United States General Accounting Office

GAO

Fact Sheet for the Chairman, Subcommittee on Science, Technology, and Space, Committee on Commerce, Science, and Transportation, U.S. Senate

May 1988

SPACE EXPLORATION

Cost, Schedule, and Performance of NASA's Mars Observer Mission

GAO/NSIAD-88-137FS

GAO

United States
General Accounting Office
Washington, D.C. 20548

National Security and
International Affairs Division

B-230525

May 27, 1988

The Honorable Donald W. Riegle, Jr.
Chairman, Subcommittee on Science, Technology, and Space
Committee on Commerce, Science, and Transportation
United States Senate

Dear Mr. Chairman:

You asked us to assess the cost, schedule, performance, and status of the National Aeronautics and Space Administration's (NASA's)

-- Galileo mission to Jupiter;

-- Ulysses mission to the sun, a joint project with the European Space Agency;

-- Magellan mission to Venus; and

-- Mars Observer mission.

This report provides the requested information on the Mars Observer mission. We are issuing separate reports[1] on the other deep space missions. In addition, the overall results of our work, including the causes and impacts of delays and other issues related to the projects, are discussed in our report, Space Exploration: NASA's Deep Space Missions Are Experiencing Long Delays (GAO/NSIAD-88-128BR, May 27, 1988).

The Mars Observer mission's objective is to explore geology, topography, and climatology on Mars. At the start of the project in fiscal year 1985, NASA estimated the total cost of the mission at $292.5 million. In October 1987, the cost

---

[1]Space Exploration: Cost, Schedule, and Performance of NASA's Galileo Mission to Jupiter (GAO/NSIAD-88-138FS, May 27, 1988); Space Exploration: Cost, Schedule, and Performance of NASA's Ulysses Mission to the Sun (GAO/NSIAD-88-129FS, May 27, 1988); Space Exploration: Cost, Schedule, and Performance of NASA's Magellan Mission to Venus (GAO/NSIAD-88-130FS, May 27, 1988).

If we can be of further assistance, please contact me on 275-4268.

Sincerely yours,

Harry R. Finley
Senior Associate Director

MARS OBSERVER MISSION TO MARS

The Mars Observer mission is the first in a series of planned planetary missions based on a low-cost approach to spacecraft and mission design. This approach, recommended by the Solar System Exploration Committee (SSEC) of the NASA Advisory Council,[2] called for focused science objectives and the use of designs and components proven in earth-orbital spacecrafts.

In 1980, SSEC began meeting to develop recommendations on the future of space science, and in 1982 it recommended two space exploration programs: one for the inner planets (Mercury, Venus, Earth, Mars) and one for the outer planets (Jupiter, Saturn, Uranus, Neptune, Pluto). In 1983, SSEC specifically recommended that NASA develop a series of low-cost, modestly scaled missions to the inner planets, which NASA called the Planetary Observer series. The Mars Geoscience Climatology Orbiter, which was approved in 1984 as a "new project start" for fiscal year 1985 was a part of this series. Its name was later changed to the Mars Geoscience Climatology Observer and subsequently shortened to Mars Observer.

