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THE PLANETARY–INTERPLANETARY PROGRAM

IV. *Mariner* Project

The intent of the first *Mariner* flights is to perform flyby missions to Venus in 1962 using the *Atlas–Agena* B vehicle.

The objectives of these early missions have been to: (1) develop and launch two spacecraft to the near vicinity of the planet Venus, (2) receive communications from the spacecraft while in the vicinity of Venus, and (3) perform a Venus-oriented scientific experiment, and as many other experiments as possible oriented toward interplanetary space and the near vicinity of the planet.

Later *Mariner* missions will be performed with the primary purpose of making scientific investigations of the planets Venus and Mars during their periods of availability in 1964 through 1967. In between periods of Mars and Venus availability, *Mariner* spacecraft will be utilized as interplanetary probes.

A more advanced *Mariner* spacecraft is being designed for precision flyby missions and will incorporate the capability of either carrying or not carrying a small entry capsule.

A. Status

Mariner 2 (Fig. 1) is presently on an encounter trajectory to Venus and all subsystems are operating normally; planetary flyby is scheduled for mid-December, 1962. A month prior to the *Mariner* 2 launch, the *Mariner* 1 flight was terminated early during the boost phase by AMR Range Safety.

The preliminary design phase of the advanced *Mariner* has been completed. Mission objectives, design characteristics and restraints, and functional specifications have been finalized and published. The *Project Development Plan* has been revised and is being prepared for re-issue.

B. Flight Operations

Prelaunch tests for *Mariner* 1 and 2 at AMR proceeded smoothly and final preparations for the launch were

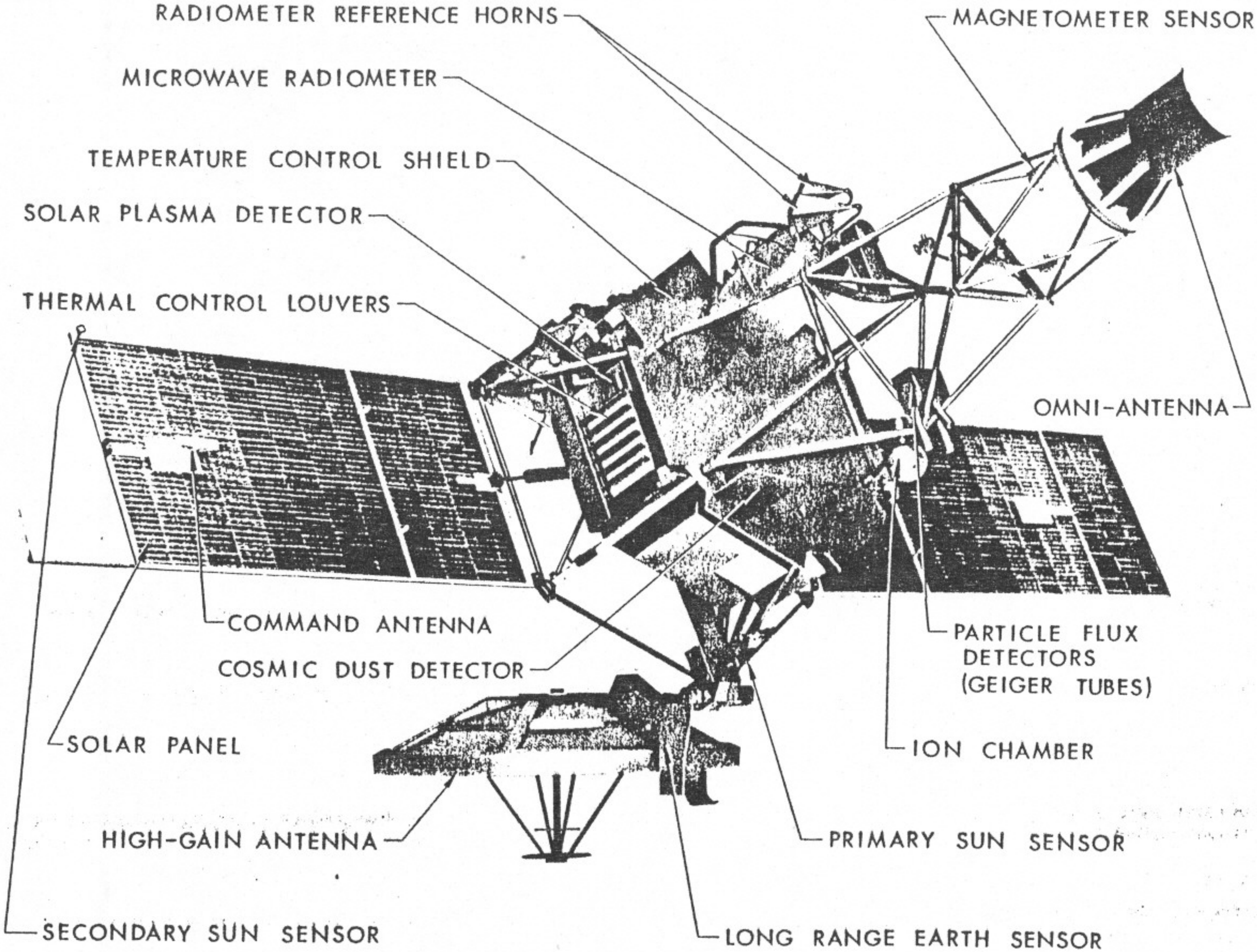

Fig. 1. *Mariner* Venus (1962) spacecraft model

conducted without major incident. A threatened aerospace strike did create some concern; however, the immediate threat was forestalled by a Presidential request for a 60-day extension of the strike deadline.

Both spacecraft were prepared as fully flight-ready units in case of failure during the final prelaunch operations. The planned mode of operation in case of spacecraft failure was to replace the entire spacecraft, adapter, and shroud, and to proceed in the next available launch window. It never became necessary to perform such a replacement as the spacecraft performed satisfactorily during the on-vehicle tests.

1. Mariner 1

Mariner 1–*Atlas* D 145–*Agena* B 3901 was launched at 09:21:23 GTM on July 22, 1962, from Complex 12, AMR. The first countdown had been cancelled on July 21 due to some anomalies that had occurred during the Range Safety system (command destruct) checks.

Liftoff occurred normally and the spacecraft operated throughout: booster engine cutoff, booster separation, and sustainer engine cutoff.

