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The Voyage of Mariner 10

Mission to Venus and Mercury

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Prepared by
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California Institute of Technology

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National Aeronautics and Space Administration
Washington, DC

Introduction

RARELY IN THE LIFETIME of an individual is he privileged to witness and be part of an historic first for mankind. Such has been my privilege. Even more rarely is one privileged to be part of such a dedicated, competent, and professional group as comprised the Mariner Venus/Mercury Project Team. It was a moderately small group of diverse talents, dedicated to accomplishing an historic scientific voyage to Mercury by way of Venus, and to do it within tight schedule and cost constraints.

These people met and exceeded the challenges and further distinguished themselves several times during the flight of Mariner 10 when emergencies were encountered which threatened the success of the mission. Their professional response to these emergencies proved the competence of this truly remarkable team of NASA, Boeing, Philco-Ford, Planning Research Corporation, university, and Jet Propulsion Laboratory people. Without this team the exciting discoveries made on the Mariner 10 flight to Venus and Mercury would not have been possible.

W. Eugene Giberson
Mariner Venus/Mercury Project Manager
Jet Propulsion Laboratory

Chapter 2

Mariner Venus-Mercury Mission

THE GRAVITY-ASSIST trajectory technique which was needed to obtain an economically acceptable mission to Mercury resulted from over 20 years of speculation, scientific research, and engineering development. The technique allows a spacecraft to change both its direction and speed without expenditure of propellant, thereby saving time and increasing scientific payload on interplanetary missions. By its use an acceptable payload could be launched to Mercury by an Atlas/Centaur. The much larger and more costly Titan III C/Centaur would be required for a direct flight to the innermost planet.

The concept of gravity-assist interplanetary missions first received serious attention in the literature of the 1950's, though multiple-planet orbits had been considered during the 1920's and 30's.

In the following years the concept was utilized mainly in studies of round-trip interplanetary flights in which the spacecraft leaves the Earth, flies by several planets, and returns to Earth. The first systematic development of the gravity-assist technique was performed at the Jet Propulsion Laboratory, Pasadena, California, in the early 1960's. Previously, such multiple-planet trajectories had been sought by inspecting computer-generated listings of parts of flight paths, such as the Earth–Venus and Venus–Earth components, and matching them in regard to velocities and time. An Earth–Venus–Earth round trip had been discovered by this method, and JPL trajectory designers next developed a mathematical technique for searching out gravity-assist trajectories so that they were able to program the equations for processing on a digital computer. They soon discovered the existence of Earth–Venus–Mercury trajectory opportunities for 1970 and 1973, but found that the gravity-assist trajectory was extremely sensitive to errors in aiming the spacecraft toward the first planet, suggesting that a new kind of guidance might be necessary to make the technique practicable. Further analysis revealed, however, that there were actually no barriers in contemporary guidance technology to prevent a multiple-planet mission. As a result, detailed plans and a navigation strategy for the 1970 Venus–Mercury opportunity were prepared, establishing its practical feasibility as a space mission.

Early in 1970, Guiseppe Colombo of the Institute of Applied Mechanics in Padua, Italy, who had been invited to JPL to participate in a conference on the Earth–Venus–Mercury mission, noted that in the 1973 mission the period of the spacecraft's orbit, after it flew by Mercury, would be very close to twice the period of Mercury itself. He suggested that a second encounter with Mercury could be achieved. An analytical study conducted by JPL confirmed Colombo's suggestion and showed that by careful choice of the Mercury flyby point, a gravity turn could be made that would return the spacecraft to Mercury six months later.