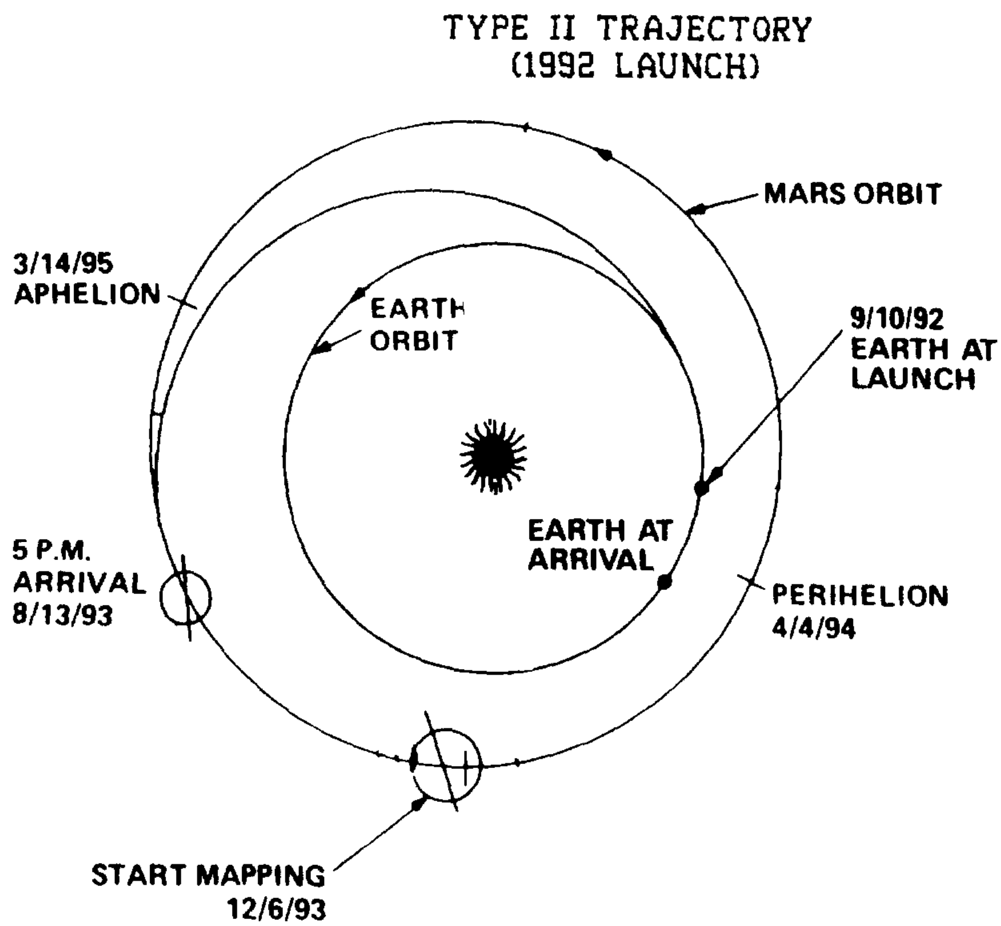
This project is managed for NASA by the Jet Propulsion Laboratory (JPL). Radio Corporation of America Astro-Electronics (now General Electric Astro Space Division) is the contractor for the spacecraft. According to project staff, the spacecraft's intermediate size prompted the design of a unique upper stage, which is used to provide propulsion into an interplanetary trajectory. JPL selected the Transfer Orbit Stage as the upper stage, and NASA's Marshall Space Flight Center contracted for it with Orbital Sciences Corporation.

The mission's objective is to explore the geology, topography, and climatology of Mars. After a 1-year transit to Mars, the spacecraft is expected to assume a low-altitude polar orbit and to repetitively map the surface and atmosphere of Mars every 59 days for 687 days, which is 1 year on Mars. Specifically, this mission is expected to

---

[2]The NASA Advisory Council was established to advise the NASA Administrator on plans for work in progress on, and accomplishments of, NASA's space programs. NASA's Chief Scientist and chairpersons of the National Research Council's Space Science Board, Space Applications Board, and Aeronautics and Space Engineering Board serve on the Council.

Figure I.1: Mars Observer Trajectory



OBJECTIVES, SCOPE, AND METHODOLOGY

Our objectives were to describe this mission and obtain information on its cost, schedule, and performance. To accomplish these objectives, we interviewed NASA and JPL program and project managers responsible for the mission's design, development, and management. We also reviewed project planning and budget documents, articles in scientific journals, and reports in technical and trade periodicals. Our work was performed at NASA Headquarters in Washington, D.C., and at JPL in Pasadena, California. A more detailed description of our objectives, scope, and methodology on this assignment is contained in appendix I of our report, Space Exploration: NASA's Deep Space Missions Are Experiencing Long Delays (GAO/NSIAD-88-128BR, May 27, 1988).

