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Briefing Report to the Chairman, Subcommittee on Science, Technology, and Space, Committee on Commerce, Science, and Transportation, U.S. Senate

May 1988

SPACE EXPLORATION

NASA's Deep Space Missions Are Experiencing Long Delays

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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 (ESA);

-- Magellan mission to Venus; and

-- Mars Observer mission.

This report summarizes this information and includes the causes and impacts of project delays. We are issuing separate reports[1] that provide more detailed descriptions of each project.

The purpose of these deep space missions is to improve scientific knowledge of our solar system and selected planets in it. However, three of the four missions have experienced significant cost increases, and all four

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[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); Space Exploration: Cost, Schedule, and Performance of NASA's Mars Observer Mission (GAO/NSIAD-88-137FS, May 27, 1988).

missions have had their launches delayed well beyond their initial schedules. In some cases, delays were attributed to funding reductions made to decrease spending in a particular fiscal year. Although such reductions helped achieve short-term spending goals, they caused the duration of the projects to be stretched out over a longer period of time and added to overall project costs. Schedule delays also prevented scientific and engineering personnel from applying their talents to designing additional space missions or to pursue other scientific opportunities. On the other hand, the delays provided NASA with the opportunity to expand the capabilities of the Galileo and Mars Observer missions.

COST

The Galileo, Magellan, and Mars Observer missions experienced increases in estimated project costs totaling about $1.4 billion. The Ulysses mission had a decrease in its cost estimate of nearly $8 million, primarily due to a reduction in its scope. Table 1 shows the changes for each mission from the initial estimate to the October 1987 estimate.

Table 1: Changes in Cost Estimates for Deep Space Missions

Project	Year began	Cost estimates: Initial	Oct. 1987	Change
		(millions)		
Galileo	1978	$ 410.1	$1,362.5	$ 952.4
Ulysses[a]	1979	215.1	207.2	- 7.9
Magellan	1984	294.6	513.5	218.9
Mars Observer	1985	292.5	513.8	221.3
		$1,212.3	$2,597.0	$1,384.7

[a]ESA's costs not included.

SCHEDULE

All four missions have experienced considerable delays in launch and completion dates, as shown in table 2.

Table 2: Estimated Delays in Launch and Completion of Deep Space Missions

Mission	Launch schedule[a]	Delay: Launch (years)	Delay: End of mission (years)
Galileo	Oct. 1989	7	10
Ulysses	Oct. 1990	7	8
Magellan	April 1989	1	2
Mars Observer	Sept. 1992	2	2

[a]As of March 1988

All of the deep space missions are scheduled to be launched by the Shuttle. However, in a March 1988 congressional testimony, officials of NASA's Office of Space Flight stated that they were evaluating whether to purchase commercial launch services for the Mars Observer mission and to use an expendable launch vehicle as a backup launch system for the other deep space missions in the event of any further shuttle launch delays.

PERFORMANCE

According to officials at the Jet Propulsion Laboratory (JPL), which manages all the projects for NASA, the Galileo, Magellan, and Mars Observer missions are expected to achieve or exceed their initial objectives. However, the Ulysses mission will not achieve its initial objective.

The Galileo mission's initial objective to study Jupiter and its satellites is expected to be exceeded. As a result of launch delays and a revised trajectory, NASA has expanded the scope of Galileo's scientific investigations to include such activities as one or more asteroid encounters and a study of clouds and lightning on Venus.

The Ulysses mission's initial objective was to launch two spacecrafts--one developed by NASA and one by ESA--to explore the remote polar regions of the sun. Due to budget reductions, NASA canceled its spacecraft; thus, this mission will not achieve its initial objective. As a result of the cancellation, one-half of the science instruments to be flown on this mission were not going to be used, and about 80 U.S. and European scientists were eliminated from this project.

The Magellan mission's objective to map at least 70 percent of Venus' surface is expected to be achieved, even though the launch date and the selected trajectory will place the spacecraft into Venus orbit shortly before the sun will be between earth and Venus. This will interrupt spacecraft communication with earth and create a gap in the mapping coverage.

The Mars Observer mission's objective of exploring geology, topography, and climatology on Mars is also expected to be exceeded. NASA has expanded the mission in several areas; for example, its magnetic field measurements will be improved, and a deep space communications band will be demonstrated.

STATUS

The Galileo spacecraft is in storage at JPL, and its scientific instruments have been returned to scientists for modifications and recalibration. The project staff is conducting aging studies, developing energy saving designs, and designing hardware changes to protect the spacecraft, since its currently planned trajectory will bring it much closer to the sun than previously planned trajectories.