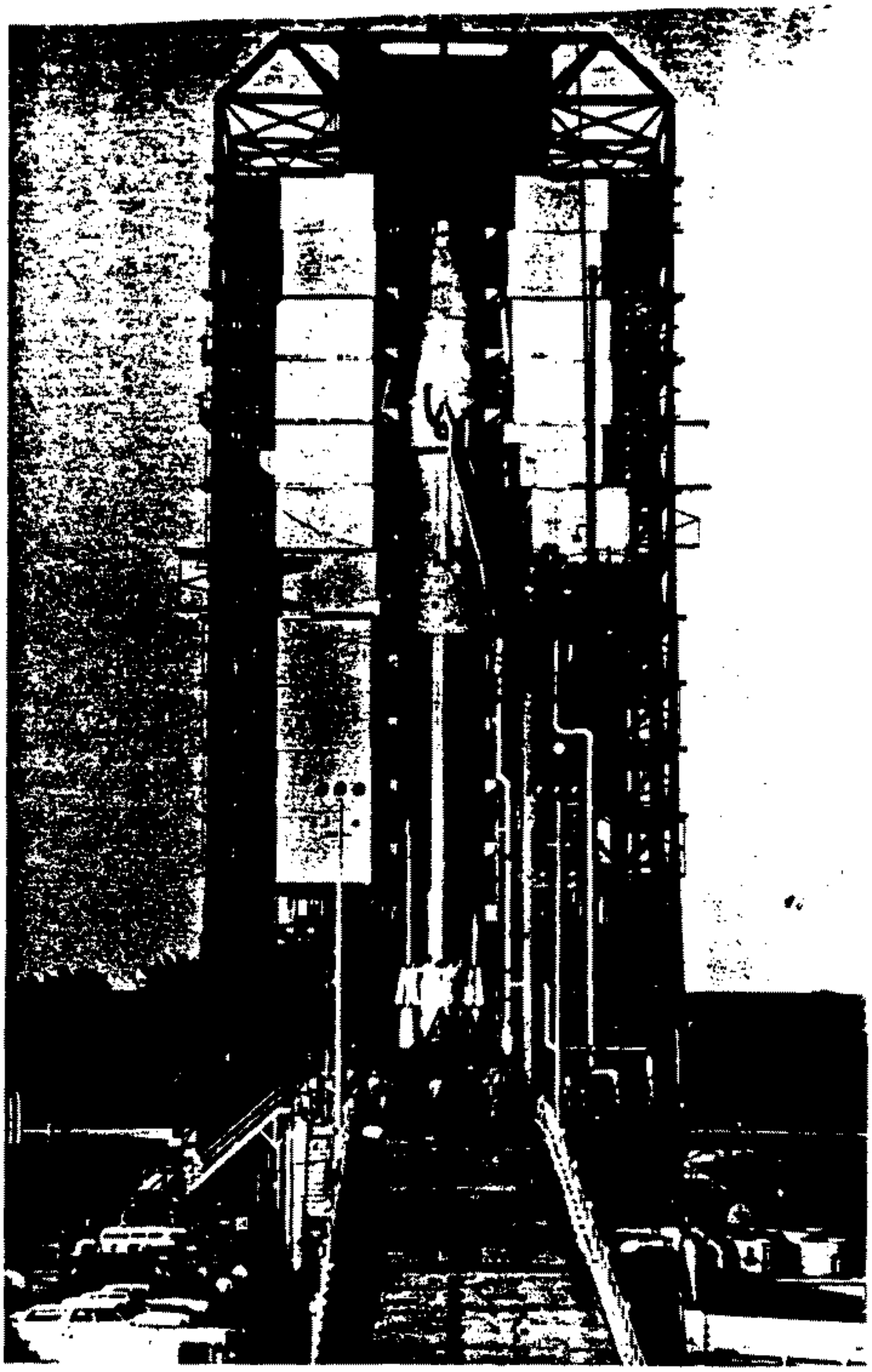


Fig. 2-1. The Atlas/Centaur provided the necessary launch capability for the Venus swingby to Mercury.

In June 1968, the Space Science Board of the National Academy of Science completed a planetary exploration study in which the mission to Mercury via Venus was endorsed. The Board recommended that a 1973 launch opportunity be aimed for and suggested some of the scientific experiments that might be carried out on the mission.

Approved by NASA in 1969, the mission which resulted from this recommendation involved the scientific community early enough for scientists to contribute to decisions concerning design of the spacecraft and selection of its subsystems. The possibility of later conflict between mission constraints and science needs would thereby be reduced.

The National Aeronautics and Space Administration selected a group of scientists to represent the several disciplines that would be involved in the science payload of a mission to Mercury via

Venus, and a Science Steering Group was officially formed in September 1969. Its purpose was to recommend objectives for and plan a good science mission within tight monetary constraints, coordinating the requirements of teams for the individual instruments and participating in project design and tradeoff studies relevant to mission, spacecraft, and flight operations.

In January 1970, a Mariner Venus/Mercury project office was established at JPL, under the direction of Project Manager Walker E. Giberson. Experiments were selected by July 1970, and by July 1971 a contract was negotiated with the Boeing Company, Kent, Washington, for design and fabrication of two spacecraft: a flight spacecraft and a test spacecraft.

Overview of the Mission

The mission plan called for launching the spacecraft with an Atlas SLV-3D/Centaur D-1A launch vehicle (Fig. 2-1) between October 16 and November 21, 1973. From such a launch window the spacecraft could encounter Venus between February 4 and 6 and Mercury between March 27 and 31, 1974.

The proposed trajectory relied upon Venus's gravitational field to alter the spacecraft's flight path and speed relative to the Sun, such that the reduction in velocity would cause the spacecraft to fall closer to the Sun and therefore to cross Mercury's orbit at the exact time needed to encounter the planet (Fig. 2-2). Closest-approach altitudes at Venus and Mercury would be 5000 and 1000 km (3100 and 620 mi), respectively.

To meet the demands of the gravity-assist technique, Mariner Venus/Mercury had to be launched on an orbit around the Sun that would intercept the planet Venus with high precision. The spacecraft could not carry sufficient propellant for very large maneuvers after the encounter with Venus, and the trajectory to Venus demanded new levels of accuracy. At least two maneuvers to correct the trajectory would be needed between Earth and Venus and two more between Venus and Mercury. Flyby of Venus had