COST

At the start of the project in fiscal year 1985,NASA estimated the total cost of this mission at $292.5 million. By October 1987, the mission cost estimate was $513.8 million, an increase of $221.3 million. Before the Challenger accident in January 1986, the project cost estimate had increased by over $48 million. According to project staff, this increase was partly due to the additional estimated costs of

-- future mission studies,

-- JPL engineering and technical assistance in evaluating proposals,

-- support for two altimeters while capability issues were resolved,

-- communications band development, and

-- JPL's Space Flight Operations Center.

After the Challenger accident, the total project cost estimate increased about $173 million. Of this amount, about $163 million was for development and $10 million was for mission operations and data analysis (MO&DA). According to project staff, the $163 million increase in the development cost estimate was due to the changes and modifications shown in table I.1.

Table I.2: Cumulative Costs by Fiscal Year for Development and MO&DA Under Fiscal Year 1985 and October 1987 Estimates

FY	1985 Estimate Development	1985 Estimate MO&DA	1985 Estimate Total	October 1987 Estimate Development	October 1987 Estimate MO&DA	October 1987 Estimate Total
	(000 omitted)					
1985	$ 6,000	-	$ 6,000	$ 5,043[a]	-	$ 5,043[a]
1986	34,600	-	34,600	19,124[a]	-	19,124[a]
1987	78,400	-	78,400	62,078	-	62,078
1988	143,900	-	143,900	117,889	-	117,889
1989	212,100	-	212,100	243,021	-	243,021
1990	252,300	$ 3,918	256,218	335,076	-	335,076
1991	-	15,999	268,299	393,379	-	393,379
1992	-	28,079	280,379	428,432	-	428,432
1993	-	40,160	292,460	427,069	$20,703	447,772
1994	-	-	-	-	42,702	469,771
1995	-	-	-	-	64,701	491,770
1996	-	-	-	-	86,700	513,769

[a]These are actual cumulative costs.

Table I.3: Annual Project Cost Estimate Growth

Fiscal year	Estimated project costs	Annual cost increase
	---(000 omitted)---	
1985	$292,460	$ -
1986	340,610	$ 48,150
1987	513,769	173,159
Total		$221,309

SCHEDULE

At the start of the project in fiscal year 1985, this mission was scheduled to be launched in August 1990 and to be completed 3 years later in 1993. Although the late issuance of the spacecraft Request for Proposal and the long selection process for the spacecraft's instruments created tight project deadlines, JPL officials believe the spacecraft still could have been launched in 1990. However, NASA decided in April 1987 to push back the launch to September 1992. According to NASA officials, too many planetary launches were scheduled in the first 2 years of the shuttle's return to service after the Challenger accident. They also cited fiscal year 1987 funding constraints as a contributing factor in the decision. Key dates in the mission's schedule, as estimated initially in fiscal year 1985 and then in October 1987, are shown in table I.4.

Table I.4: Schedule for the Mars Observer

Event	Estimate: Initial	Estimate: Oct. 1987	Increase in years
Project start	1984	-	-
Launch	1990	1992	2
End of mission	1993	1995	2
Project duration (years)	9	11	2

PERFORMANCE

JPL staff expect the original mission objective to be fully achieved. In addition, the mission is scheduled to be expanded in several areas. First, France is supplying an Electron Reflectometer that is designed to measure Mars surface magnetic fields from an altitude of 120 kilometers. When the measurements made by this instrument are combined with those of the Magnetometer, which is designed to measure Mars surface magnetic

MARS OBSERVER PROJECT CHRONOLOGY

FY 1980 SSEC meets to develop recommendations on the future of space science.

FY 1982 SSEC recommends two core space exploration programs: one for the inner planets and one for the outer planets.