Just prior to *Atlas–Agena* separation, the flight was terminated by Range Safety action 293 sec after liftoff; the vehicle was in an "out-of-control" condition. The JPL Launch Station lost lock momentarily with the spacecraft transponder signal upon booster destruction, but re-acquired the signal 3 sec later and maintained contact intermittently for 1 min 38 sec.

The performance of the *Mariner* 1 spacecraft throughout its brief flight was quite satisfactory. From the standpoint of spacecraft design, probably the most significant aspect of the aborted mission was the fact that, when the launch vehicle was destroyed, the spacecraft had already passed through the region of maximum vibration, and all subsystems were apparently performing normally. (The principal subsystems operating at liftoff are the central computer and sequencer, transmitter, telemetry data encoder, and gyros.)

The findings of the Postflight Review Board were as follows: "The failure of the *Mariner* 1 mission was the result of a missile-borne . . . rate beacon malfunction and the omission of a data editing function in the guidance equation, neither of which alone would have caused failure. Because the data editing function should have been able to compensate for the rate beacon malfunction, the primary cause of mission failure is attributed to the omission in data editing."

2. Mariner 2

Mariner 2–*Atlas* D 179–*Agena* B 6902 was launched at 06:53:14 GMT on August 27, 1962 from Complex 12, AMR (Fig. 2). The first countdown had been cancelled on August 26 (GMT) due to a Range Safety problem of a stray voltage in the command destruct system.

The *Atlas* first stage performed nominally, except for a period of 60 sec (10 sec prior to, to 50 sec after, booster-engine cutoff) during which time the vehicle displayed a hard-over roll rate due to a malfunction of one of the vernier engines. The vehicle thereafter stabilized and performed nominally until *Agena* separation.

The *Agena* second stage booster vehicle performed nominally, and the *Mariner* 2 spacecraft was injected into a near-nominal Venus encounter trajectory at liftoff plus 26 min 3 sec. All spacecraft operations were normal, including signal acquisition. The cruise science instruments aboard spacecraft were turned on by ground radio command from the DSIF station in South Africa at 16:13 GMT August 29. All instruments responded and appear to be working normally.

Earth acquisition by *Mariner* 2 occurred as a result of the scheduled command by the central computer and sequencer on September 2, and all functions were considered to be normal. The only possible exception to completely normal operation was the indicated Earth sensor "Earth brightness" measurement, which was lower in intensity than expected. Earth lock and antenna positioning, however, appear normal.

In order to more thoroughly analyze the telemetry during and subsequent to Earth acquisition, the midcourse trajectory correction maneuver was delayed from September 3 to September 4. Trajectory corrections were successfully performed at 00:23 GMT September 5 as a result of ground radio commands transmitted from the DSIF station at Goldstone, California, on September 4; the spacecraft then made its scheduled return to cruise mode operation. The predicted miss distance was changed from an uncorrected 370,000 km to 15,000 km, and the time-of-arrival at Venus was changed from 20:42 GMT December 13 to 17:45 GMT December 14.

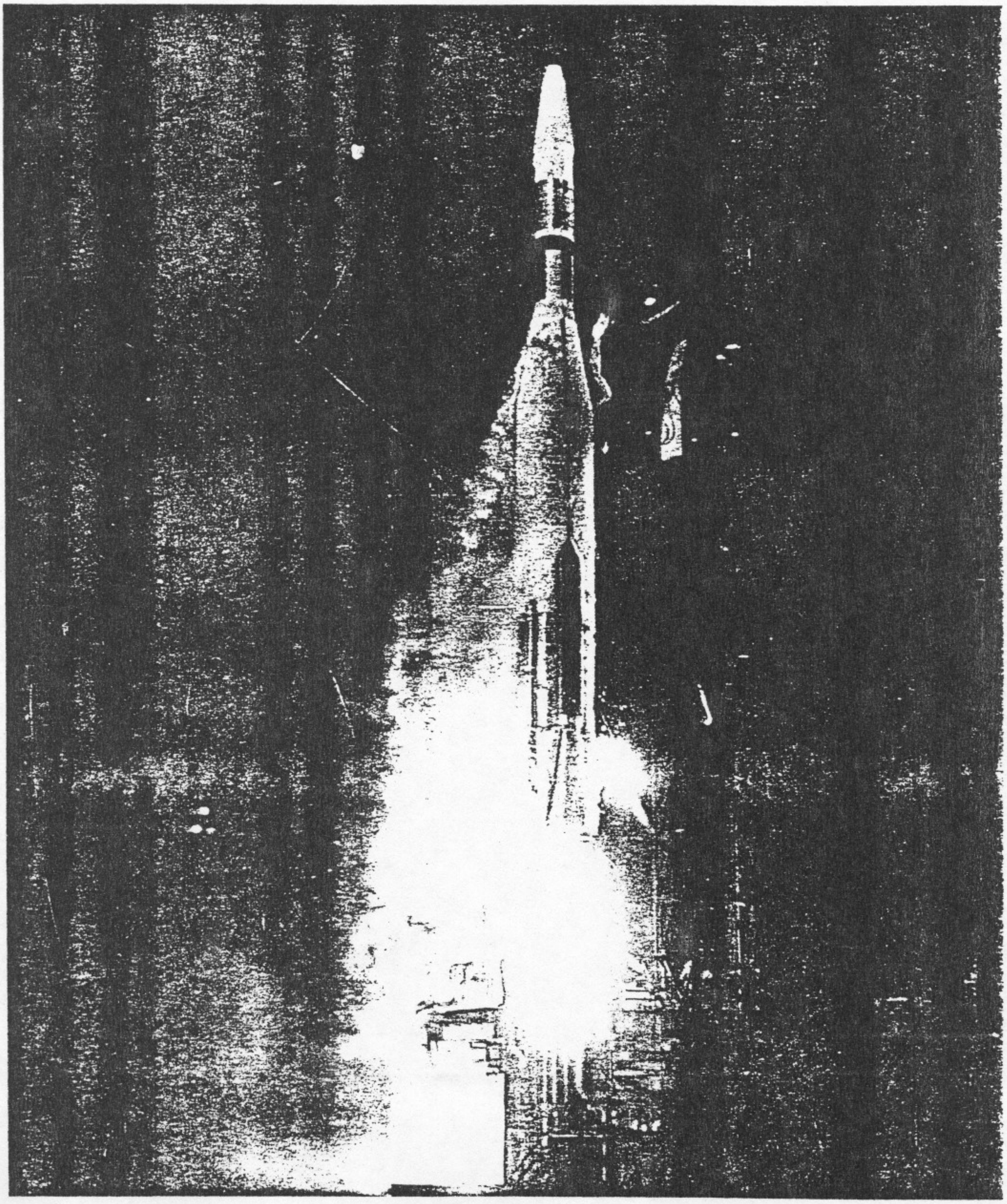

Fig. 2. *Mariner 2*

C. Preflight Operations

1. Mariner 1

Precountdown checks were completed on July 19, 1962. The *Mariner* 1 spacecraft, having been operationally checked out and carefully analyzed by cognizant persons in all areas, was considered to be ready for flight. *Mariner* 2 had also been made flight ready to give maximum support for fulfilling the *Mariner* mission early in the Venus launch period.