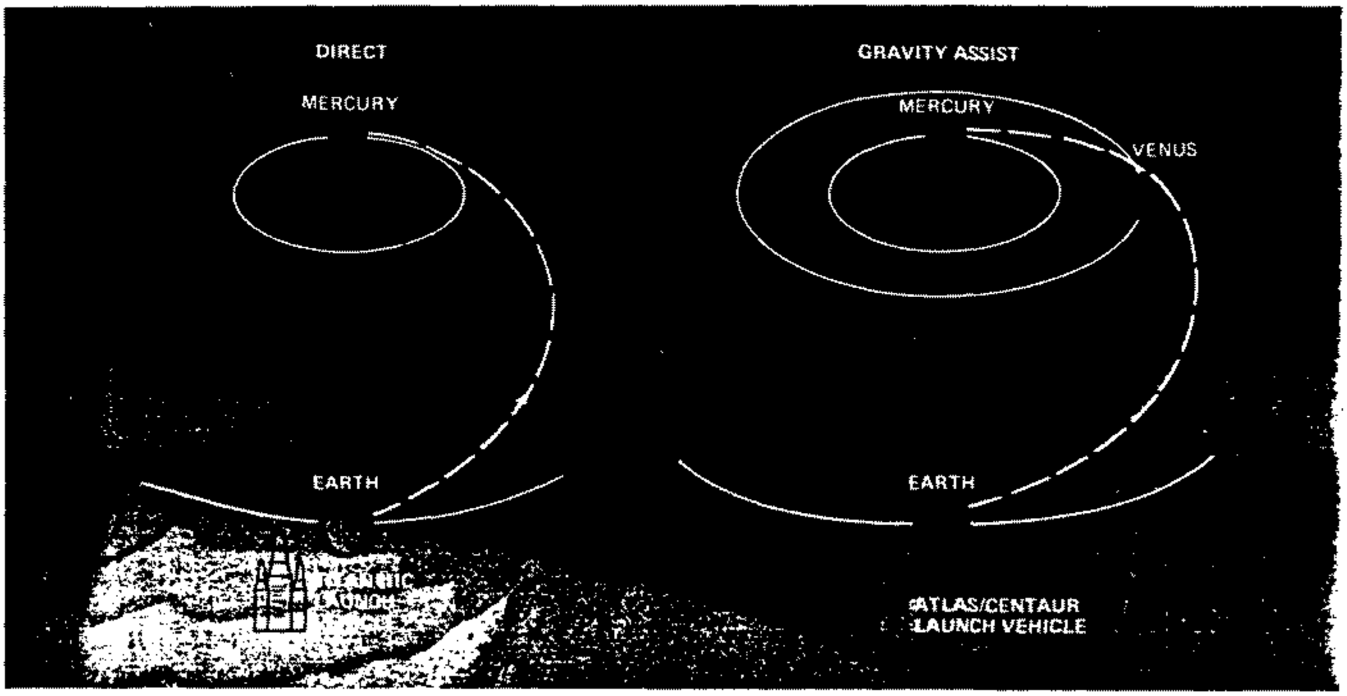


Fig. 2-2. The gravity-assist trajectory to Mercury uses the gravity and orbital motion of Venus to provide a slingshot that hurls a spacecraft into the inner Solar System without further use of propellants except for minor corrections to the trajectory. A direct flight to Mercury would require a much larger launch vehicle to deliver the same payload of scientific instruments without this Venus assist.

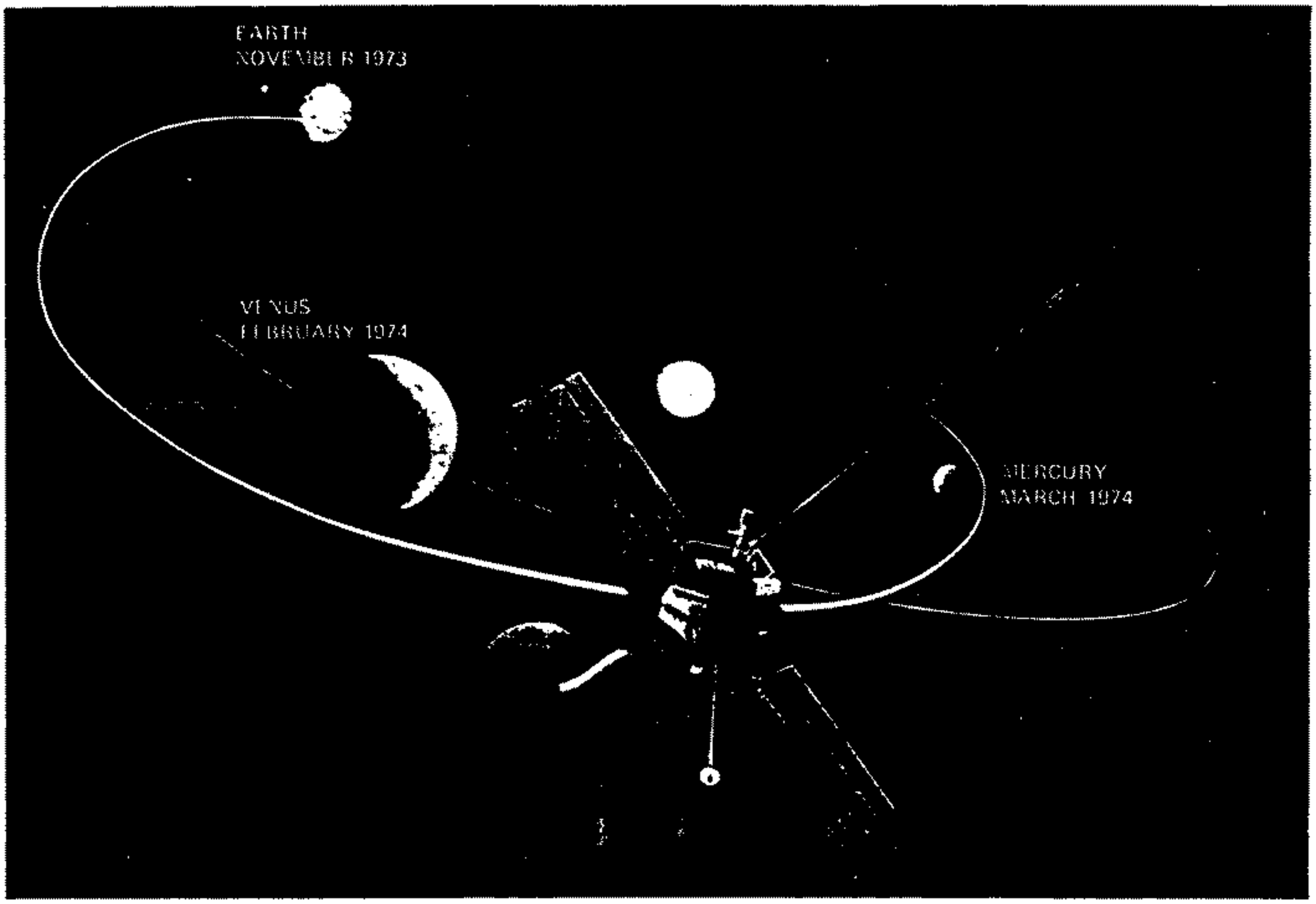


Fig. 2-3. Times of launch and arrival at the planets were clearly defined.

to be controlled within 400 km (250 mi), otherwise no Mercury encounter could take place.

In overview (Fig. 2-3), the mission would start with liftoff from Kennedy Space Center, the Centaur engine cutting off shortly thereafter, placing the spacecraft in a parking orbit which would carry it partway around the Earth for 25 min.