FY 1983 SSEC recommends that the Mars Geoscience Climatology Orbiter be made part of the Planetary Observer series.

The mission is renamed the Mars Geoscience Climatology Observer.

FY 1985 The mission is renamed the Mars Observer.

Mars Observer becomes a "new project start" for JPL.

An Announcement of Opportunity for the selection of the instruments is released.

NASA decides to develop two instruments for this and future missions: the Gamma ray spectrometer and the visual and infrared mapping spectrometer.

A Request for Proposals for a flight system is issued.

FY 1986 The Challenger accident occurs.

The Hughes Aircraft Company files a bid protest with GAO, alleging that an amendment to the Request for Proposals was so substantial that the procurement should be canceled and resolicited.

The selection of Mars Observer experiments and investigations is completed. NASA decides to test Ka-band communications and plans to acquire photographs for public distribution.

GAO decides that the Request for Proposals does not require resolicitation and rejects Hughes Aircraft Company's bid protest, clearing the way for NASA to sign the Transfer Orbit Stage contract with the Orbital Sciences Corporation and for JPL to sign the Radio Corporation of America spacecraft contract.

GLOSSARY

Altimeter	An instrument used for measuring altitude.
Announcement of Opportunity	A formal announcement issued by NASA advising scientists about an opportunity to participate in a scientific mission.
Aphelion	The point farthest from the sun in an orbit in the solar system. It is also a point in the trajectory when the Mars Observer spacecraft will be farthest from the sun.
Bi-propellant	A rocket propellant consisting of two uncombined chemicals (fuel and oxidizer) that are fed to the combustion chamber separately.
Climatology	The branch of the atmospheric sciences that deals primarily with the study of weather and atmosphere.
Deep Space Network	NASA's worldwide set of deep space communications stations with a central control facility located at JPL. The stations are located at Goldstone in the California desert, near Madrid, Spain, and near Canberra, Australia. The network provides high-gain steerable antennae, ultra-low noise receivers, high-power transmitters, and precise radiometric data for navigation.
Electron Reflectometer	An instrument measuring the ratio of the energy of a reflected wave to that of an incident wave.
Expendable launch vehicle	A nonreusable rocket such as the Titan IV.
Gamma rays	Penetrating electromagnetic radiation with a similar wavelength as X-rays.
Gamma ray spectrometer	An instrument used to investigate the energy distribution of gamma rays.
Geosciences	A term that denotes the collective discipline of the geological sciences.

Mission Operations and Data Analysis (MO&DA)	A NASA term that denotes an operational phase of a mission, generally beginning with launch.
New project start	A NASA term that denotes the start of a new project at the beginning of a fiscal year.
Orbiter	A spacecraft or mission involving insertion of a vehicle into orbit around a celestial body; it is also the orbital flight vehicle of the Shuttle system.
Payload	The useful or net weight that is placed into orbit during a space mission.
Perihelion	The point nearest to the sun in an orbit in the solar system. It is also a point in the trajectory when the Mars Observer spacecraft will be nearest to the sun.
Pressure modulator infrared radiometer	An instrument used to develop profile measurements of atmospheric temperature, water vapor, and dust content contingent on latitude, longitude, and season.
Radiometer	An instrument used for detecting and measuring radiant energy.
Radar altimeter/ Radiometer	An altimeter operating on the radar principle to determine the altitude of the spacecraft.
Radio science	Experiments and instruments utilizing the analysis of radio waves.
Shuttle	A U.S. Space Transportation System vehicle that place payloads into orbit. It consists of a reusable piloted orbiter with three main engines, two reusable solid rocket boosters, and an expendable liquid propellant tank.
Solar power array	A large assembly of photovoltaic (solar) cells.
Space Flight Operations Center	JPL's multi-mission space flight operations facility that provide communications, computing, networking, and data management services in support of space flight projects.

