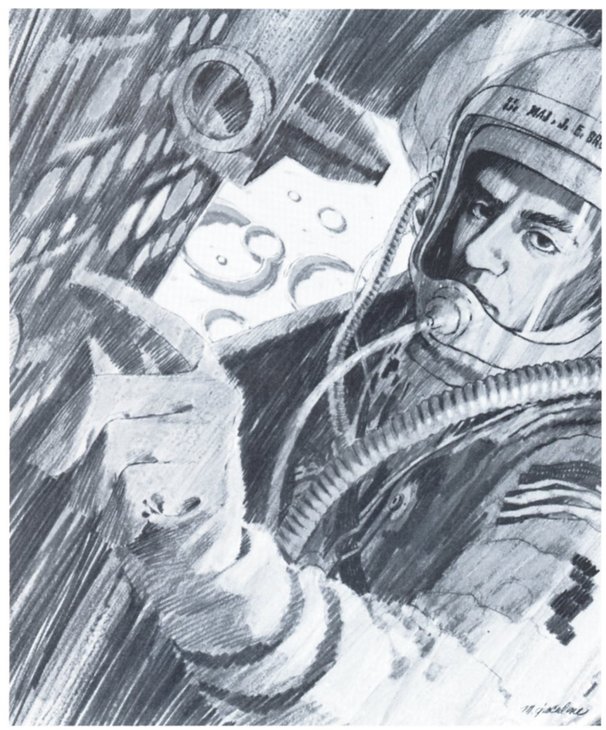
Solid state devices have been used as transmitters because of the high reliability, and their significantly lower voltage and power requirements.

SPURIOUS SIGNAL REJECTION

The basic task of the frequency trackers is to detect relative motion between the vehicle and the target (lunar surface). However, certain physical objects on the Lunar Module descent stage in radar "visible range" may also be moving and produce a spurious signal. To avoid acquisition and tracking of these signals, unique circuitry has been incorporated into the frequency trackers to examine all signals during the search mode and reject all except the true return signal.

LIGHT WEIGHT MATERIALS

To keep the weight of the landing radar to an absolute minimum, magnesium has been used extensively. The entire phased array, hybrids, balanced mixers and electronic assembly have been made of magnesium with a significant reduction in overall weight, and a gain in strength to weight ratio.



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SPECIAL TEST EQUIPMENT

Special landing radar test equipment is designed and built by Ryan to:

a) Support the in-process manufacturing (Manufacturing Test Stations Fig. 10)

b) To confirm that the landing radar performs as required and meets all acceptance criteria (Vendor Acceptance Test Equipment Fig. 11)

c) To allow last minute check and confirmation of "system go status" at the various evaluation and launch sites utilizing the landing radar (Bench Test Consoles Fig. 12). This equipment includes remote controllers for system checkout when the radar is in the final stages prior to launch.

Simple interconnection diagrams of the landing radar and the special test equipment are shown in Figures 10 and 11. At the system or section level the test equipment provides a simple, quick, errorless method of determining that the equipment meets requirements. It provides a means to exercise the radar over the complete dynamic range of expected signal frequencies and signal-to-noise ratios. This is accomplished by a special microwave adapter (Hat Coupler) which captures a portion of the transmitted RF energy. This portion is routed via waveguide to the special test equipment, wherein the RF energy is modulated to simulate Dopplers or range frequencies. Doppler simulators and variable attenuators are used to simulate high or low altitude, high or low incidence beam grazing angles, narrow or wide band signal spectrums, and high or low signal-to-noise ratios. Once modulated, the RF energy is then returned to the antenna assembly, and is coupled back to the receiving array apertures. For all practical purposes, the radar is exercised and performs as though it were in actual flight. Additional environmental stimulus created by conventional environmental laboratory facilities, such as deep space vacuum, high g vibration, operation in the presence of vibrating spacecraft parts, and so forth.

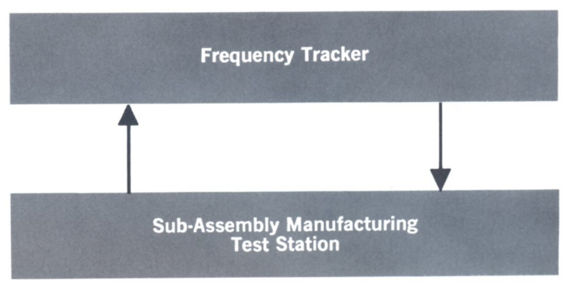


FIGURE 10.

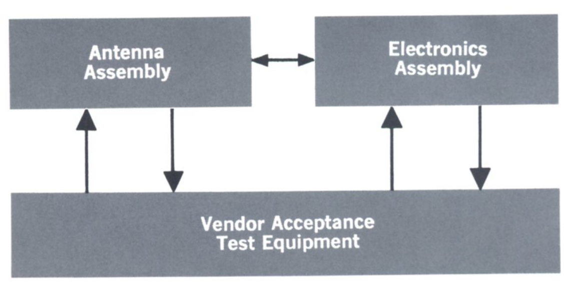
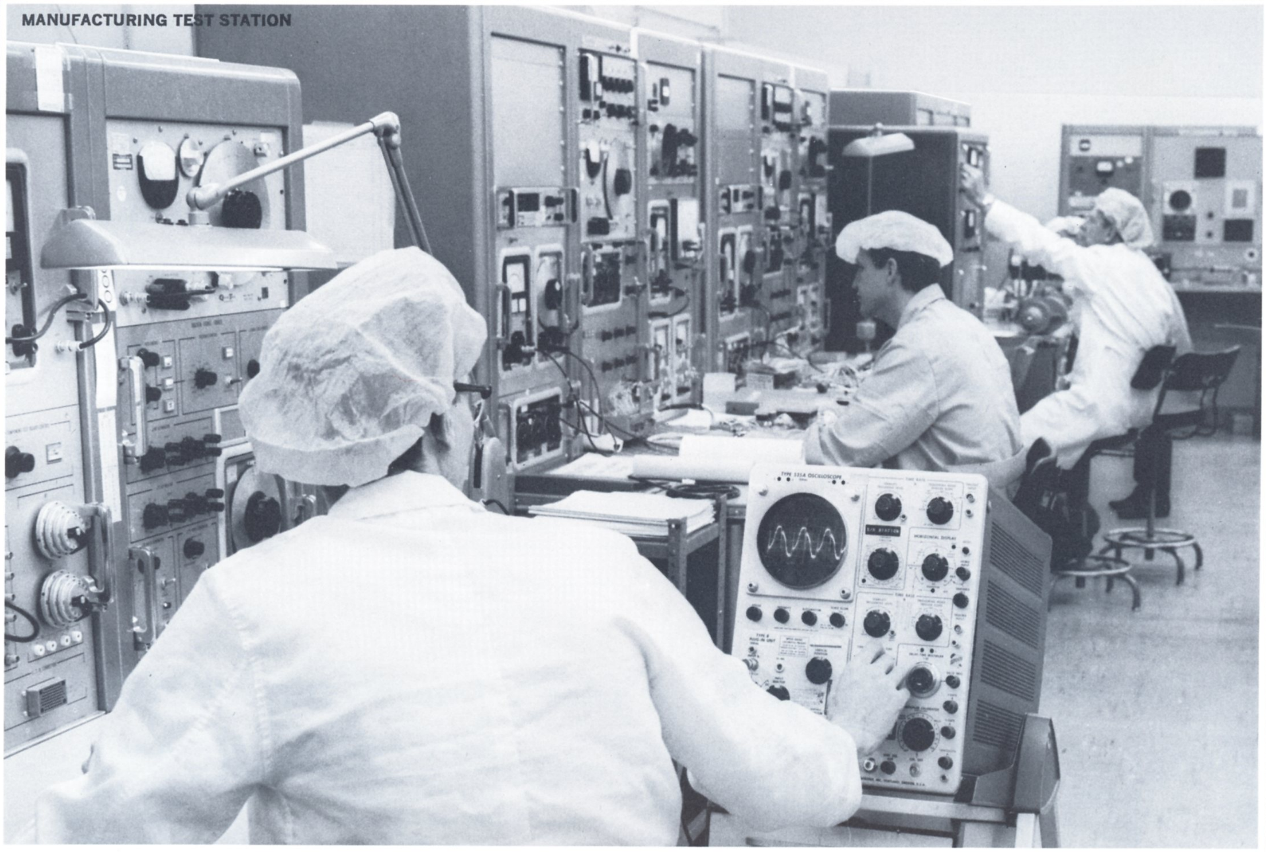
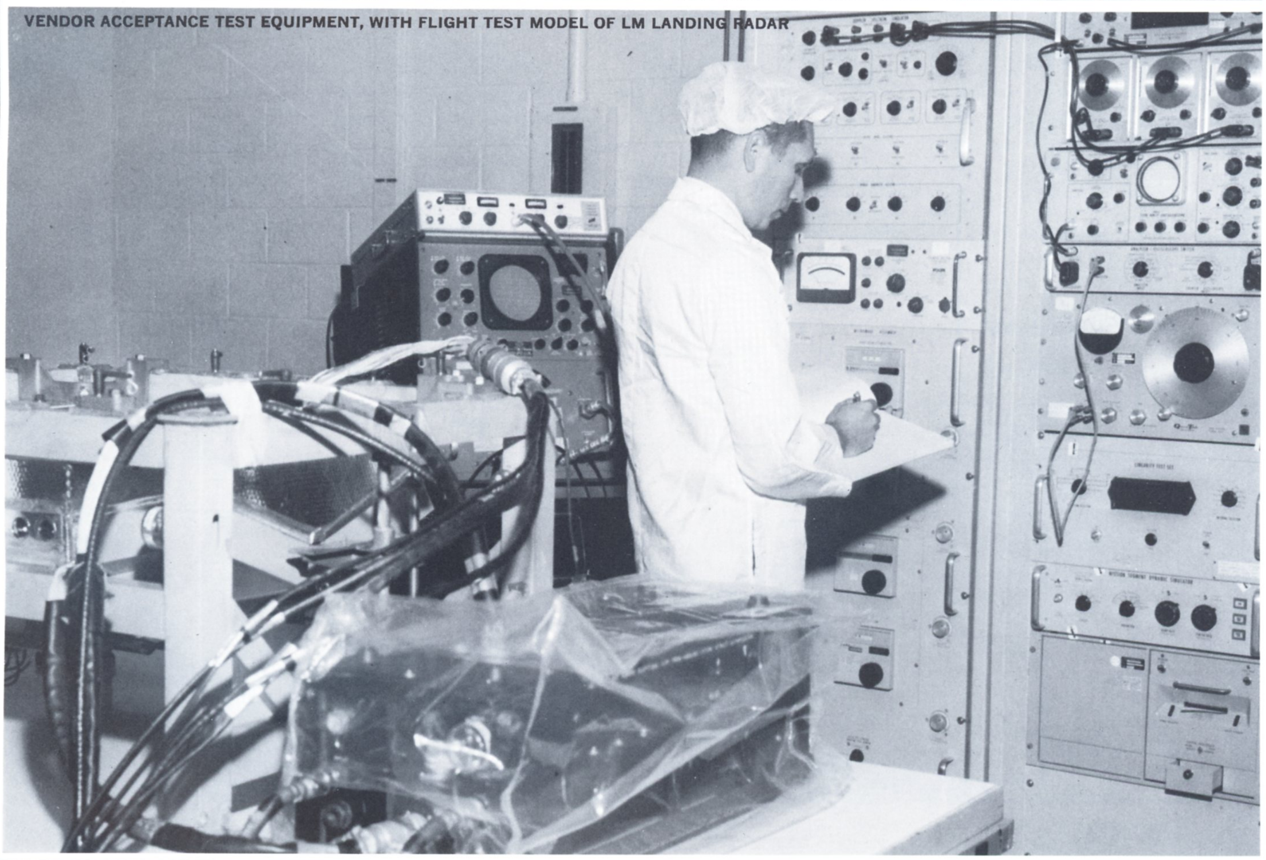