2. Mariner 2

Three complete, and one modified, AMR system tests were run performed on *Mariner* 2 prior to the *Mariner* 1 launch. The same emphasis on testing and analysis was applied to *Mariner* 2 that was given to *Mariner* 1. The modified system test was run which exercised every function of the attitude control system, central computer and sequencer, and the infrared and microwave radiometers. The test was successful and verified the *Mariner* 2 flight readiness.

Explosive Safe Area (ESA) tests were again performed after the flight preparations were completed; the spacecraft was moved to the ESA on July 13. A special test was performed to verify that the attitude control gas system nozzles were acceptable for flight. The attitude control pressurization was completed on July 15.

The spacecraft was stored in the capsule lab on July 16 in a flight-ready condition with a protective covering and dry nitrogen purging. The spacecraft then was moved to the assembly building on July 19, where it remained until July 23 to support *Mariner* 1 launch in standby condition.

If needed, *Mariner* 2 was capable of being moved to Launch Complex 12 within 4 to 6 hr, the time required to install the flight battery, install the shroud and perform final electrical tests.

Following the *Mariner* 1 launch, additional tests, including a fourth AMR system test, were performed on *Mariner* 2. On August 13, the spacecraft flight squibs were installed and checked out, mating with *Agena* adapter was completed, and attitude control pressurization was started.

Shroud-off and shroud-on electrical tests were completed satisfactorily on August 14. The only difficulty experienced was in the dummy-run trailer blockhouse data encoder GSE. Breadboard launch complex checkout for the central computer and sequencer was performed immediately following the shroud-on tests. All functions checked out satisfactorily.

Before installation of the shroud, a thorough inspection was performed, and all protective (nonflight) equipments were removed, except the Earth sensor cover, which was removed on the pad after mating with the *Agena*. All subsystem, system and program personnel were permitted to inspect the spacecraft before the shroud was installed.

The spacecraft was continuously purged with dry nitrogen in flight-ready configuration with shroud on (except for the flight battery). Engineering measurements were made several times with spacecraft power on during the period between August 15, and August 22. All readings were in tolerance with the exception of the mid-course motor propellant tank pressure which showed a 20-psi increase in pressure over a 5-day period; this increase was not considered to warrant concern.

Final ESA operations were completed on August 23, and the spacecraft was moved to Complex 12 on August 24. Precountdown checks were performed on August 24 and the spacecraft was verified as ready for launch.

D. Trajectory Considerations

Trajectories for *Mariner* missions to the planet Venus in the year 1964 are characterized by injection energies significantly higher than the energies associated with the Venus (1962) trajectories. This results in a situation wherein the current performance of the *Atlas/Agena* D launch vehicle must be increased in order to provide a reasonable length period in which to launch an essentially unchanged 1962 design *Mariner* spacecraft. In view of this situation, it has been suggested by JPL through Marshall Space Flight Center that Lockheed Missiles and Space Company (LMSC) and General Dynamics/Astronautics undertake a comprehensive study of all possible methods for increasing the payload capability of the *Atlas/Agena* D. Improvement measures to be studied were constrained to those which would jeopardize neither the reliability nor availability of the launch vehicle system for 1964 missions.

After several meetings, it was decided that study efforts should include several possible configurations which could meet the 1964 performance requirement independent of the outcome of discussions regarding *Agena* D improvement and the standardized *Atlas* programs.

Three configurations have been proposed by LMSC. Preliminary performance estimates in terms of the maximum launch period possible with a 446-lb spacecraft are 42, 37, and 35 days.

E. Spacecraft and Component Testing

1. Antenna Pattern Measurements

Radiation pattern measurements on a full-size *Mariner* (1962) spacecraft mockup have been completed for the forward omnidirectional antenna, and for the command antennas. Because of a lack of time, on-vehicle patterns of the high gain antenna were not made. However, sufficient patterns of the high gain antenna alone have been made to ensure proper analysis of its performance.

Fig. 3 shows the spacecraft mockup mounted on the rotator used for taking the antenna patterns; Fig. 4 is a representative pattern of the forward omni-antenna, taken at 960 Mc; and Fig. 5 is a representative pattern of the command antennas, taken at 890 Mc. The patterns indicated that program requirements for the omnidirectional and command antennas have been met.

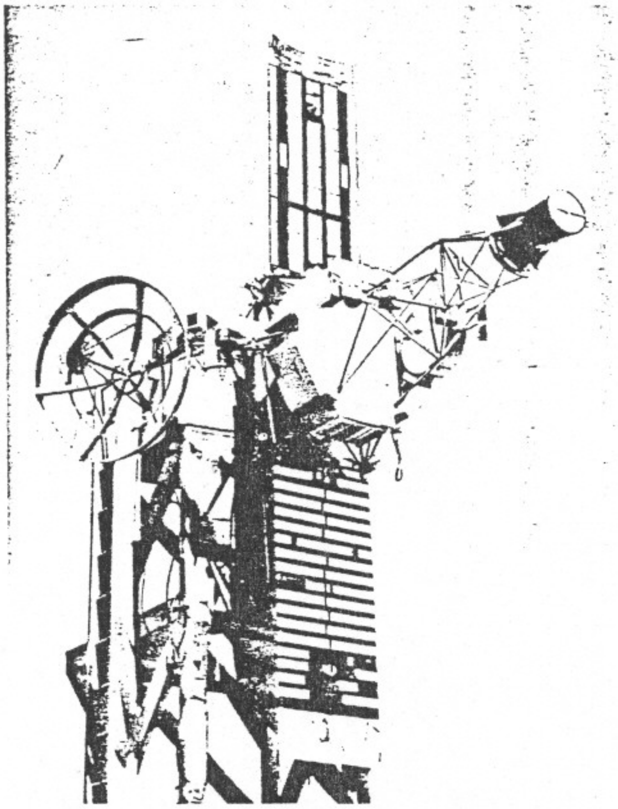

Fig. 3. *Mariner* mockup mounted on antenna-range spacecraft rotator

2. Vibration and Space Simulation Testing

During July a standard *Mariner* (1962) solar panel was tested with various damping structures to determine the most effective design to reduce the vibration amplification at resonance. Nine damper configurations were evaluated over the range 8 to 200 cps with the panel attached to the *Mariner* structural test model. Resonance gain was reduced by a factor of 5. The results are applicable to *Ranger* solar panel damping as well as to *Mariner*.