Requests for copies of GAO reports should be sent to:

U.S. General Accounting Office
Post Office Box 6015
Gaithersburg, Maryland 20877

Telephone 202-275-6241

The first five copies of each report are free. Additional copies are $2.00 each.

There is a 25% discount on orders for 100 or more copies mailed to a single address.

Orders must be prepaid by cash or by check or money order made out to the Superintendent of Documents.

United States
General Accounting Office
Washington, D.C. 20548

Official Business
Penalty for Private Use $300

First-Class Mail
Postage & Fees Paid
GAO
Permit No. G100

Thermal emission spectrometer	An instrument that maps the mineral composition of surface rocks and frosts as well as the composition of clouds.
Topography	The delineation of the natural and artificial features of an area.
Trajectory	The path traced by a rocket or spacecraft moving as a result of an externally applied force, considered in three dimensions.
Transfer Orbit Stage	A mid-sized upper stage to be used to launch the Mars Observer mission.
Transponder	A receiver/transmitter that generates a reply signal upon proper interrogation; the interrogation and reply use different radio frequencies. It is also an electronic system that receives a radio signal, amplifies it, changes its frequency, and immediately and automatically retransmits it.
Type II trajectory	An interplanetary trajectory in which the spacecraft will complete between one-half to less than one full orbit around the sun (where the angle formed by the injection-point-to-sun line and the arrival-point-to-sun line is 180 to 360 degrees).
Ultrastable oscillator	A high-precision clock device used to provide timing for the transmission of spacecraft radio signals.
Upper stage	A vehicle that is used to propel payloads into higher-than-earth orbit, interplanetary trajectories, or other high-energy orbital maneuvers.
Visual and infrared mapping spectrometer	An instrument that furnishes a mineralogical map of Mars and charts concentrations of water and carbon dioxide in the atmosphere as clouds and on the surface as frost and snow.
Volatile material	Material that changes readily to a vapor.

(392350)

*U.S. G.P.O. 1988-201-749:80132

Gravity assist	A technique used to give a spacecraft sufficient added velocity by aiming it toward a planet to use the planet's free gravitational pull.
Gravitational field	That region of space in which appreciable gravitational force exists.
High-gain antenna	A highly sensitive antenna capable of receiving and transmitting radio signals at great distances.
Horizon sensor	A part of a spacecraft's attitude control system that provides data on the spacecraft's position in relation to a planet's horizon.
Infrared	The portion of the electromagnetic spectrum with a wavelength between 1 and 1,000 micrometers.
Interdisciplinary investigations	Investigations in which scientists work with data from several experiments and provide a broad link among many disciplines.
Jupiter	The fifth planet from the sun, which is the largest planet in the solar system (318 times the mass of earth). It has 16 known satellites, with the four largest known as the Galilean moons (Io, Europa, Ganymede, and Callisto).
Ka-band	A deep space communication band (34.2 to 34.7 GHz for transmission, 31.8 to 32.2 GHz for reception).
Launch vehicle	A rocket used to launch a missile or space vehicle; it is also called a booster rocket.
Magnetic field	A region of space in which there is an appreciable magnetic force.
Magnetometer	An instrument used for comparing the intensity and direction of magnetic fields.
Mars	The fourth planet from the sun, which has two known satellites, Phobos and Deimos.

FY 1987 NASA decides to expand the mission to include France's Electron Reflectometer.