FIGURE 11.



MANUFACTURING TEST STATION



VENDOR ACCEPTANCE TEST EQUIPMENT, WITH FLIGHT TEST MODEL OF LM LANDING RADAR

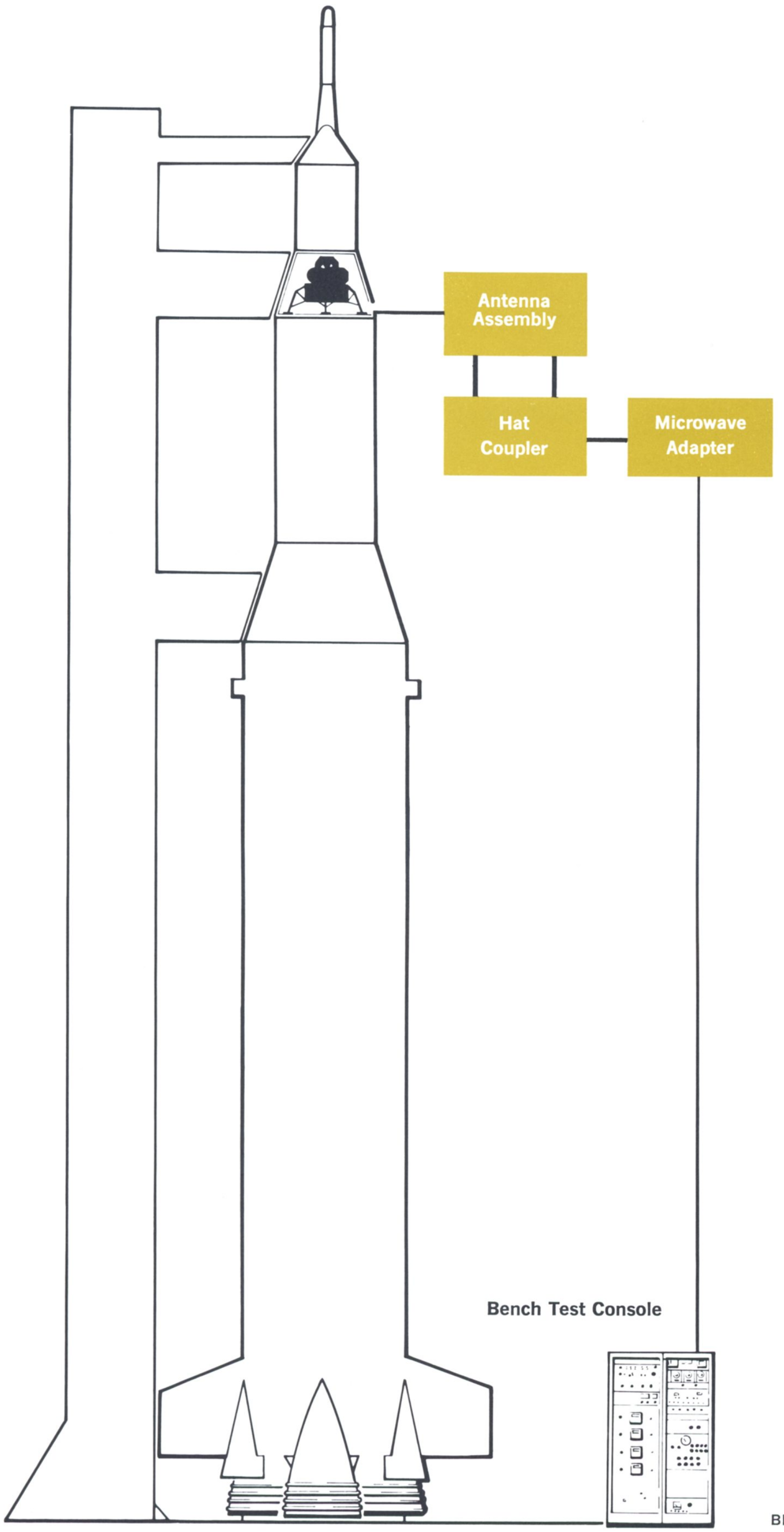


FIGURE 12.
BENCH TEST CONSOLE LAUNCH SITE

5

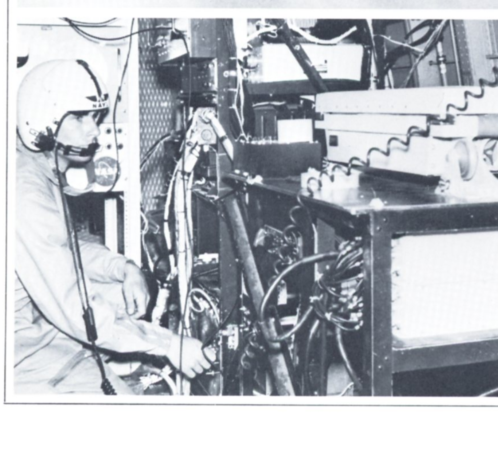
TEST PROGRAMS

Comprehensive testing is being accomplished on the landing radar to ensure proper performance and reliability. In addition to the normal design feasibility and design verification testing performed in the laboratory under simulated environmental conditions, extensive "free space" vibration and flight testing is being accomplished. The following is indicated:

RADAR MODEL	LOCATION	VEHICLE OR TEST	PERIOD
PP-3	Ryan, San Diego	RFI test, Engine Skirt and Landing Leg	Mar.-Aug. 1966
PP-4	Grumman, N.Y.	EMI, Integration by GAEC and MIT	
PP-7	Holloman AFB, N.M.	Flight test simulation of lunar landing, in jet and helicopter (Pre-production)	Aug. 1966-Jan. 1968
PP-8	Grumman, N.Y.	LM Test Article-1 System Integration Tests	July 1966
P-9	Manned Spacecraft Center, Houston	LM Test Article-8 Space Environmental Tests	Aug. 1966
P-10	Cape Kennedy	LM-1 Flight (Antenna only, non-operational), unmanned Earth-orbit	Jan. 22, 1968
	Cambridge, Mass.	MIT engineering tests (Electronics Assy only)	1969
P-11	Ryan, San Diego	Qualification tests	Nov. 1966-Nov. 1967
	Holloman AFB, N.M.	Flight test simulation of lunar landing, in jet and helicopter (Production model)	Apr. 1968
P-13	Ryan, San Diego	Qualification tests	Feb. 1967
		Post-qualification tests	1969
P-14	Cape Kennedy	LM-2 (cancelled, retained as spare)	
P-18	Cape Kennedy	Apollo 9, LM-3 Flight First manned earth orbit of complete Apollo system	Mar. 3, 1969
P-19	Ryan, San Diego	Post-qualification tests	1969
P-27	Cape Kennedy	Apollo 10, LM-4 Flight Manned lunar orbit, test of LM in moon environment	1969
P-46	Cape Kennedy	Apollo 11, LM-5 Flight Scheduled for first manned lunar landing	1969
P-42 through P-47 and P-51 through P-55	Cape Kennedy	Available for manned lunar landings	1969

The series of flight evaluations of the Apollo Lunar Module landing radar at Holloman AFB, N.M., simulated as nearly as possible on earth, the speeds, altitudes and rates of descent of the Lunar Module. The SH-3A helo rehearsed the vertical descent and hover. High speed approach and start of the descent sequence was simulated by the jet.