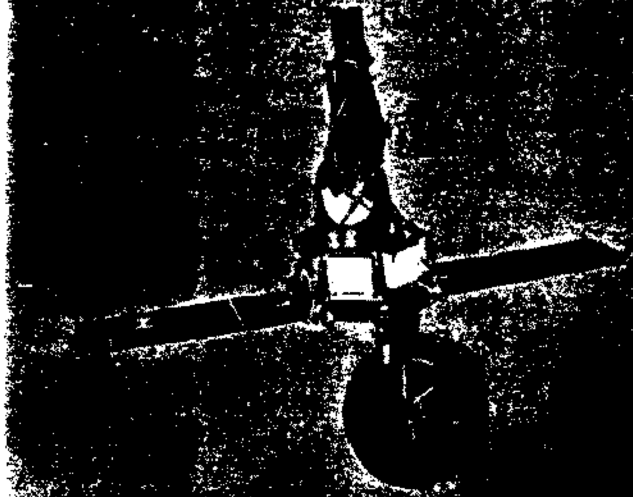
The Centaur then would burn a second time, thrusting Mariner in a direction opposite to the Earth's orbital motion. This direction was required to provide the spacecraft with a lower velocity relative to the Sun than Earth's orbital velocity, allowing the spacecraft to be drawn inwards in the Sun's gravitational field to achieve its encounter with Venus.

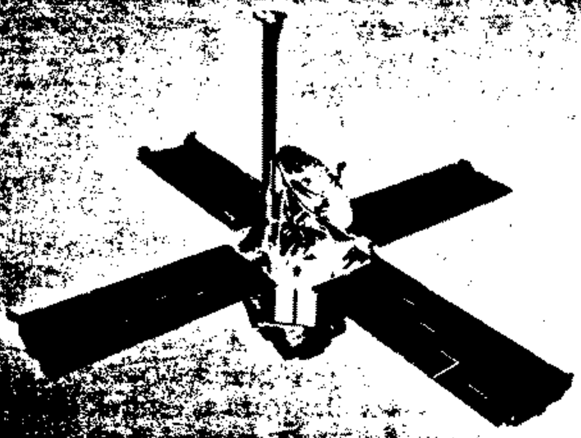
A few months later the Mariner spacecraft would approach Venus from the planet's dark side, passing over the sunlit side and, slowed by Venus, falling closer to the Sun to rendezvous with Mercury.

The Mariner 10 Spacecraft

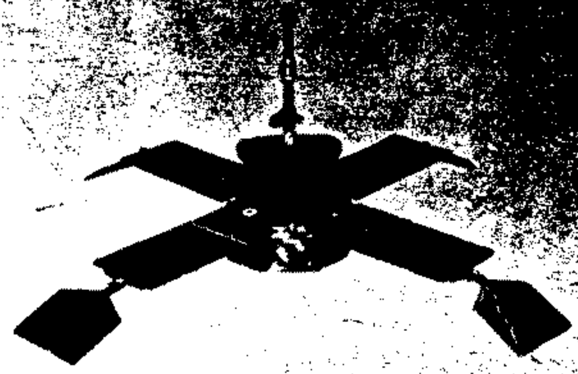
More than a decade of evolution of Mariner technology was continued by the Mariner Venus/Mercury 1973 spacecraft, which was the sixth of a series that began with Mariner Venus in 1962 and included Mariner Mars 1964, Mariner Venus 1967, Mariner Mars 1969 and Mariner Mars Orbiter 1971 (Figure 2-4). In common with

Fig. 2-4. Mariner Venus/Mercury continued a line of successful Mariner spacecraft that had previously explored Venus and Mars.



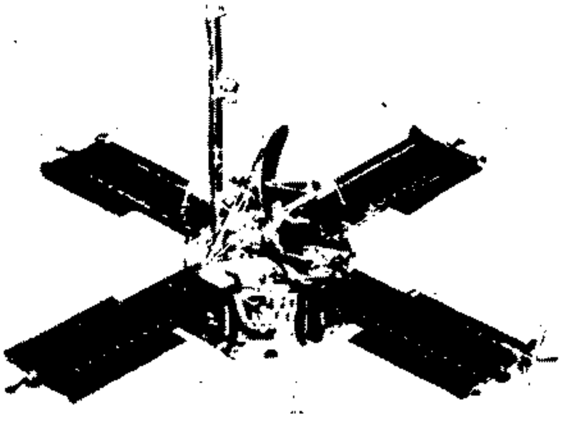


MARINERS 6 AND 7
MARS 1969



MARINER 4
MARS 1964

MARINER 9
MARS 1971



MARINER 5
VENUS 1967

MARINER 10
VENUS AND MERCURY 1973

earlier spacecraft, it used an octagonal main structure, solar cells and a battery for electrical power, three-axis attitude stabilization and control by nitrogen gas jets, celestial references by star and Sun sensors, S-band radio for command, telemetry, and ranging, a high-gain antenna, a low-gain antenna, a scan platform to point science instruments, and a hydrazine rocket propulsion system for trajectory corrections. The spacecraft was designed to fit folded into the launch configuration of the Atlas SLV-3D/Centaur D-1A launch vehicle ready to unfold its appendages and sensors when it reached space.