The *Mariner* solar panel was tested in the 6-ft space simulator (Fig. 6) to evaluate its front-to-back thermal absorptivity and emissivity. The environment was: vacuum, 10^{-4} mm Hg or better; wall temperature, $-300°F$; solar simulation temperature of the solar panel ranged from ambient to 70°C.

Thirty-two 150-w heat lamps were mounted to a frame which allowed their radiation to be directed uniformly across the entire front side of the solar panel. The heat lamps were held to a constant intensity until the temperature of the panel had stabilized. This procedure was repeated at seven different lamp intensities.

3. Environmental Specifications

Environmental specifications to simulate *Mariner* launch and flight conditions are used as the bases for system type approval testing and flight acceptance testing. These specifications are periodically reviewed and up-dated in accordance with project policy. They do not define the unit functional tests or the unit pass-or-fail criteria. Some interpretation of the specifications is required in order to determine the degree of applicability to specific com-

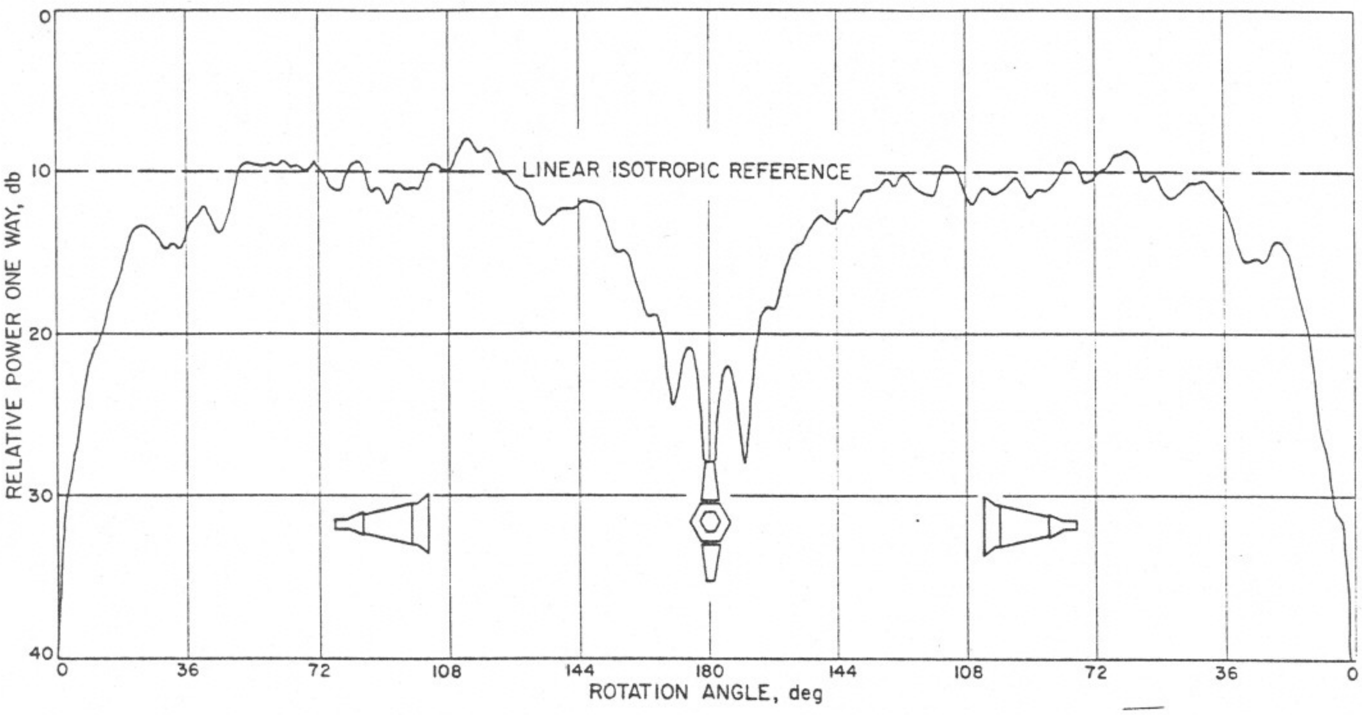

Fig. 4. *Mariner* omni-antenna radiation pattern

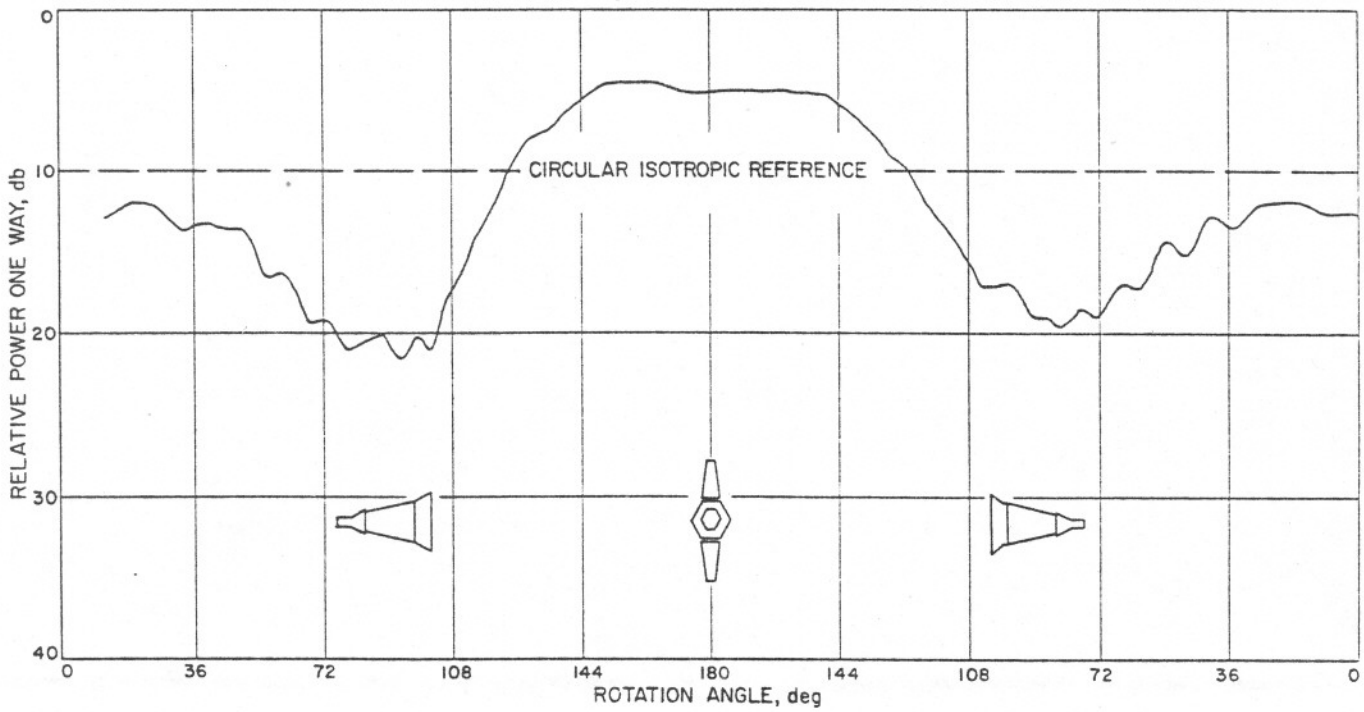

Fig. 5. Command antenna radiation pattern

ponent items on the spacecraft. For this reason, the component cognizant engineers have provided the test specifications for their own equipment, including all functional tests, pass-fail criteria, and environmental tests, along with permissible deviations due to location, flight sequence, and past history of similar hardware.

4. Environmental Test Facilities

a. Mariner *life test facility.* A *Mariner* life test facility is scheduled for completion late in 1962. The chamber will be used to make vacuum–thermal life tests, without solar simulation, on a complete *Mariner* spacecraft. The minimum duration of a test is expected to be 5 months.

The test chamber will be a horizontal stainless steel tank, 7 ft in diameter by 14 ft long with a shrouded test volume 6 ft in diameter by 12 ft long. The chamber will be lined with a copper shroud through which circulates pressurized nitrogen gas furnishing controlled temperatures from −100°F to 150°F. The shroud will be adequate for liquid nitrogen temperatures if such service is required. The chamber will be back-filled with nitrogen to minimize contamination.