The LM antenna was encased in a radome on the underside of the helicopter and jet aircraft. The electronic assembly was installed within the aircraft with other monitoring and recording equipment. Special range cameras and ground computers were used in gathering and analysis of test data.



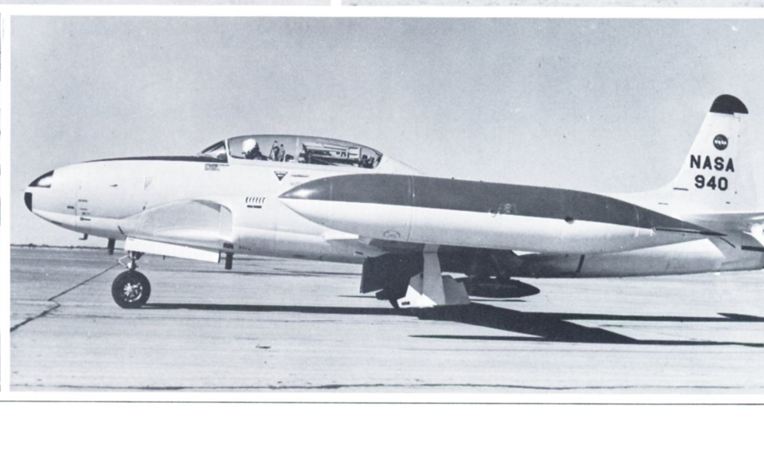


TABLE 2 / LANDING RADAR PHYSICAL AND OPERATIONAL CHARACTERISTICS

Type of System	
Velocity Sensor	CW, 3-beam
Radar Altimeter	FM/CW
Altitude Capability	
Velocity	5 to 25,000 feet
Altimeter	10 to 40,000 feet
Velocity Capability	V_{xa}: −2000 to + 500 fps
	V_{ya}: −500 to + 500 fps
	V_{za}: −500 to +3000 fps
Altimeter Antenna	
Type	Planar array
Gain (Two-way)	50.4 db
Beamwidth (Two-way)	3.9 degrees E plane
	7.5 degrees H plane
Velocity Sensor Antenna	
Type	Planar array
Gain (Two-way)	49.2 db
Beamwidth (Two-way)	3.7 degrees E plane
	7.3 degrees H plane
Transmitters	
Type	Solid State
Frequency	
Velocity Sensor	10.51 gc
Radar Altimeter	9.58 gc
Output Power	
Velocity Sensor	200 mw minimum
Altimeter	175 mw minimum
Altimeter Modulation	Sawtooth FM
Modulation Frequency	130 cps
Deviations	8 mc and 40 mc
Response time 11,000 feet	0.08 sec nominal

Outputs:

a) Serial Binary to Computer

Parameter	Limits	Counting Time	Scale Factor
V_{xa}	(—2000 to + 500 fps)	400 m sec	.12880 fps/count
V_{ya}	(— 500 to + 500 fps)	400 m sec	.24231 fps/count
V_{za}	(— 500 to +3000 fps)	400 m sec	.17335 fps/count
Range (high alt. mode)	(2500 to 40,000 feet)	80 m sec	5.3955 ft/count
Range (low alt. mode)	(10 to 2500 feet)	80 m sec	1.0791 ft/count

b) Displays

Parameter	Limits	Scale Factor
Analog		
V_{ya}	(—200 to +200 fps)	25 mv / fps
V_{za}	(—200 to +200 fps)	25 mv / fps
Pulse Trains		
V_{xa}	(—500 to +500 fps)	19.41 pps/fps
Range	(2500 - 40,000 ft)	2.3167 pps/ft
Range	(10 - 2500 ft)	11.583 pps/ft

c) Status Indications (Contact Closures referenced to 28 ± 11V)

LGC:

- Velocity Data Good
- Range Data Good
- Range Low Scale Factor
- Antenna Position 1
- Antenna Position 2

Displays: (Isolated Contact Closures)

- V_{xa} Sense
- Power On

Instrumentation: (Contact Closures)

- Range Data No Good
- Velocity Data No Good
- Antenna Position 1
- Antenna Position 2

Accuracy	Altitude, feet	Accuracy
Range (digital and pulse train)	10-2,000	±(1.4% +5 ft)
	2,000-25,000	±(1.4% +15 ft)
Velocity		
V_{xa} (digital)	5-25,000	±1.5% or ±1.5 fps
V_{ya} (digital)	5-200	±2% or ±1.5 fps
	200-2000	±3.5% or ±3.5 fps
	2000-25,000	±2% or ±2 fps
V_{za} (digital)	5-200	±2% or ±1.5 fps
	200-2000	±3% or ±3 fps
	2000-25,000	±2% or ±2 fps
Velocity		
V_{xa} (pulse train)	5-50	±0.6 fps
	50-200	±0.7 fps
	200-2000	±1.4% or ±1.4 fps
	2000-25,000	±1.3%
V_{ya} (analog)	5-50	±1.2 fps
	50-200	±1.6 fps
	200-2000	±2.8% or ±2.8 fps
	2000-25,000	+1.7%
V_{za} (analog)	5-50	±1.0 fps
	50-200	±1.3 fps
	200-2000	3.0% or ±3.0 fps
	2000-25,000	3%

Self Test Conditions

V_{xa}	=	–493.9 fps	V_{za}	=	1329.4 fps
V_{ya}	=	1858.1 fps	R	=	8275.2 feet

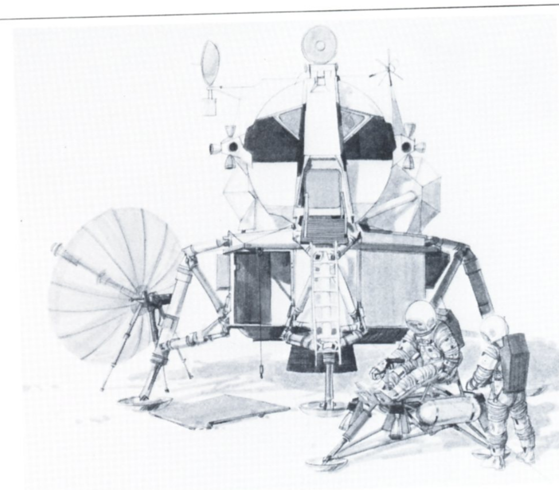
Power Consumption

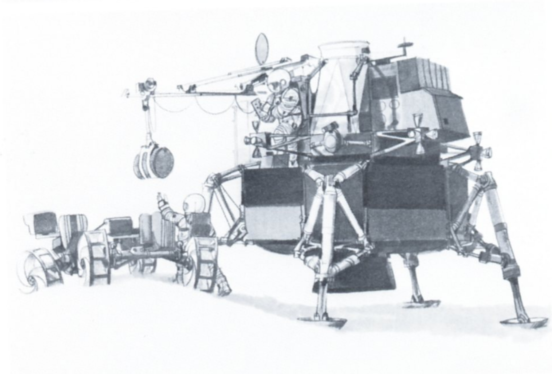
Electronic Subassemblies	132 watts maximum
Variable Cycle Thermal Control Heater	63 watts nominal, when required
Tilt Mechanism	15 watts maximum, momentary

Weight (including antenna pedestal) 43.3 lbs.