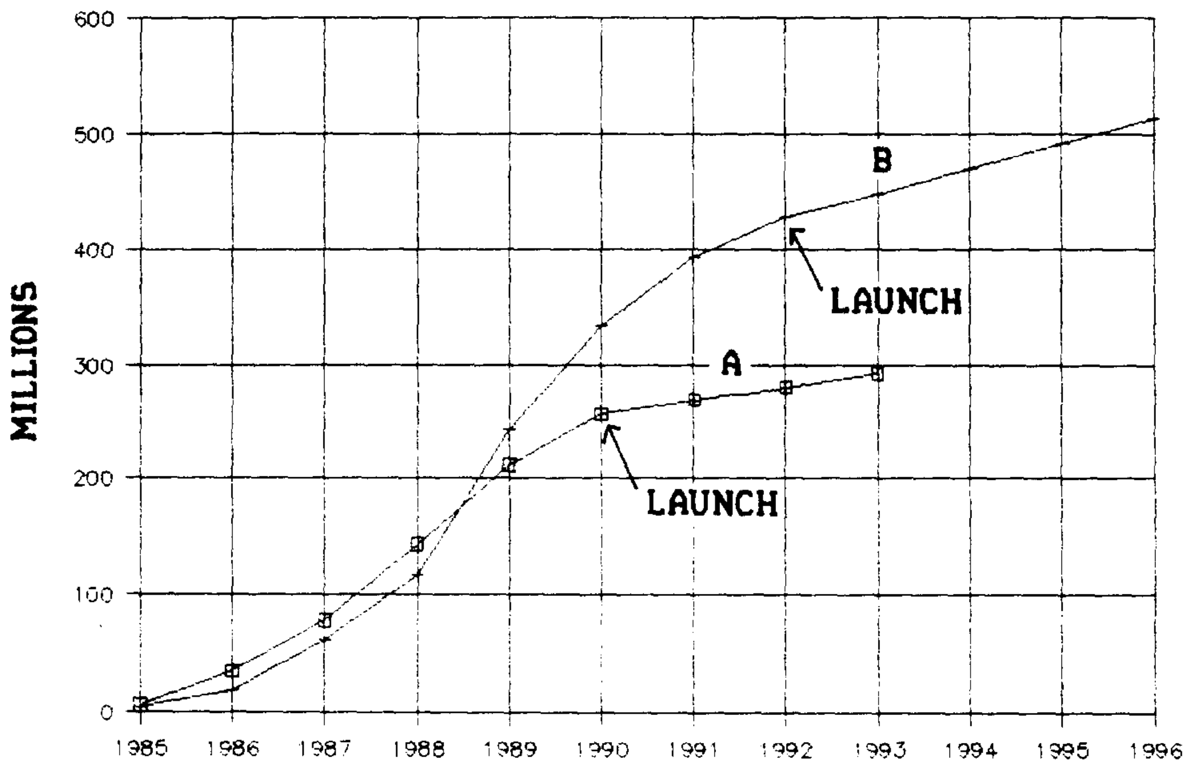
The scheduled launch date is delayed from August 1990 to September 1992.

JPL issues a partial stop work order to the Radio Corporation of America, and initiates mission replanning for the new launch date.

JPL continues development of key instruments. All other efforts, including spacecraft development, are reduced to support levels.

fields from an altitude of approximately 350 kilometers, this mission will be able to generate more precise data on the Mars surface magnetic field. Second, NASA decided to do a first-time test of transmission at Ka-band frequencies on the spacecraft. Third, NASA plans to have the spacecraft take photographs that will be made available to the public because of increased interest in Mars exploration, according to project officials.

Figure I.3: Development and MO&DA Cost



FISCAL YEARS

CUMULATIVE COSTS

CURVE A - INITIAL FISCAL YEAR 1985 ESTIMATE

CURVE B - OCTOBER 1987 ESTIMATE

The annual growth in the project cost estimate is shown in table I.3. The total project costs are estimated at least twice each year by NASA and represent an estimate of total project cost through completion.

Table I.1: Breakdown of Estimated Development Cost Increase After the Challenger Accident

Change or modification	Increased estimated costs (millions)
Mission rephasing	
JPL science	$16.1
Instruments and spacecraft	23.6
Loss of common buys[a]	8.7
Inflation	22.3
	70.7
Project scope - new work	
Public relations picture products	1.2
Instrument and spacecraft spares	54.1
Early computer buy	2.2
Additional system test time	.3
	57.8
Reserves[b]	**17.7**
Liens[c] against adjustment for program allowances	**17.0**
Total	**$163.0**

Figures do not add to total due to rounding.