b. The 25-ft space simulator. The 25-ft space simulator was not completed on schedule in time for the *Mariner* (1962) environmental tests. However, vacuum plus cold-wall tests were possible in the uncompleted facility using a JPL-constructed *Mariner* mount and auxiliary cold wall. These tests were conducted during March and April 1962. Since April 30 the contractor, Consolidated Vacuum Corporation, has been engaged full time in completing the facility.

A series of tests was recently conducted by JPL with virtual source mirrors designed to illuminate a 5-ft off-the-axis area in the 25-ft simulator. The system will provide an intensity of 135 w/ft^2 with 131 mercury-xenon arc lamps. This system will be used temporarily for testing *Mariner* and *Ranger* spacecraft in the 25-ft space simulator until plans for major improvements can be formulated.

A test frame 40 ft in height has been erected to provide a large-scale "optical bench" for testing full-scale solar simulation systems. Landings at every 7 ft will permit the suspension of lamp arrays and associated optics. This facility will be used initially to upgrade the operation of the 5-ft off-axis solar simulation system.

c. Advanced solar simulation development. A new optical system is being considered by JPL for large solar simulators and will be investigated both analytically and experimentally. A preliminary analysis indicates that this system will produce a uniformly illuminated test volume about 13 ft in diameter at the Venus-distance intensity of 275 w/ft^2. This system contains approximately 90 identical lamp–reflector–lens units whose output energy is collected on a single reflector inside the chamber and which in turn illuminates a final off-axis mirror about 15 ft in diameter.

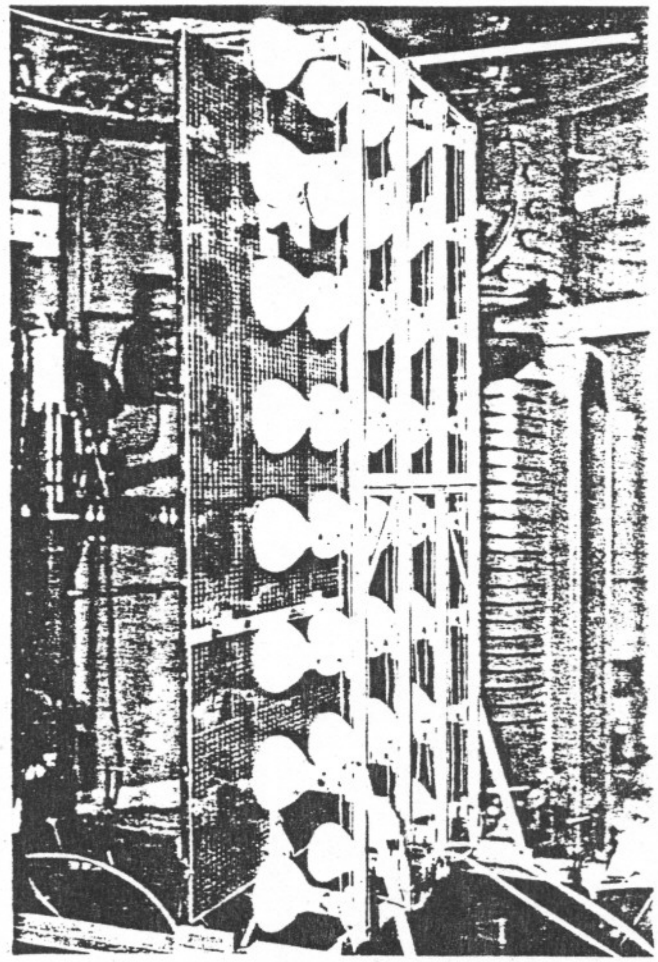

Fig. 6. Solar panel test using 6-ft space simulator

d. Carbon arc tests. A significant development in solar simulation equipment is the extension in continuous operating time of the carbon arc lamp. The new Strong Acromatic carbon arc lamp can operate 50 min without electrode loading and may also be equipped with magazine loaders for continuous operation up to 24 hr.