Size (L x W x H)

Antenna Assembly	20.0″ x 24.6″ x 6.5″
Electronic Assembly	15.75″ x 6.75″ x 7.38″





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RYAN PHOTO

PHOTO NO. 5024-C

SOFT LANDING ON THE MOON, Apollo 11 Astronauts Neil Armstrong and Edwin Aldrin will use the Lunar Module's landing radar system to measure how high they are and how fast they are descending. Built by Ryan Aeronautical Company, the radar is on the underside of the descent stage, near the descent engine. Illustrated, from left, is engine turn-on at 50,000 feet; rotation to "windows up" at 45,000 feet so the landing radar will acquire return signals from the moon; near vertical descent from 500 feet, with the astronauts in control and the radar supplying indications of altitude and descent rate; and the actual landing surface exploration in the Sea of Tranquility. (Illustration by Robert Watts)

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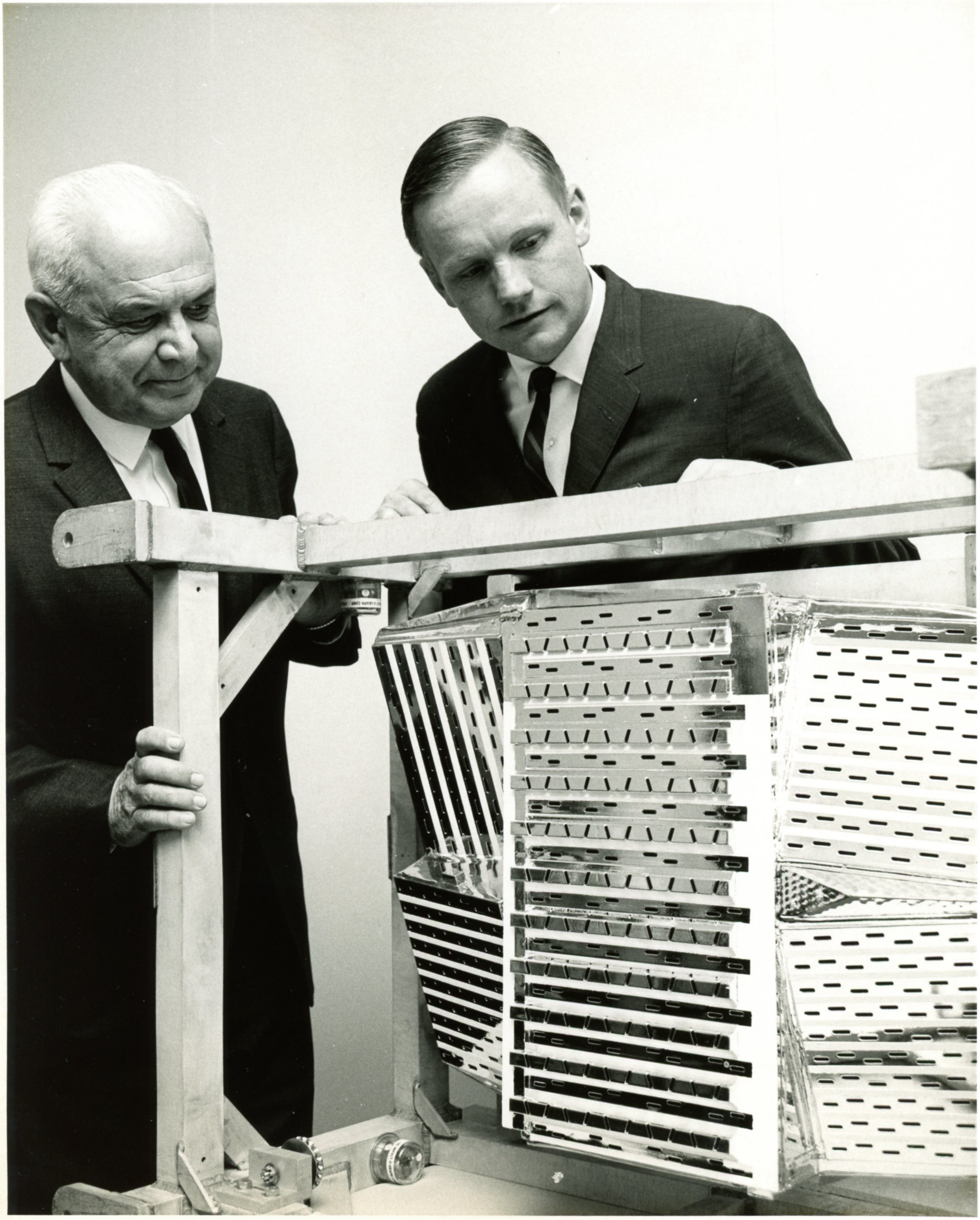

RYAN PHOTO

PHOTO NO. 89587

AVIATION PIONEER, SPACE PIONEER -- Apollo 11 Commander Neil Armstrong, right, who is scheduled to be the first man to set foot on the moon, and T. Claude Ryan, founder of the Ryan Aeronautical Company, discuss the historic landing mission and the role of the Ryan landing radar during a visit by Armstrong to the San Diego-based company. In 1927, Ryan Airlines, Inc. built Charles Lindbergh's Atlantic-crossing "Spirit of St. Louis" monoplane. Today Ryan is building the Apollo Lunar Module landing radar system that the astronauts will use to make soft landings on the moon. In the foreground is the landing radar antenna.

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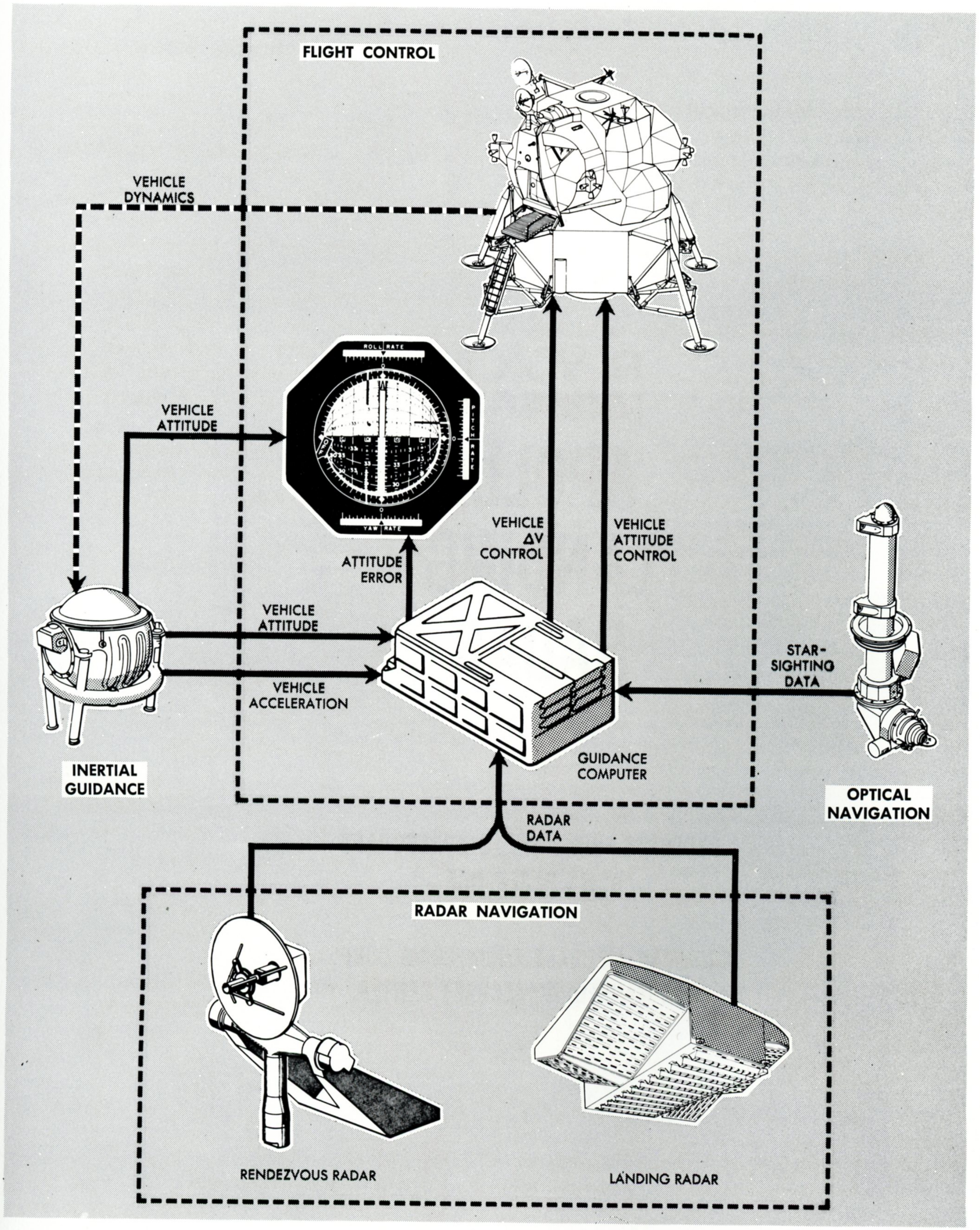
RYAN