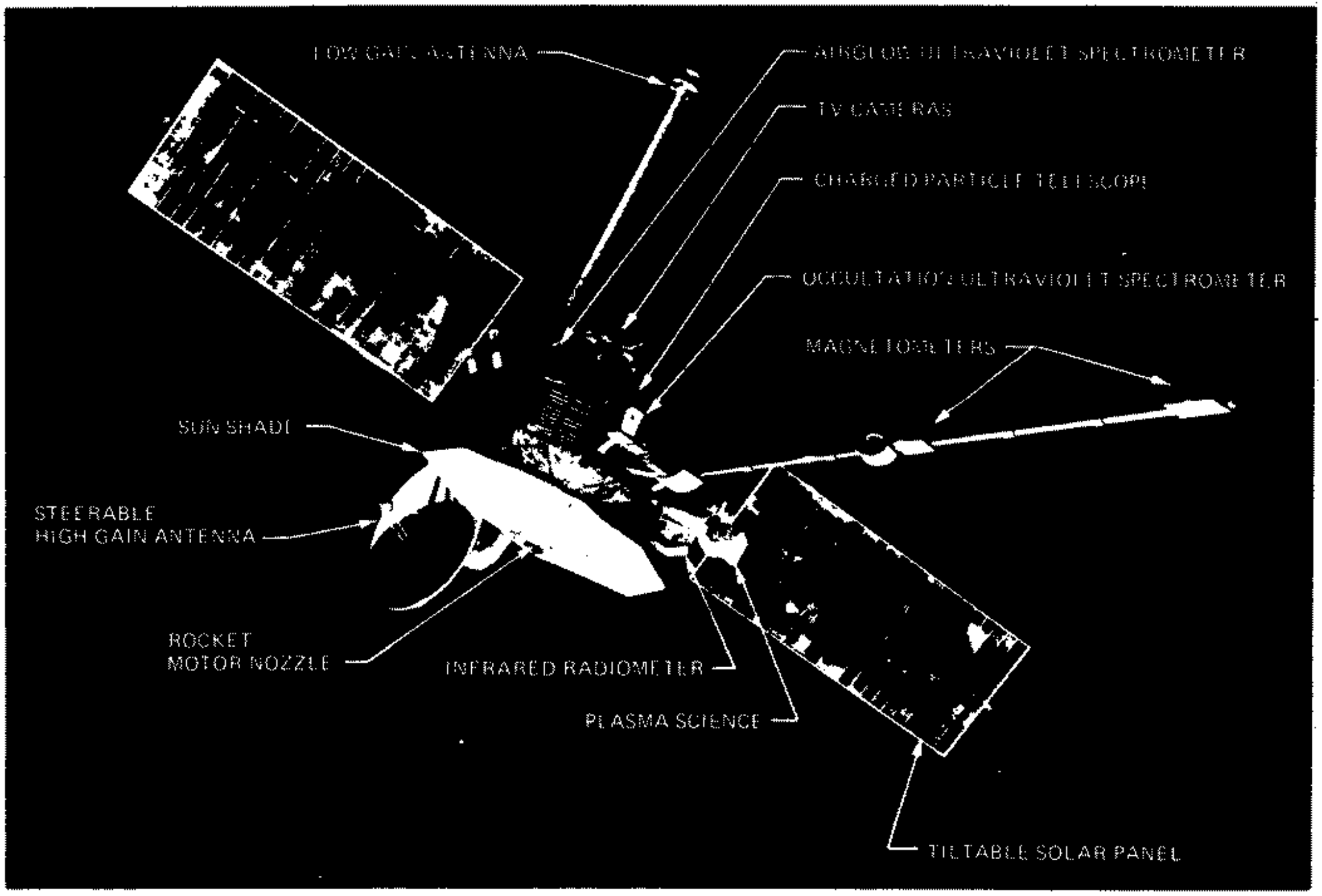
Figure 2-5 shows the relative arrangements of major parts of the Mariner spacecraft: basic structure, power and thermal control, telecommunications and data, navigation and orientation, and scientific payload.

Launch weight of the spacecraft was 533.6 kg (1175 lb), including 29 kg (64 lb) of hydrazine propellant and 30 kg (66 lb) associated with the adapter to the launch vehicle. The payload of scientific instruments weighed 78 kg (172 lb).

Subsystems included equipment to modulate and demodulate electrical signals, generate, store, and distribute power, handle flight data, control spacecraft attitude, release mechanical devices, propel the spacecraft, control temperature, articulate and point spacecraft devices, store data onboard the spacecraft, and communicate with Earth. There was also a central computer and sequencer. All these subsystems together with mechanical devices used for deployment supported the science experiments.

Some changes to the Mariner concept were needed for the mission to Mercury, principally

Fig. 2-5. The Mariner Venus/Mercury spacecraft consists of several basic parts, each one essential to the success of the mission. These include its basic structure, power and thermal control, telecommunications, navigation, propulsion, orientation, and science payload. Solar cells provide electrical energy for the spacecraft power system.



because the spacecraft had to approach the Sun much closer than any previous planetary spacecraft. This required improved ways to insulate the spacecraft from solar radiation. Thermal control of the new Mariner had to protect it from solar intensities up to 4 1/2 times that incident upon the Earth. Thermal control required, in addition to a large sunshade, louvers and protective thermal blankets, the ability to rotate the solar panels about an axis that ran along their length. By changing the angle at which the sunlight shone on the panels, the solar cells were kept at a suitable temperature—about 115°C (239°F)—as the spacecraft approached closer to the Sun. Both panels could turn up to a total of 76 deg from directly facing the Sun and could be rotated individually in fine steps. Other major design changes from past Mariners included the addition of a capability to handle up to 118 thousand bits per second of TV data and 2450 bits/sec for nonimaging science and engineering data as well as the capability for both S- and X-band ranging and X-band carrier transmission. Also, a central flight data subsystem for science and engineering data processing and science control allowed engineering format to be reprogrammed in flight and provided 21 data modes for television, nonimaging science, engineering, and data storage playback.

In addition, the new Mariner had a central articulation and pointing subsystem for its scan platform, its two-degree-of-freedom high-gain antenna, and its tiltable solar panels, with either closed-loop positioning or discrete incremental command capability. Finally, the propulsion system had to be capable of multiple firings, in order to accommodate the number of in-flight trajectory correction maneuvers required for precise navigation.