F. Development

1. Secondary Power

a. Mariner *2 flight results.* *Mariner* 2 solar panel extension and Sun acquisition appear to have occurred properly, having been completed in about 5 min. Because of the short acquisition time, the amount of energy drained from the battery was fairly small.

The solar panel power capability appears to be more than adequate. Preliminary estimates indicate a power capability of about 167 w at the estimated battery open circuit voltage of 28.5 v; the spacecraft demand of about 137 w at this time resulted in a 30 w switching margin.

Solar panel front temperatures have increased from initial values of about 75°F to stabilize at 125°F and 128°F. The panel back temperature had stabilized at 77°F for one of the panels.

During the near-Earth cruise period, with the battery fully charged and with the cruise science load energized, there was a power margin of about 50 w. This margin is sufficient to allow battery charging and science to be on concurrently. Therefore, following the *Mariner* 2 midcourse maneuver, the science experiments were permitted to remain on while the battery was recharging.

b. **Mariner** *1.* Data from the telemetry channels showed that the *Mariner* 1 spacecraft was functioning properly during prelaunch and flight. Following liftoff, the power system operated normally until destruct time.

c. Battery performance. The *Mariner* battery type approval or design testing program has been completed. This testing was terminated with the removal of the type approval Battery 3 (TA 80°F) from the temperature–vacuum chamber on July 13, after 5 months of simulated space flight. The final phase of this test prior to removal from the test chamber consisted of a discharge of 1.3 amp for 18 hr followed by several days in the open circuit mode. During the 18 hr of discharge, the battery voltage remained above the required minimum. During the subsequent open circuit period, the voltage of three cells dropped to zero, indicating the presence of internal short circuits. The components of all cells in this battery are undergoing a detailed examination to determine the cause of these shorts. This battery had passed the *Mariner* test requirements.

2. Central Computer and Sequencer

The *Mariner* (1962) central computer and sequencer (CC&S) is responsible for all spacecraft time-sequenced events, excluding the science experiment sequence. In performing this function, the CC&S must keep track of spacecraft time after launch and must execute commands at predetermined times as well as at Earth command times during the *Mariner* mission.

A total of three CC&S flight subsystems was delivered to Spacecraft Assembly Facility to support the two *Mariner* (1962) launches. The first CC&S subsystem was assigned to the *Mariner* 1 spacecraft, and after spacecraft integration and extensive testing was launched as part of the *Mariner* 1 spacecraft. The CC&S subsystem appeared to function satisfactorily for 5 min after launch at which time the boost vehicle was destroyed by AMR Range Safety. Telemetry information indicated that the CC&S operated normally for an additional 1 min after the booster was destroyed.

The second *Mariner* CC&S subsystem was assigned to the *Mariner* 2 spacecraft and was flown as part of that system. Telemetry thus far indicates normal CC&S performance.

The third subsystem was assigned to the spare spacecraft and will be employed in future tests as part of that system.

The next possible Venus launch will be early 1964. It is planned that the present *Mariner* design, with minor modifications, will be used to provide CC&S subsystems for these missions. Present plans call for three CC&S flight subsystems to support these launchings. In addition, proof test model (PTM) and type approval (TA) subsystems will be built.

Minor modifications will be made to the present *Mariner* circuit design to incorporate improvements as a result of *Mariner* (1962) testing, integration and flight experience. Fabrication of the first two PTM and TA CC&S subsystems will begin, at JPL, in September 1962.

The design of the present *Mariner* CC&S incorporated the use of the most reliable components available, consistent with subsystem delivery dates. High reliability has been attained by the use of *Minuteman* and JPL component specifications. To date, no component failures have occurred during normal CC&S operation on any of the three *Mariner* subsystems delivered for spacecraft integration. The three subsystems have logged an approximate total operating time of 1500 hr.

3. Mariner (1962) Command Subsystem

The *Mariner* command subsystem provides the capability to initiate any of 12 independent events aboard

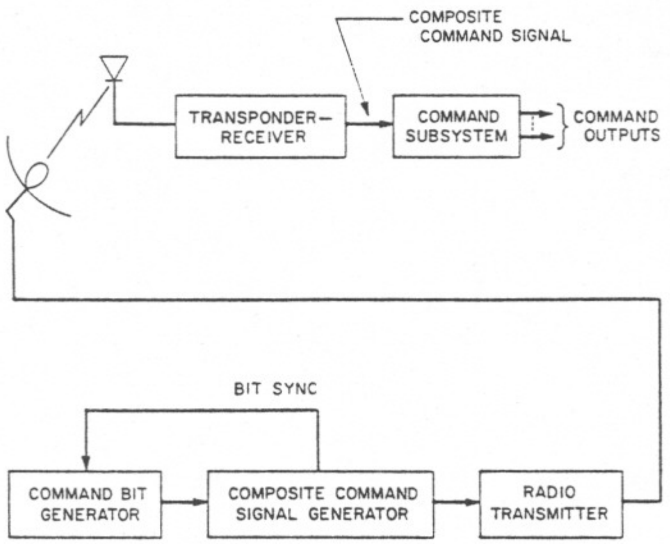

Fig. 7. *Mariner* (1962) command flow diagram

the spacecraft and the capability to transmit the 18-bit mid-course maneuver parameters to the spacecraft central computer and sequencer. The basic elements of the command link are presented in Fig. 7. Each command which is to be transmitted to the spacecraft is encoded in the standard binary command word format. The command word modulates a command information subcarrier signal. This subcarrier is combined with a synchronization code, and the resultant combined command signal is transmitted to the spacecraft over the 890-Mc radio link. The received combined command signal is applied to the command subsystem. The command detector recovers the transmitted command word. The command decoder identifies the command and then issues the appropriate command signals to the designated spacecraft subsystem.

The *Mariner* (1962) command subsystem is significantly different from the command subsystems of the *Ranger* spacecraft:

(1) A different form of modulation and detection is employed.

(2) Sophisticated "worst case" circuit designs were employed which utilized high reliability components.