APOLLO LANDING RADAR

EXCERPTS FROM APOLLO SPACECRAFT
NEWS REFERENCE

GRUMMAN AIRCRAFT ENGINEERING CORP.
NASA MANNED SPACECRAFT CENTER



Guidance, Navigation, and Flight Control Functions

NAVIGATION AND THE LUNAR MODULE

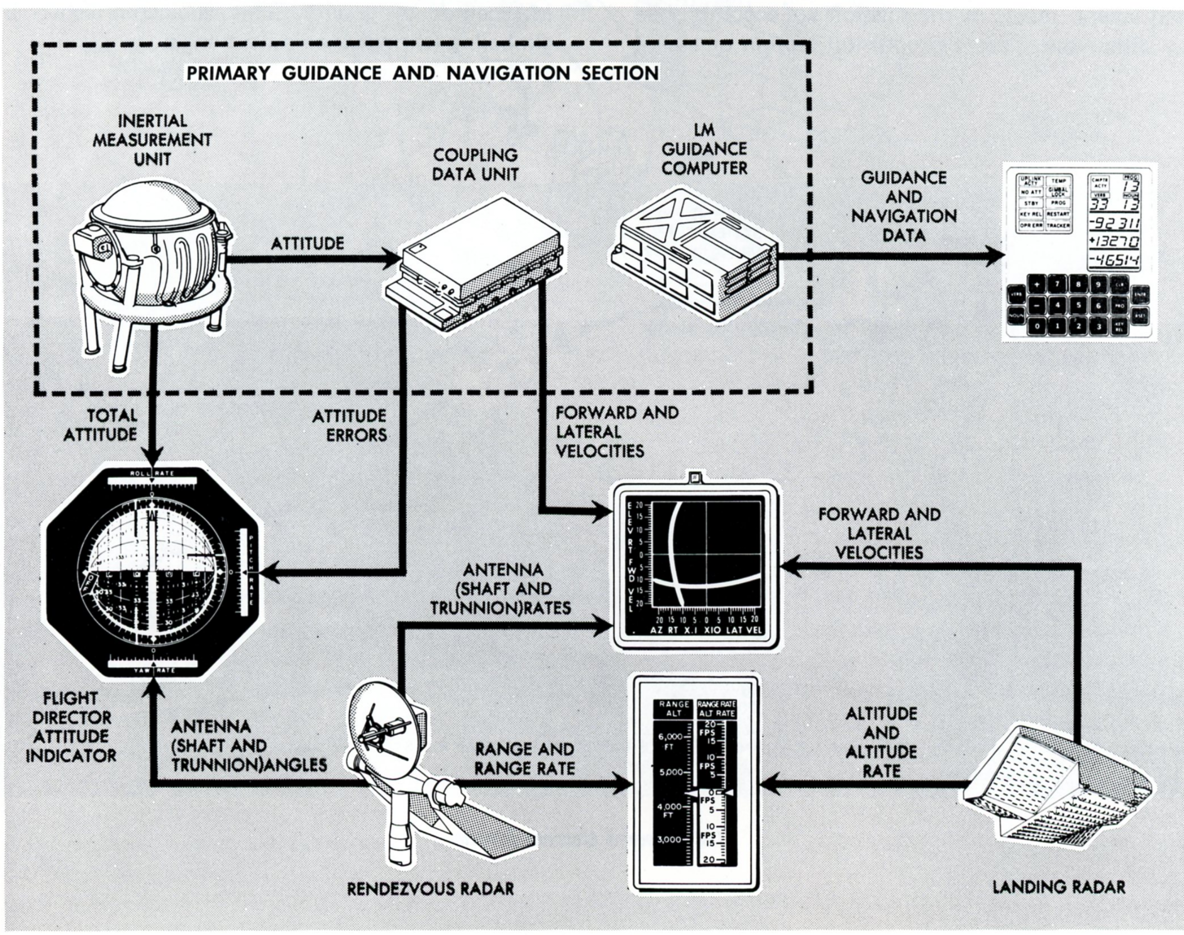
LM navigation involves the determination of the vehicle's present position and velocity so that the guidance function can plot the trajectory that the LM must follow.

When flying an aircraft between two points on earth, both points remain fixed with respect to each other. In spaceflight, however, the origin of the spacecraft's path and its destination or target are moving rapidly with respect to each other.

To determine the present position of the LM, celestial navigation is used to align the guidance system. This is accomplished by determining the vehicle's position in relation to certain fixed stars. Even though the stars may be moving, the distance that they move in relation to the total distance of the stars from the vehicle is so small that the stars can be thought of as being stationary.

The optical device which the astronauts use for navigation is an alignment optical telescope (AOT) protruding through the top of the vehicle and functioning as a sextant. The astronauts use it to take direct visual sightings and precise angular measurements of pairs of celestial objects. These measurements are transferred by the astronaut to the guidance elements to compute the position and velocity of the vehicle and to perform alignment of an inertial guidance system. There is a direct relationship between the angular measurements taken with the telescope and the mounting position of the telescope. The computer program knows the telescope's mounting position which is in alignment with the LM body axes and from this knowledge and astronaut-generated information, the computer is able to calculate the LM position.

During the landing phase and subsequent rendezvous phase, the LM uses radar navigational techniques to determine distance and velocity.



Primary Guidance Data Displayed

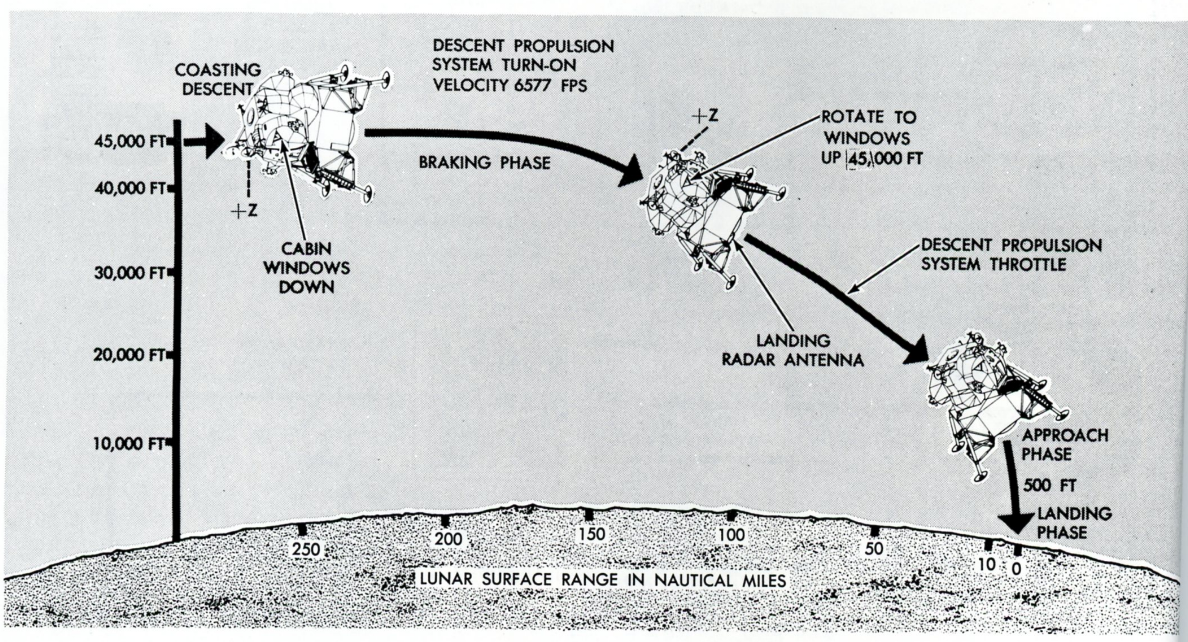
Each phase uses a radar designed specifically for that phase (rendezvous radar, landing radar). Both radars inform the astronaut and the computer concerning position and velocity relative to acquired target. During lunar landing, the target is the surface of the moon; during rendezvous, the target is the Command Module.

FLIGHT CONTROL AND THE LUNAR MODULE

Flight control involves controlling the LM trajectory (flight path) and attitude. Flight path control depends on the motion of the LM center of gravity; attitude control primarily involves rotations about the center of gravity.

In controlling the LM in its flight path, the thrust of its engines must be directed so that it produces a desired variation in either magnitude or direction to place the LM in some particular orbit, position, or attitude. The major velocity changes associated with the lunar orbit, injection, landing, and ascent phases of the mission are accomplished by either the descent propulsion section or ascent propulsion section of the Main Propulsion Subsystem (MPS). The engines can produce high thrust in specific directions in inertial space.

During the descent phase, the LM must be slowed (braked) to place it in a transfer orbit from which it can make a soft landing on the lunar surface. To accomplish braking, descent engine thrust is controllable so that the precise velocity (feet per second) necessary to alter the vehicle's trajectory can be achieved. For a soft landing on the lunar surface, the weight of the LM must be matched by an upward force so that a state of equilibrium exists, and from this point, the descent engine is shut off and the LM free falls to the lunar surface. The thrust of the descent engine provides this upward force, and since the weight of the vehicle is a variable (due to consumption of expendables) this is another reason why the magnitude of the engine thrust is controllable. In addition, the center of gravity is also variable and the thrust must be such that it is in line with the LM center of gravity. This is accomplished by gimbaling (tilting) the descent engine.