[a]According to project staff, the initial cost estimate for the spacecraft assumed that the Radio Corporation of America would build it as part of a larger project, including the development of five Defense Meterological Space Program satellites. This planned common buy was no longer possible after the Challenger accident and subsequent changes in the Mars Observer's schedule.

[b]These are funds contributed by NASA for project costs not controlled by JPL. The increase was due to the estimated costs of (1) replacing a transponder that was terminated because of technical problems, (2) efforts to develop a dual-launch compatibility using the Shuttle or an expendable launch vehicle, (3) efforts to develop an experiment to demonstrate Ka-band frequency over deep space distances, and (4) engineering and integration support for France's Electron Reflectometer.

[c]An unencumbered reserve funds allocated to a NASA project and used by project managers to pay for unforeseen costs.

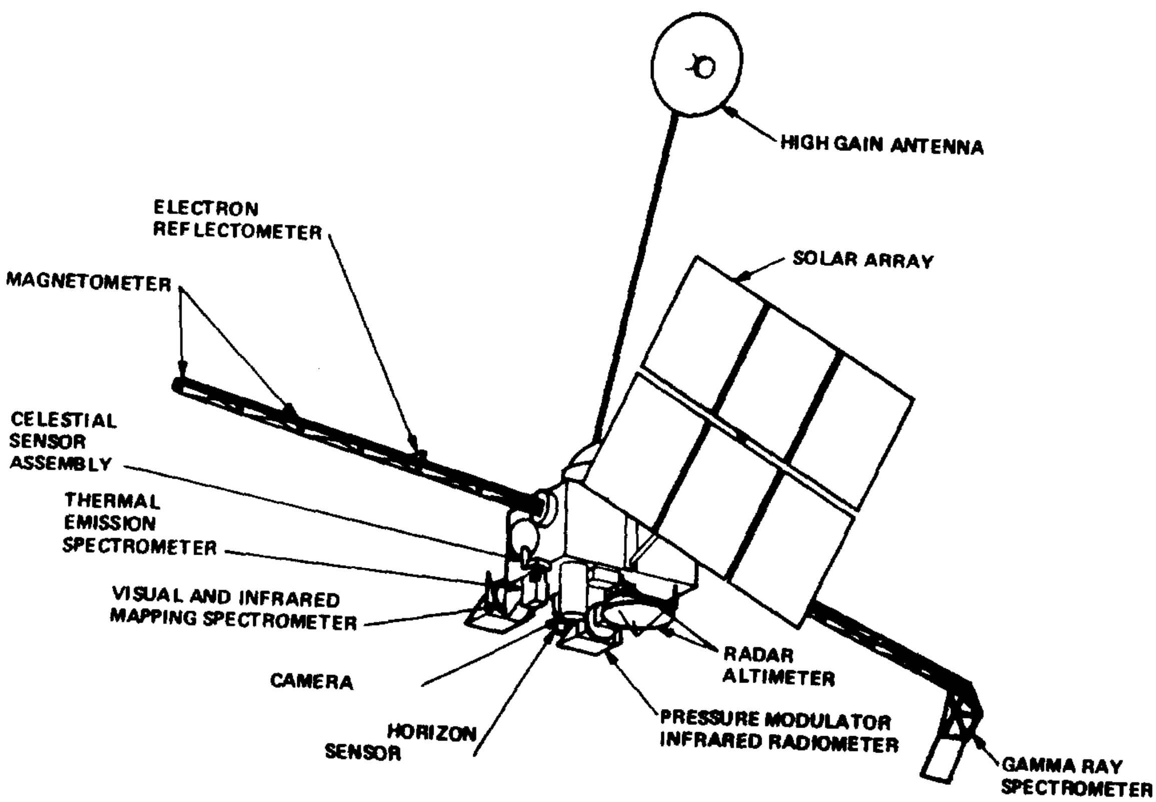
The cost increases by fiscal year are shown in figure I.3 and table I.2.