(3) A unique package design was developed which utilized encapsulated circuit modules.

a. Modulation and detection. The *Ranger* command subsystem employed an asynchronous frequency shift-keyed subcarrier. Although this method of modulation provides adequate performance for lunar missions, a more optimum modulation scheme is required for the long duration, long range command operation involved in planetary exploration. The *Mariner* command subsystem employs a synchronously phase-shift-keyed command information subcarrier in conjunction with a pseudonoise digital synchronization code.

The *Mariner* detector has the distinct advantage that command action is prohibited unless the detector phase-locked loop is in-lock, and lock may be prevented merely by switching the composite command signal off. Since commands are infrequently transmitted, this ability to "turn-off" the command subsystem significantly decreases the probability of a false command.

b. Circuit design. Sophisticated "worst case" design practice was used on each circuit. This consisted of listing the performance requirements of each circuit, and then designing the circuit to operate satisfactorily under worst-case conditions: worst-case (1) power supply voltages, (2) temperature values, and (3) component parameter values (including life derating factor). Each circuit design was subsequently covered by a circuit report which listed the assumed worst-case range of each component parameter and listed the design equations. Since the circuits were individually packaged in encapsulated circuit modules, it was possible to check the circuit performance directly against the design equations. It is believed that the subsystem reliability is significantly improved by individually testing circuit modules prior to installing them in the subsystem.

c. Package design. The *Ranger* package design consisted of pre-assembled circuit boards which were then bonded to the web of a standard subchassis. The *Mariner* command subsystem employed a package design in which the circuit modules were sandwiched between two printed wiring boards with half of the circuit modules connecting to one board and half to the other (Fig. 8).

The "sandwich" is bonded together with contact cement to form a rigid structure. The sandwich assemblies are finally bolted into a standard outline subchassis (Fig. 9). This package design allows very dense packing of the circuit modules without encountering a prohibitively difficult interconnection problem. Also, the module interconnection solder joints are all visible after final assembly of the individual sandwiches.

Three production *Mariner* command subsystems were built. With the exception of a case of circuit damage