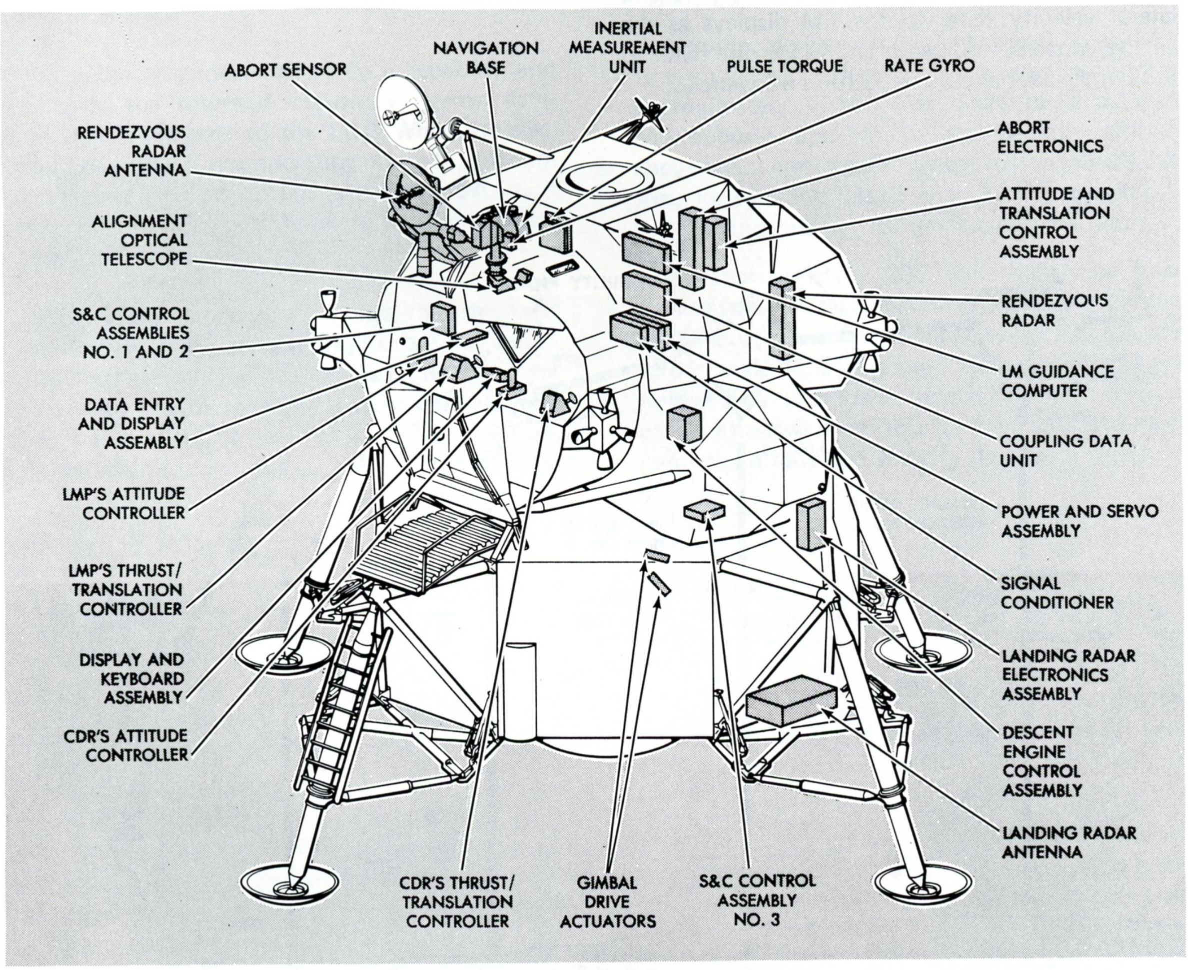


LM Powered Descent Profile

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

To accomplish guidance, navigation, and control, the astronauts use 55 switches, 45 circuit breakers, and 13 indicators which interface with the various GN&CS equipment. This equipment is functionally contained in a primary guidance and navigation section, an abort guidance section, a control electronics section, and in the landing and rendezvous radars.

The primary guidance and navigation section (PGNS) provides, as the name implies, the primary means for implementing inertial guidance and optical navigation for the LM. When aided by either the rendezvous radar or the landing radar, the section provides for radar navigation. The section when used in conjunction with the control electronics section (CES) provides automatic flight control. The astronauts can supplement or override automatic control, with manual inputs.

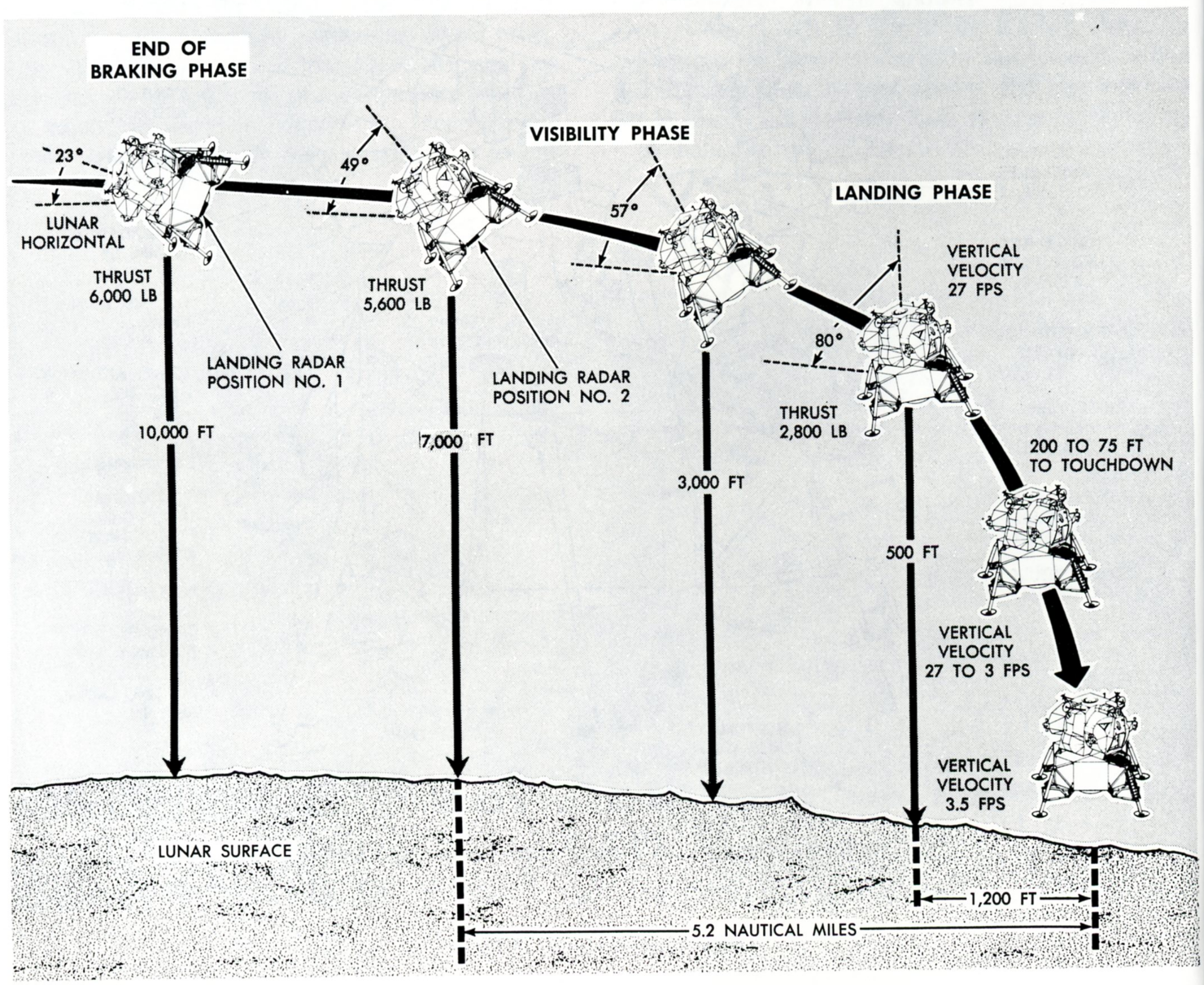


Guidance, Navigation, and Control Major Equipment Location

The landing radar, located in the descent stage, provides altitude and velocity data during lunar descent. The primary guidance and navigation section calculates control signals for descent rate, hovering, and soft landing. Altitude data begins at approximately 39,500 feet above the lunar surface; velocity data, at approximately 23,200 feet.

The landing radar senses the velocity and altitude of the LM relative to the lunar surface by means of a three-beam Doppler velocity sensor and a single-beam radar altimeter. Velocity and range data are made available to the LM guidance computer as 15-bit binary words; forward and lateral velocity data, to the LM displays as d-c analog voltages; and range and range rate data, to the LM displays as pulse-repetition frequencies.

The landing radar antenna has a descent position and a hover position. In the descent position, the antenna boresight angle is 24° from the LM X-axis. In the hover position, the antenna boresight is parallel to the X-axis and perpendicular to the Z-axis. Antenna position is selected by the astronaut during manual operation and by the LM guidance computer during automatic operation. During automatic operation, the LM guidance computer commands the antenna to the hover position 7,000 feet above the lunar surface.