All the subsystems were designed on the basis of using both Mariner residual hardware as well as Mariner technology. The tight budget constraint on the program made it necessary to use proven techniques to keep development costs low. This was achieved by applying existing hardware or existing designs with such modifications as were needed, making best use of earlier Mariner hardware units by upgrading existing prototypes and eliminating many of the traditional spares by using the qualification test unit as either a spare or a flight unit.

As planning for the mission became more detailed and revisits to Mercury in an extended mission more attractive, spacecraft design decisions were made accordingly. While the basic spacecraft design concept was not initially intended for such an extended mission, once that mission had been accepted as a possibility, design alternatives were chosen that would not rule it out. Thus, when alternatives presented themselves, and costs were the same, that alternative was picked which favored the extended mission. Major decisions that had great significance ultimately to the capability for multiple Mercury encounters were to increase the amount of attitude control nitrogen gas carried by the spacecraft and to incorporate the capability to rotate the panels in both directions so that the solar panel angles could be decreased as well as increased, allowing operation beyond the first Mercury encounter.

Appendix C

Spacecraft and Science Teams

Mariner 10 Project Management

Office of Space Science, NASA Headquarters, Washington, D.C.

John E. Naugle	Associate Administrator for OSS
Vincent L. Johnson	Deputy Associate Administrator for OSS
Robert S. Kraemer	Director, Planetary Programs
Ichtiaque Rasool	Deputy Director, Planetary Programs
N. William Cunningham	Program Manager
Gunther Strobel	Program Engineer
Stephen E. Dwornik	Program Scientist
Joseph B. Mahon	Director, Launch Vehicle Programs
T. Bland Norris	Manager, Medium Launch Vehicles
F. Robert Schmidt	Manager, Atlas-Centaur

Office of Tracking and Data Acquisition, NASA Headquarters, Washington, D.C.

Gerald M. Truszynski	Associate Administrator for OTDA
Arnold C. Belcher	Network Operations
Maurice E. Binkley	Network Support

Jet Propulsion Laboratory, Pasadena, California

William H. Pickering	Laboratory Director
Charles H. Terhune, Jr.	Deputy Laboratory Director
Robert J. Parks	Assistant Laboratory Director for Flight Projects
Walker E. Giberson	Project Manager
John R. Casani	Spacecraft System Manager
James N. Wilson	Assistant Spacecraft System Manager
Norri Sirri	Mission Operations System Manager
Victor C. Clarke, Jr.	Mission Analysis and Engineering Manager
James A. Dunne	Project Scientist
Clayne M. Yeates	Assistant Project Scientist
Nicholas A. Renzetti	Tracking and Data System Manager
Esker K. Davis	Deep Space Network Manager
Gael F. Squibb	Chief of Mission Operations
Dallas F. Beauchamp	Deputy Chief of Mission Operations

Lewis Research Center, Cleveland, Ohio

Bruce T. Lundin	Center Director
Edmund R. Jonash	Director, Launch Vehicles
W.R. Dunbar	Deputy Director, Launch Vehicles
Daniel J. Shramo	Atlas-Centaur Project Manager
Rodney M. Knight	Center Project Engineer

Kennedy Space Center, Florida

Kurt H. Debus	Center Director
John J. Neilon	Director, Unmanned Launch Operations, ULO
John D. Gossett	Chief, Centaur Operations Branch, ULO
Donald C. Sheppard	Chief, Spacecraft Operations Branch, ULO
James E. Weir	Spacecraft Operations Engineer

Boeing Company, Kent, Washington

Edwin G. Czarnecki	Project Manager
Haim Kennet	Deputy Project Manager

Mariner 10 Project Staff

The project staff of the Mariner 10 program, together with those many people in industry and at NASA facilities and universities who jointly made this exploratory mission possible, received group achievement awards from NASA and are listed in Appendix D.

Experiments and Investigators

Television Experiment

Team Leader:

Bruce C. Murray
California Institute of Technology

Team Members:

Michael J. S. Belton
Kitt Peak National Observatory

G. Edward Danielson, Jr.
Jet Propulsion Laboratory

Merton E. Davies
Rand Corporation

Bruce Hapke
University of Pittsburgh

Brian T. O'Leary
Hampshire College

Robert Strom
University of Arizona

Verner E. Suomi
University of Wisconsin

Newell J. Trask
U.S. Geological Survey

Associate Team Members:

James L. Anderson
California Institute of Technology

A. Dollfus
Observatoire de Paris

Donald E. Gault
NASA Ames Research Center

John Guest
University of London Observatory

Robert Krauss
University of Wisconsin

Gerard P. Kuiper
University of Arizona

Plasma Science Experiment

Principal Investigator:

Herbert S. Bridge
Massachusetts Institute of Technology

Co-Investigators:

J. Ashbridge
Samuel J. Bame
M. Montgomery
Los Alamos Scientific Laboratory

A. Hundhausen
University of Colorado

Leonard Burlaga
R. E. Hartle
Keith W. Ogilvie
NASA Goddard Space Flight Center

J. H. Binsack
A. J. Lazarus
S. Olbert
Massachusetts Institute of Technology

Clayne M. Yeates
Jet Propulsion Laboratory

George L. Siscoe
University of California at Los Angeles

Ultraviolet Spectroscopy Experiment

Principal Investigator:

A. Lyle Broadfoot
Kitt Peak National Observatory

Co-Investigators:

M. B. McElroy
Harvard University

Michael J. S. Belton
Kitt Peak National Observatory

Infrared Radiometry Experiment

Principal Investigator:

Stillman C. Chase, Jr.
Santa Barbara Research Center

Co-Investigators:

Ellis D. Miner
Jet Propulsion Laboratory

David Morrison
University of Hawaii

Gerry Neugebauer
California Institute of Technology

Charged Particles Experiment

Principal Investigator:

John A. Simpson
University of Chicago

Co-Investigator:

J. E. Lamport
University of Chicago

Radio Science Experiment

Team Leader:

H. T. Howard
Stanford University

Team Members:

Irwin I. Shapiro
Massachusetts Institute of Technology

John D. Anderson
Gunnar Fjeldbo
Arvydas J. Kliore
Gerald S. Levy
Jet Propulsion Laboratory

Associate Team Members:

G. Tyler
Stanford University

R. D. Reasenberg
Massachusetts Institute of Technology

D. Lee Brunn
Richard Dickinson
Robert E. Edelson
Pasquale B. Esposito
Charles T. Stelzried
Jet Propulsion Laboratory

Magnetic Fields Experiment

Principal Investigator:

Norman F. Ness
NASA Goddard Space Flight Center

Co-Investigators:

Kenneth W. Behannon
Ronald P. Lepping
J. Scheifele
NASA Goddard Space Flight Center

Kenneth H. Schatten
Victoria University, Wellington, New Zealand

Y. C. Whang
Catholic University

Mariner 10 Key Subcontractors

Spacecraft system and support

The Boeing Company
Kent, Washington

Spacecraft Engineering Hardware

Celestial sensors

Honeywell Radiation Center
Lexington, Massachusetts

Data storage tape transport

Lockheed Electronics Co.
Plainfield, New Jersey

Radio frequency subsystem, flight data subsystem

Motorola, Inc., Government Electronics Division
Scottsdale, Arizona

Data storage subsystem, flight command unit, telemetry modulation unit

Texas Instruments, Equipment Group
Dallas, Texas

Power subsystem

Xerox Corp., Electro-Optical Systems
Pasadena, California

Flight batteries

TRW Systems Group
Redondo Beach, California

Reaction control jet nozzle assemblies

Sterer Engineering and Manufacturing Co.
Los Angeles, California

Electronic parts screening

General Electric, Space Division
Valley Forge, Pennsylvania

Solar cells

Centralab, Semiconductor Division of Globe-Union Inc.
El Monte, California

Printed circuit boards

Innovative Electronics
Monrovia, California

Solar cell glass cover filters

Optical Coating Laboratory, Inc.
Santa Rosa, California

TWT amplifiers

Watkins-Johnson
Palo Alto, California

Science Instruments

Infrared radiometer

Santa Barbara Research Center
Goleta, California

Television

Xerox Corp., Electro-Optical Systems
Pasadena, California

Appendix D Mariner 10 Award Recipients

On Friday, August 16, 1974, Dr. William H. Pickering, Director of the Jet Propulsion Laboratory, welcomed guests to a special awards ceremony following the successful completion of the nominal mission of Mariner 10 to Mercury via Venus:

"We are honored today in welcoming Dr. James Fletcher, Administrator of NASA, and our distinguished guests to an awards ceremony that offers special recognition to those individuals and teams who have contributed outstandingly to the mission of Mariner 10 to Venus and Mercury. The Venus/Mercury 1973 Project has added another notable chapter to the 12-year story of Mariner – a spacecraft that has led the way in exploring the near planets of the Solar System.

"The Jet Propulsion Laboratory and the California Institute of Technology are proud of you awardees. You have demonstrated high professional competence and brought great credit to yourselves and to our institution. Congratulations on a job well done."

In presenting the awards, Dr. James Fletcher emphasized the importance of Mariner 10 in planetary exploration and in demonstrating how an advanced scientific project can be accomplished within cost goals:

"The Mariner 10 Awards Ceremony we are holding today recognizes the splendid achievements of the NASA-Industry-University team in the Mariner Venus/Mercury 1973 mission. Mariner 10 will be remembered in history as an engineering triumph which gave mankind unique television pictures and other scientific data from two distant planets. But we know that these accomplishments were the result of human endeavor and today we pay tribute to it as a human triumph by honoring some of the men and women who made Mariner 10 the success that it was.

"As a scientific achievement in interplanetary scientific exploration, Mariner 10 is adding to the laurels of the Mariner series of projects a new perspective on the planet Venus, our first close-up study of the planet Mercury, new observations of the interplanetary medium and the stars, and even some new data on the Moon. Although a full understanding of all the Mariner 10 scientific information will take years of study, it is already clear that we will gain valuable new insights on the two innermost planets. In addition to its direct scientific value, a better understanding of these planets will lead to a better understanding of our own Earth, its probable history, and its possible destiny.

"As a technical achievement of space engineering, the Mariner 10 mission broke new ground in interplanetary flight. It was the first flight demonstration of the gravity-assist technique, a promising propulsion aid for future missions. The two-planet flight plan called for a new degree of navigation accuracy, with Mariner 10 being directed within seven miles of its aiming point at Venus. The spacecraft passed within 416 miles of Mercury's surface, giving the experimenters excellent close-range planetary data; Mariner 10 is now en route to a second encounter with Mercury in September. The spacecraft successfully flew closer to the Sun than any man-made object ever has before. Finally, the adaptive nature of the mission and spacecraft permitted a number of in-flight modifications and additions to the scientific program.

"Mariner 10 was also a triumph of management. The Project Team developed and agreed to a restrictive financial plan at the outset, and proceeded to deliver full performance on time and under cost estimate. This establishes the Mariner Venus/Mercury 1973 Project not only as a distinguished member of the Mariner, and indeed the entire NASA family of projects, but as a model of cost-effectiveness as well.

"Mariner 10 is nominally 'completed' and has met in full all the objectives that were stated in advance. It is now continuing on an extended mission which, hopefully, will give NASA, the scientific community, and the taxpayers the bonus of a second mission to Mercury on the same flight. All of us in NASA take great pride in the achievements of the Mariner 10 team—scientific, technical, and managerial—and offer them our enthusiastic congratulations."