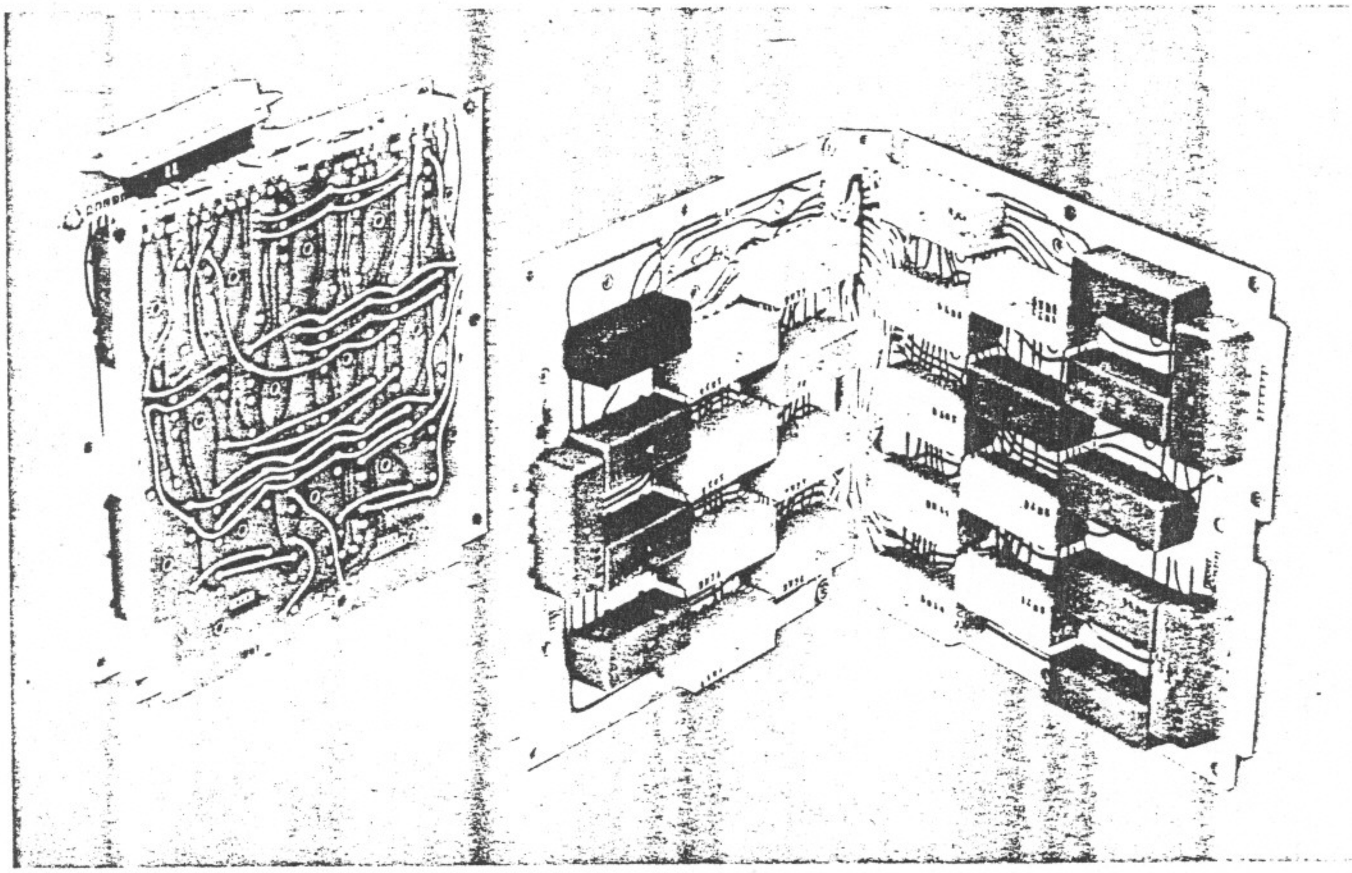

Fig. 8. Command subassembly circuit sandwich

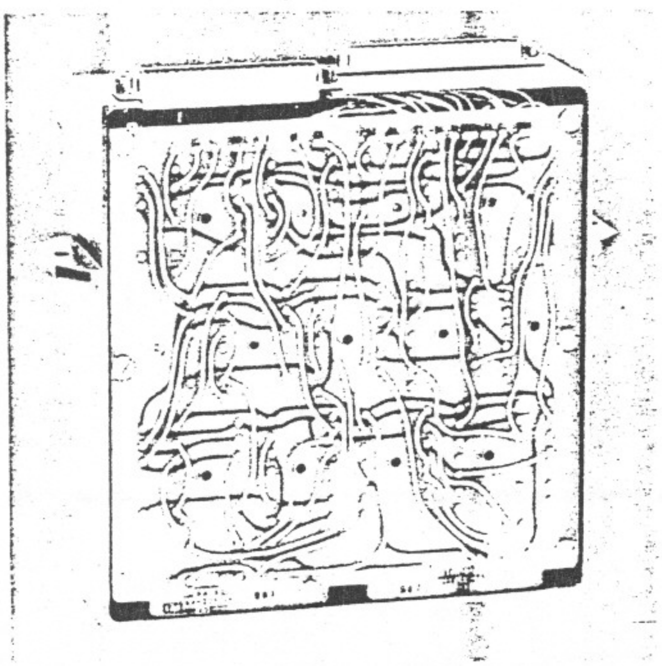

Fig. 9. Complete command subsystem

caused by improper connection of an external cable, no failures have been detected on any of the three subsystems. At the time of this writing, the *Mariner* 2 spacecraft is on its way to Venus and all attempted commands have been successfully executed.

4. Mid-course Propulsion System

a. Mariner *1.* The *Mariner* 1 propulsion system was fueled and pressurized on July 12. The pressures remained constant up to and through launch which occurred on July 21. Based on telemetry data the *Mariner* 1 propulsion system remained leaktight and apparently suffered no damage during the *Atlas* boost phase up to the time of vehicle destruct by AMR Range Safety.

b. Mariner 2. The second *Mariner* propulsion system was fueled and pressurized on July 6. The pressures remained constant uo to the time the propulsion system was installed in the *Mariner* 2 spacecraft on July 14. The *Mariner* 2 spacecraft remained in a flight-ready backup condition through the *Mariner* 1 launch. The propulsion system was removed from the *Mariner* 2 spacecraft on July 23, and it was noted that the fuel tank pressure had dropped to zero psig. Subsequent evaluation indicated that the beryllium copper diaphragm in the nitrogen regulator was leaking and had allowed the propellant tank to vent down. The regulator was replaced and the tank again pressurized. A new regulator with stronger and more compatible diaphragm was shipped to AMR and installed on the third (spare) propulsion system.

As a result of a propellant tank pressure rise which started to occur roughly 1 month after the second unit was initially fueled and the fact that the third propulsion system was equipped with an improved regulator, the third propulsion system was fueled and pressurized on August 11, for utilization in the *Mariner* 2 spacecraft.

The third propulsion system was fueled and pressurized 3 days prior to installation in the spacecraft on August 13. The propulsion system pressures remained constant during the 3-day monitoring period. After installation in the spacecraft and during the 13-day period up to *Mariner* 2 launch, a fuel tank pressure rise of, roughly, 3 psi/day was witnessed and recorded by telemetry. It was felt that the pressure rise was not excessive and would not jeopardize the engine operation at midcourse.

With regard to the propellant tank pressure rise noted in both the second and third propulsion systems, it is felt that an incompatibility exists between the N_2H_4 and the particular butyl compound employed in the propellant bladder. Tests are being conducted to determine what incompatible constituents are present in the butyl compound used in the *Mariner* propellant bladders.

V. *Voyager* Project

The primary objective of the *Voyager* Project is the scientific exploration of Mars and Venus by means of spacecraft designed for use with *Saturn* boost vehicles. Secondary objectives are the scientific exploration of interplanetary space in the Mars–Venus region, and the determination of the feasibility of, the development of technology for, and the collection of scientific data necessary to, successful manned flights to these planets.

The *Voyager* Project is currently in the planning phase. An Advanced Planetary Spacecraft Study Committee has been organized to determine possible mission objectives and design concepts of *Voyager* and later spacecraft for use on the *Saturn* class of boost vehicle. Conventional spacecraft designs as well as designs incorporating advanced propulsion techniques are being analyzed.

A. Propulsion

A study of *Voyager* propulsion system requirements for Mars and Venus orbiters has been completed. Early estimates of the propulsion system mass and configuration are required for preliminary designs of the spacecraft. This is true because the propulsion system for orbiters represents 60 to 80% of the total spacecraft mass. In comparison, planetary flyby and lander missions require propulsion systems of less than 10% of the spacecraft mass, assuming the use of atmospheric braking.

A range of gross spacecraft mass from 5,000 to 20,000 lb has been assumed in comparing various propulsion system concepts. Spacecraft velocity increments required for the various maneuvers (mid-course corrections, terminal corrections, orbiting retro and possibly orbit trim) were estimated from computer trajectory analyses and estimates of guidance system accuracies.

A wide variety of chemical propulsion system concepts and propellant combinations was given preliminary consideration. Of these, three systems were selected for more detailed study on the basis of potential reliability, simplicity of design and operation, and payload performance:

(1) Solid–storable liquid.

(2) All-storable liquid.

(3) Cryogenic liquid–storable liquid.

For each of the selected systems, thrust, chamber pressure and nozzle expansion ratio were chosen so as to maximize payload. These optimizations include the effects of spacecraft shroud mass, interstage structural mass, and gravity-burning-time losses during retro operation, as well as propulsion system mass and motor performance.

Since variations in the payload (nonpropulsion system mass) capabilities among the three optimized systems are found to be small, the choice of a *Voyager* propulsion system will be based on factors other than performance; such factors include (1) the degree of success in certain critical advanced developments implied in the selected systems, and (2) the relationships of propulsion system configuration and storage temperatures to those of other spacecraft systems.

A separate part of the study concerns the selection of trajectory characteristics to maximize orbited payload. The maxima are obtained for selected firing periods using the payload versus velocity-increment characteristics of typical boost systems and of typical spacecraft propulsion systems together with computed trajectory relationships generated for specific planetary opportunities. If the spacecraft propellant load can be varied continuously in an optimal manner for different firing dates, the additional degree of freedom in the payload optimization procedure can result in larger payloads for any prescribed firing period. However, this is not always the case, and the small payload increase would not warrant the complications in the launch operations brought about by having to make changes in the spacecraft propellant load during the firing period.

Any of the three selected propulsion systems can be designed for variable propellant loading. For the solid–storable liquid system (System 1), this is most easily accomplished by designing the system with a relatively large vernier propellant load which is varied as the firing date progresses.