Nominal Descent Trajectory from High Gate to Touchdown

The landing radar consists of an antenna assembly and an electronics assembly. The antenna assembly forms, directs, transmits, and receives the four microwave beams. Two interlaced phased arrays transmit the velocity- and altimeter-beam energy. Four broadside arrays receive the reflected energy of the three velocity beams and the altimeter beam. The electronics assembly processes the Doppler and continuous-wave FM returns, which provide the velocity and slant range data for the LM guidance computer and the LM displays.

The antenna assembly transmits velocity beams (10.51 gHz) and an altimeter-beam (9.58 gHz) to the lunar surface.

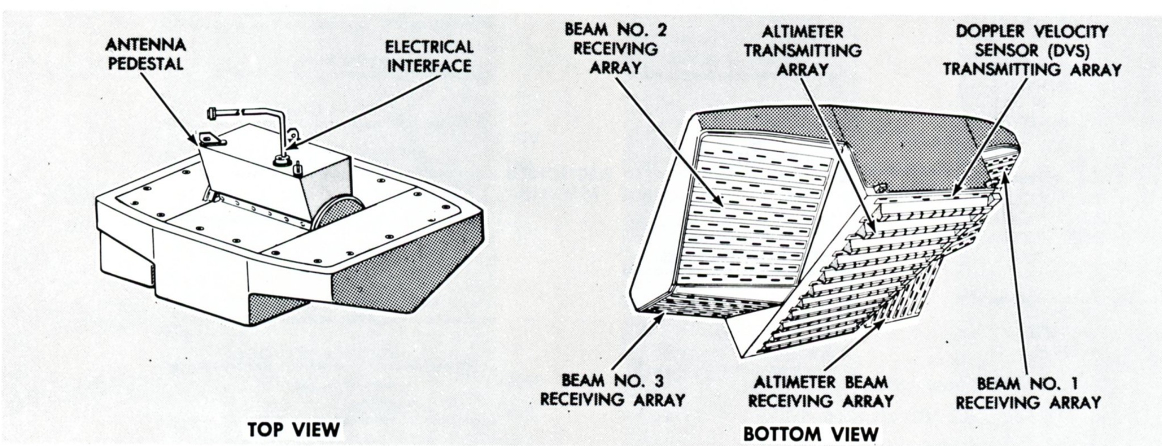
When the electronics assembly is receiving and processing the returned microwave beams, data-good signals are sent to the LGC. When the electronics assembly is not operating properly, data-no-good signals are sent to the pulse code modulation timing electronics assembly of the Instrumentation Subsystem for telemetry.

Using LM controls and indicators, the astronauts can monitor LM velocity, altitude, and radar-transmitter power and temperatures; apply power to energize the radar; initiate radar self-test; and place the antenna in descent or hover position. Self-test permits operational checks of the radar without radar returns from external sources. An antenna temperature control circuit, energized at earth launch, protects antenna components against the low temperatures of space environment while the radar is not operating.

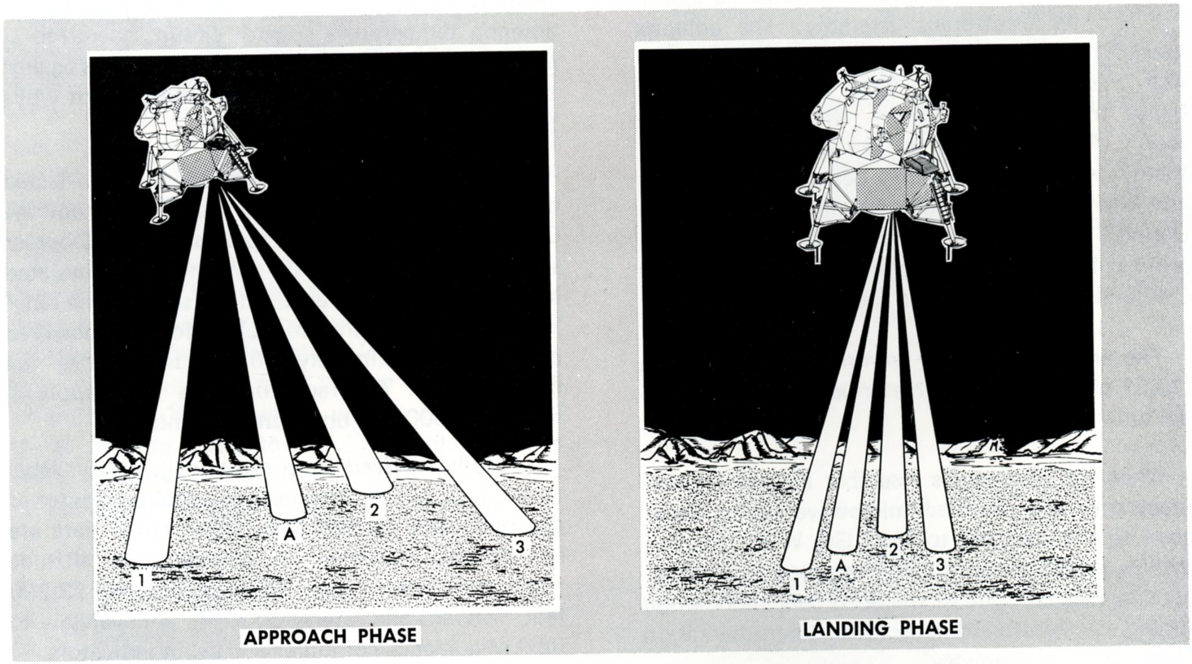
The radar is first turned on and self-tested during LM checkout before separation from the CSM. The self-test circuits apply simulated Doppler signals to radar velocity sensors, and simulated lunar range signals to an altimeter sensor. The radar is self-tested again immediately before LM powered descent, approximately 70,000 feet above the lunar surface. The radar operates from approximately 50,000 feet until lunar touchdown.

Altitude (derived from slant range) is available to the LGC and is displayed on a cabin indicator at approximately 39,500 feet. Slant range data are continuously updated to provide true altitude above the lunar surface. At approximately 23,200 feet, forward and lateral velocities are available to the LM guidance computer and cabin indicators.

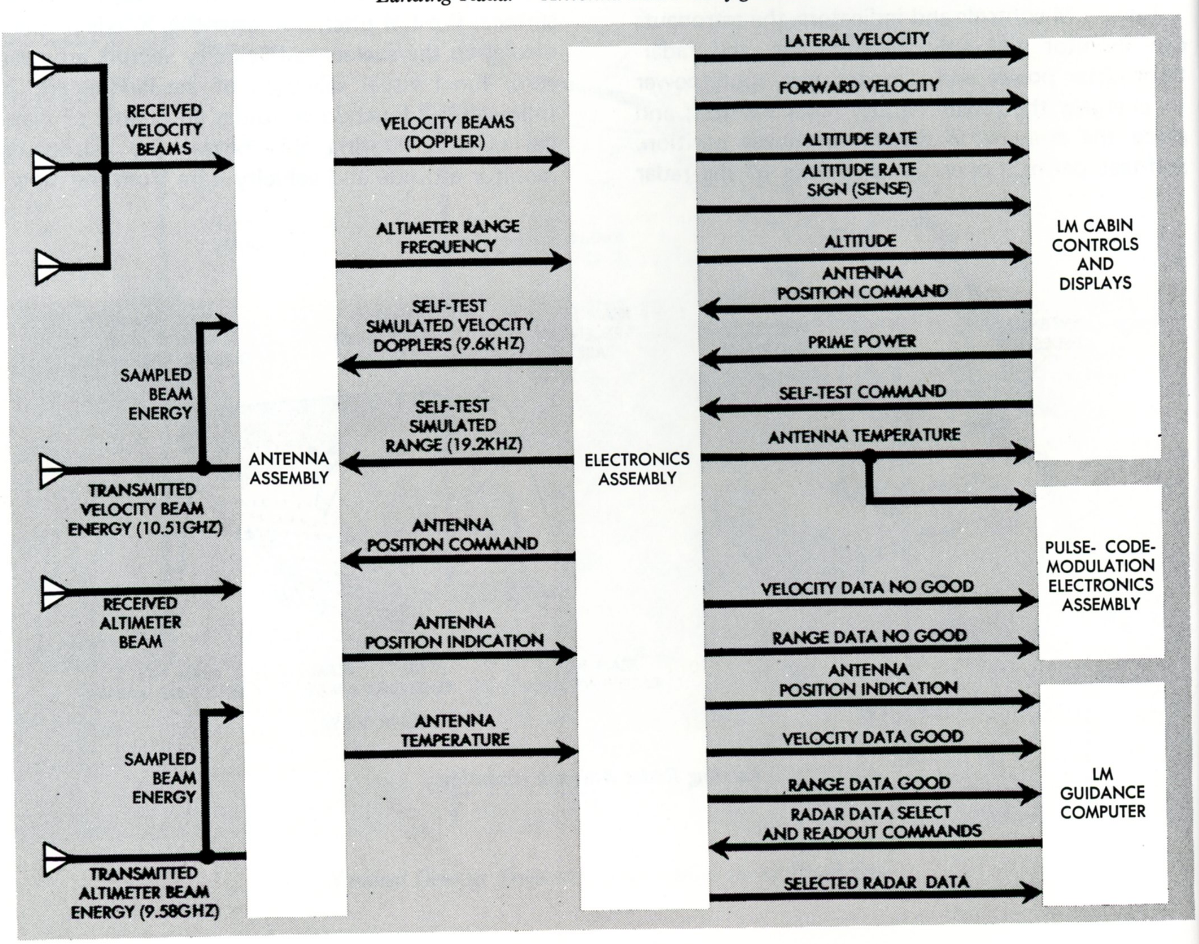
At approximately 200 feet above the lunar surface, the LM pitches to orient its X-axis perpendicular to the surface; all velocity vectors are near zero. Final visual selection of the landing site is followed by touchdown under automatic or manual control. During this phase, the astronauts monitor altitude and velocity data from the radar.