SPACECRAFT CONFIGURATION

The spacecraft will be dominated by four features: two long instrument booms for the magnetometer and gamma ray spectrometer instruments, a steerable high-gain antenna, and a 458-watt solar power array. The spacecraft configuration and the location of its major components are shown in figure I.2.

Many of the spacecraft's features will be derived from existing spacecraft designs. The spacecraft's structure, thermal design, and solar power array are derived from the SATCOM-K communications satellite design, and the attitude control, command/data handling, power conditioning, and telecommunications designs are from the TIROS/Defense Meterological Satellite Program. The spacecraft will also incorporate some unique features, including a steerable high-gain antenna and a bi-propellant propulsion system.

Figure I.2: Spacecraft Configuration



-- determine the elemental and mineralogical character of surface material;

-- define the topography and gravitational field;

-- examine the nature of the magnetic field;

-- discover the distribution, abundance, and sources of volatile material and dust over a seasonal cycle; and

-- explore the structure and circulation of the atmosphere.

The spacecraft is scheduled to carry eight scientific instruments supported by eight Team Leaders and Principal Investigators and five scientists who will be doing interdisciplinary investigations.

Instruments and Investigations

Visual and infrared mapping spectrometer
Gamma ray spectrometer
Radar altimeter
Pressure modulator infrared radiometer
Camera
Thermal emission spectrometer
Magnetometer
Radio science (ultrastable oscillator)

Interdisciplinary Investigations

Geosciences
Atmospheric studies in the polar regions on Mars
Interactions between the surface and atmosphere on Mars
Climatology
Science data management, including storage

Most of these instruments/investigations are described in the glossary.

The mission is being expanded in several areas. France is supplying a $3 million Electron Reflectometer, which is an instrument that measures the ratio of the energy of a reflected to that of an incident wave, and NASA has chosen this mission to test Ka-band frequency transmission over deep space distances to provide information on the Deep Space Network antenna performance.

The planned trajectory for this mission is shown in figure I.1.

Contents

ABBREVIATIONS

JPL	Jet Propulsion Laboratory
MO&DA	Mission operations and data analysis
NASA	National Aeronautics and Space Administration
SSEC	Solar System Exploration Committee

estimate was $513.8 million, an increase of $221.3 million. Before the Challenger accident, the estimate rose by about $48 million, principally due to the additional estimated costs related to future mission studies, Jet Propulsion Laboratory (JPL) engineering and technical assistance in evaluating proposals, communications band development, and support for two altimeters. After the Challenger accident, the estimate increased by about $173 million, principally to replan the mission and expand its scope.

At the start of the project, the mission was scheduled to be launched in 1990 and to be completed 3 years later in 1993. However, NASA decided in April 1987 to delay the launch until 1992 because too many planetary missions were scheduled during the first 2 years of the Shuttle's return to service, according to NASA officials. Fiscal year 1987 funding constraints were also cited as a contributing factor in the decision.

JPL, which manages the project for NASA, expects the initial mission objectives to be fully achieved. In addition, the mission is scheduled to be expanded in several areas. France is supplying an instrument for improving the magnetic field measurements, and NASA has decided to test deep space communications frequencies and equipment on this mission. Furthermore, NASA plans to have the spacecraft take photographs that will be made available to the public because of the increased interest in Mars exploration.

As requested, we did not obtain official agency comments on this report. However, we discussed the report with NASA and JPL officials, and they agreed with the facts as presented. The objectives, scope, and methodology of our work are discussed in appendix I. A glossary of technical terms follows the project chronology in appendix II.

Unless you publicly announce its contents earlier, we plan no further distribution of this report until 10 days from its issue date. At that time, copies will be sent to other interested parties upon request.