NASA Distinguished Service Medal

Jet Propulsion Laboratory

Walker E. Giberson

NASA Outstanding Leadership Medal

Jet Propulsion Laboratory

John R. Casani

NASA Distinguished Public Service Medals

The Boeing Aerospace Company

Edwin G. Czarnecki

California Institute of Technology

Bruce C. Murray

NASA Exceptional Scientific Achievement Medals

Massachusetts Institute of Technology

Herbert S. Bridge

Jet Propulsion Laboratory

Victor C. Clarke, Jr.
James A. Dunne

University of Chicago

Enrico Fermi Institute

John A. Simpson

NASA Exceptional Service Medals

Jet Propulsion Laboratory

Lida M. Bates
Lyle V. Burden
Elliott Cutting
G. Edward Danielson, Jr.
Esker K. Davis
Richard L. Foster
Daryal T. Gant
Harold J. Gordon
Adrian J. Hooke
William R. Howard (Deceased)
Edward H. Kopf, Jr.
William I. Purdy, Jr.
Norri Sirri
F. Louis Sola
Anthony J. Spear
Gael F. Squibb
Francis M. Sturms, Jr.
Fred Vescelus
Peter B. Whitehead
James N. Wilson

NASA Public Service Awards

The Boeing Aerospace Company

Richard A. Axell
William E. Bramel
Haim Kennet
Bernard M. Lehv
George B. Rickey

Planning Research Corporation

Kunihei Kawasaki

NASA Group Achievement Awards

Flight Project Representative Team
(Award acepted by Allen P. Bowman)

Jet Propulsion Laboratory

Allen P. Bowman
Frank A. Goodwin
Harold J. Gordon
Eugene A. Laumann
Floyd A. Paul
William I. Purdy, Jr.
Michael J. Sander
F. Louis Sola
Anthony J. Spear
Eric E. Suggs, Jr.
Herbert G. Trostle

Flight Data Subsystem Development Team
(Award accepted by Alan Messner)

Jet Propulsion Laboratory

Frank F. Baran
James E. Blue
Gordon A. Crawford
Raymond P. Del Negro
Ralph De Santis
Harvey L. Jeane
Ronald R. Manaker
Carl F. Mazzocco
Alan Messner
Martin N. Orton
Richard Piety
Thomas Shain
John H. Shepherd
L. Richard Springer
James Stahnke
Fred A. Tomey
Ralph E. West
Peter B. Whitehead
Jervis L. Wolfe
Larry W. Wright

Motorola, Inc.

Philip Girard
William Hatcher
David Skoumal
Harry Wagner

Ground Data System Integration Team
(Award accepted by Robert G. Polansky)

Jet Propulsion Laboratory

James W. Capps
John M. Carnakis
Edward L. Dunbar, Jr.
Richard L. Foster
C. Wayne Harris
Jay A. Holladay
David B. Lame
H. Richard Malm
Robert G. Polansky
Thomas M. Taylor

Philco-Ford Corp.

Nick Fanelli

Mission Control and Computing Center
(Award accepted by Michael J. Sander)

The Boeing Aerospace Company

D. M. Sargent

Jet Propulsion Laboratory

Wailen E. Bennet
Richard L. Foster
Ralph P. Hurt
David B. Lame
Gary D. Metts
Rolf H. Niemeyer
George M. Reed
Michael J. Sander
William H. Stapper
Michael R. Warner

Philco-Ford Corp.

Bruce H. Walton
Eugene G. Herrington
Edward R. Kelly
Allan L. Sacks

Planning Research Corp.

Kunihei Kawasaki

Mission Sequence Working Group
(Award accepted by Rodney Zieger)

Jet Propulsion Laboratory

G. Edward Danielson, Jr.
Adrian J. Hooke
Kenneth P. Klaasen
Lawrence Koga
Sergio X. Madrigal
Donna L. Shirley
Ronald C. Spriestersbach
Gael F. Squibb
Kennis Stowers
Robert I. Toombs
William A. Webb
Clayne M. Yeates
Steven J. Zawacki

Philco-Ford Corp.

Roy E. Bates
Patricia M. Kirkish

The Boeing Aerospace Company

Michael R. Cramer
George M. Elliott
Merlyn J. Flakus

Bernard R. Migas
Dudley A. Vines
Rod Zieger

Navigation Development and Operations Team

(Award accepted by Jeremy B. Jones)

Jet Propulsion Laboratory

Marvin H. Bantell, Jr.
Raymond A. Becker
Carl S. Christensen
Leonard Dicken
Vincent L. Evanchuk
Harold J. Gordon
Jeremy B. Jones
Roger E. Koch
C. Jeffrey Leising
Edward L. McKinley
Richard V. Morris
V. John Ondrasik
Gerald E. Pease
Stephen J. Reinbold
Andrey Sergeyevsky
Gary L. Sievers

The Boeing Aerospace Company

Jarrett H. Thomas

Roll Axis Anomaly/Solar Sailing Team

(Award accepted by Walter F. Havens)

Jet Propulsion Laboratory

Teofile A. Almaguer, Jr.
Alan T. Campbell
A. Earl Cherniack
Vincent L. Evanchuk
Patrick J. Hand
Walter F. Havens
John M. Kent
Edward H. Kopf, Jr.
William I. Purdy, Jr.
Jack W. Rhoads
Lawrence L. Schumacher
Robert L. Shrake
Stephen Z. Szirmay
Jaiyun M. Yuh

The Boeing Aerospace Company

John R. Barton
Julius D. Budos
Tord Dannevig
C. Thomas Golden
Jerome H. Hardman
Robert P. Lang
David H. Merchant
Bernard R. Migas
Paul H. Stern

Television Subsystem Development Team

(Award accepted by David Norris)

Jet Propulsion Laboratory

Lloyd A. Adams
G. Edward Danielson, Jr.
Harry T. Enmark
Mark Herring
Kenneth C. La Bau
Clayton C. La Baw
Leonard Larks
David Norris
Gerald M. Smith
Daniel L. Smyth
Fred Vescelus
Joachim G. Voeltz

Electro-Optical Systems

William Cunningham
Nicolaas M. Emmer

Work Unit Management Team

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