Landing Radar Antenna Assembly



Landing Radar – Antenna Beam Configuration



Landing Radar Signal Flow

Velocity sensor	Continuous-wave, three-beam
Radar altimeter	Frequency modulated/continuous wave (FM/CW)
Altitude capability	10 to **39,500** feet
Velocity capability	From altitude of **23,200** feet
Weight (approx)	39 pounds
Power consumption	125 watts dc (nominal) 147 watts dc (maximum)
Heater power consumption	44 watts dc (maximum)
Altimeter antenna	
Type	Planar array, space-duplexed
RF power	100 mw (minimum)
Velocity sensor antenna	
Type	Planar array, space-duplexed
RF power	200 mw (minimum)
Transmitter frequency	
Velocity sensor	10.51 gHz
Radar altimeter	9.58 gHz
Warmup time	1 minute
FM sweep duration	0.007 second
Acquisition time	12 seconds (maximum)
Primary power	25 to 31.5 volts dc (nominal) 3.5 to 6.5 amperes
Temperature range	
Electronics assembly	-20° to $+110^\circ$ F
Antenna assembly	$+50^\circ$ to $+150^\circ$ F

LANDING RADAR

ELECTRONICS ASSEMBLY

The electronics assembly comprises frequency trackers (one for each velocity beam), a range fre- quency tracker, velocity converter and computer, range computer, signal data converter, and data- good/no-good logic circuit.

ANTENNA ASSEMBLY

The assembly comprises four microwave nixers, four dual audio-frequency preamplifiers, wo microwave transmitters, a frequency modu- ator, and an antenna pedestal tilt mechanism.

The antenna consists of six planar arrays: two for transmission and four for reception. They are mounted on the tilt mechanism, beneath the descent stage, and may be placed in one of two fixed positions.

The landing radar uses four microwave beams; three to measure velocity by Doppler shift contin- uous wave, one to measure altitude by continuous-wave frequency modulation.

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News Reference

APOLLO 11 (Mission G) TRAJECTORY EVENTS

RYAN LM LANDING RADAR

1. Landing radar activation and check out -- 15 minutes prior to powered descent.

2. Powered descent initiation (engine on) -- 50,000 feet, 3780 mph horizontal velocity.

3. Landing radar on -- 49,400 feet, for 30 second warm-up.

4. 174 deg yaw maneuver to windows up, causing radar contact with the moon -- 45,300 feet, 2790 mph horizontal velocity, 37.5 mph descent rate.

5. Altimeter acquisition, first radar update of LM Guidance Computer -- 39,500 feet, 2100 mph horizontal velocity, 63 mph descent rate. 80 degrees pitch angle.

6. Landing radar update (altitude) of primary guidance and navigation system -- 27,600 feet, 1220 mph, 90 mph descent rate, 70 degrees pitch angle.

7. Velocity acquisition, forward-looking third beam locks on moon's surface -- 23,200 feet, 900 mph horizontal velocity, 88 mph descent rate, 65 degrees pitch angle.

8. "High Gate," start of visibility phase; astronaut's first view of landing site; switch of radar antenna from descent to hover position -- 7,000 feet, 350 mph horizontal velocity, 100 mph descent rate, 51 degrees pitch angle.

9. 2000-foot mark -- 125 mph horizontal velocity, 37 mph descent rate.

10. "Low Gate," possible start of manual control of descent -- 500 feet, 43 mph horizontal velocity, 10.2 mph (15 feet per second) descent rate, approximately 22 degrees pitch angle.

11. 200-foot mark -- manual control attitude hold, null out horizontal velocities over landing site.

12. 3-feet-per-second descent rate -- approximately 130-110 feet above the moon. Manual control with altitude and altitude rate indications to the touchdown.

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NEWS BUREAU

CHIEF: BOB BATTENFIELD

For Immediate Release

ROLE OF RYAN RADAR 'SIGNIFICANTLY INCREASED'

FOR APOLLO 11 LUNAR LANDING MISSION

As the Apollo 11 Lunar Module (LM) brakes toward the moon July 20, the Ryan landing radar will start to update the spacecraft's guidance computers at an altitude of 39,500 feet -- a mark 14,500 feet higher than required in earlier plans.

The decision by NASA to move the radar's first altitude update 14,500 feet higher is a "significant increase in the role of the Ryan radar in the lunar landing mission," according to J. R. Iverson, vice president-Ryan Electronic and Space Systems, Ryan Aeronautical Company, builder of the system.

Iverson said the changes in the final plan for Apollo 11's landing trajectory "reflect increased confidence" in the capability of the Ryan radar to operate reliably at great distances from the lunar target.

In the final trajectory, or flight path, announced by NASA for the Apollo 11 lunar descent phase, Astronauts Neil Armstrong and Edwin Aldrin will initiate a 174-degree yaw maneuver at 45,300 feet above the moon to bring the radar's beams of microwave energy into contact with the rough surface of the moon. Formerly, this maneuver was scheduled for 35,000 feet.

Iverson said, "Two of the three velocity sensor beams should lock on to the surface right away, and the single altimeter beam should acquire an indication of slant range altitude at about 39,500 feet.

"At this altitude, the LM guidance computer will use the radar information for the first time, to update the altitude reading. This first altitude update was

More . . . . .

originally set 14,500 feet closer to the moon, farther down the trajectory, at 25,000 feet.

"Increasing the altitude at which the Ryan radar becomes effective is a significant increase in the role of the Ryan radar in the Apollo lunar landing mission, I believe."

In Apollo 10, flown May 18-26, the radar performed far above expectations.

"The first data point in the telemetered radar information came at a slant range altitude of about 82,800 feet from the moon," Iverson reported. "This is more than 32,000 feet higher than the landing radar was supposed to work for Apollo 10, and more than 42,000 feet above our contract specification for performance, which is 40,000 feet."

Continuing with the Apollo 11 flight plan, Iverson said velocity measurements from the radar will become available to the astronauts when the Lunar Module has pitched forward to about 65 degrees and the third beam, which is directed ahead of the spacecraft, strikes the surface and locks on.

From this point -- an altitude of 23,200 feet -- to the landing, the flight computers will use more and more of the moon-referenced landing radar measurements, and less and less of the inertial on-board measurements.

At 7,000 feet above the surface, the radar antenna will switch automatically from its descent position -- a cocked position 24 degrees off the horizontal plane of the spacecraft -- to the hover position, which is zero degrees and parallel to the bottom of the spacecraft.

Trajectory planners also place this point in the descent as "high gate," or as the start of the visibility phase. The astronauts will have their first opportunity to visually align their descent path with the planned landing site.

Reaching "low gate" at 500 feet altitude, the Lunar Module will be cruising over the moon at 43 mph, with a descent rate of 10.2 mph (15 feet per second). Pitch angle will be about 22 degrees.

Soon after this milestone, Apollo 11 Commander Armstrong will take manual control of the descent, something he has practiced in simulators and in the Lunar Landing Training Vehicle (LLTV), which also has Ryan radar aids.

Descent rate will have slowed to three feet per second, and by the time the Apollo 11 moonship reaches a radar-measured altitude of about 110-130 feet, Armstrong will have nulled out any horizontal velocities.

"He will hold his descent rate at three feet per second and fly vertically down to the surface, much like a radar-controlled hover and vertical descent landing of a helicopter," Iverson explained.

Once on the moon, the role of the landing radar is completed. It stays on the surface of the moon with the descent stage when Armstrong and Aldrin lift off in the ascent stage for the rendezvous with the orbiting Command Module and CM Pilot Michael Collins.

Ryan furnished a similar landing radar system for the Surveyor unmanned moon landers, five of which successfully soft-landed to scout for potential landing sites for Apollo. Surveyor 5 sits some 12 miles north of the site selected for the Apollo 11 landing, in the moon's Sea of Tranquility.

Building on the technology and experience of Surveyor and Apollo, Ryan has proposed to furnish a four-beam velocity sensor and two altimeter systems for Project Viking, the funded two-spacecraft mission to be launched for Mars in July 1973.

Ryan is building 14 space hardware systems, nine test units and two spares for Apollo.

Ryan furnishes the radar to RCA Defense Electronic Products, Burlington, Mass., which is responsible for LM radar subsystems to Grumman, the prime contractor to NASA for the Lunar Module.

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