After the *Challenger* accident, the ESA spacecraft was returned to the European Space Research and Technology Center. Its instruments were removed and returned to the scientists for storage, and the spacecraft was sent to Dornier Systems in West Germany for storage. The project staff is currently integrating the spacecraft with a new upper stage, which will be used to provide propulsion from earth orbit into interplanetary trajectory. Its previous upper stage, the Centaur, was canceled as a safety-related measure based on post-*Challenger* reviews.

The Magellan spacecraft and its radar system are being prepared for 6 months of functional and environmental testing. The contract to build the spacecraft for the Mars Observer mission is being renegotiated so its activities can be rescheduled to accommodate its latest launch date.

FACTORS CONTRIBUTING TO SCHEDULE DELAYS AND COST INCREASES

The schedule delays and increases in the estimated project costs for the four deep space missions can be attributed primarily to mission redesign and hardware modifications caused by delays in the Shuttle launch schedule, frequent upper stages changes, and funding reductions.

The delays in the Shuttle launch schedule often required extensive mission redesign (e.g., development of new trajectories) and the retaining of project teams for extended periods. Also, NASA's frequent changes in upper stages, primarily because of problems in the upper stage programs, required extensive and costly mission redesign and hardware modifications to integrate the spacecraft with its new upper stage, redesign the mission trajectory to be compatible with the new upper stage's capabilities, and modify spacecraft hardware for the new trajectory. Finally, NASA's budget cuts, although helping NASA deal with budget constraints for specific fiscal years, also increased long-term costs by contributing to launch delays and the need to redesign missions.

There are two categories of added costs associated with mission delays: monetary costs and human resource costs. In the first category, the $1.4 billion increase in the cost of the three deep space projects is mostly needed to sustain the original missions, thus making these resources unavailable to initiate additional missions or for other purposes. In the second category, skilled mission designers, engineers, and scientists spend extra time on mission and hardware redesign; therefore, they are not available to design other missions or to pursue other scientific opportunities.

Our objectives, scope, and methodology are described in appendix I. As requested, we did not obtain official agency comments on this report. However, we discussed the results of our work with NASA and JPL officials, and we considered their comments in preparing the report. They generally agreed with the information presented. A glossary of technical terms and phrases is located at the end of 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 others interested parties upon request.

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

Sincerely yours,

Harry R. Finley
Senior Associate Director

Contents

ABBREVIATIONS

ELV	Expendable launch vehicle
ESA	European Space Agency
IUS	Inertial Upper Stage
JPL	Jet Propulsion Laboratory
NASA	National Aeronautics and Space Administration
OSSA	Office of Space Science and Applications
POP	Program Operating Plan
RTG	Radioisotope Thermoelectric Generator
SAR	Synthetic Aperture Radar

OBJECTIVES, SCOPE, AND METHODOLOGY

Our objectives were to review the cost, schedule, performance, and status of the

-- Galileo mission to Jupiter;

-- Ulysses mission to the sun, a joint National Aeronautics and Space Administration (NASA) and European Space Agency (ESA) project;

-- Magellan mission to Venus; and

-- Mars Observer mission.

We also examined the factors contributing to schedule delays and cost increases.

To obtain information on the cost, schedule, performance, and status of the four missions, we interviewed NASA and Jet Propulsion Laboratory (JPL) program and project managers responsible for their design, development, and management. We also reviewed and analyzed project planning and budget documents, articles in scientific journals, and reports in technical and trade periodicals.

The Galileo and Ulysses projects were initiated in fiscal years 1978 and 1979, respectively. Since the length of the projects and the related turnover in project staff has limited the depth of historical knowledge, we adopted an approach designed to make up for this lack of historical information. We started with a literature search and a review of trade periodicals from 1975 to 1987. The historical information identified in this review was then supplemented by information obtained from JPL and NASA documents and scientific journals. Finally, we discussed the information with JPL project staff.

Our analysis of project costs is based on JPL's Program Operating Plans (POPs), which are part of NASA's biannual budget development process--its preliminary budget in the spring and its final budget in the early fall.[2] It was difficult to reconstruct project fiscal history because the POP format varies from project to project, and there were many changes in the POP format over time. Also, POP estimates do not include all costs

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[2]Project managers must prepare two POPs annually; however, they may be required to prepare additional POPs reflecting revised cost estimates in the event of program changes, launch delays, or changes in the upper stage.

associated with each project. Items or activities for which costs are partially or totally excluded include advanced studies, launch vehicle and launch, a Radioisotope Thermoelectric Generator (RTG), upper stages, and NASA employees assigned to the projects. Excluding these items and activities is consistent with the approach NASA takes in estimating project cost for ongoing programs, which focuses primarily on costs under its research and development appropriation once a project has been approved.

All estimated project costs include estimates of future years' inflation made at the time each estimate was prepared. We did not verify the accuracy of the POP data.

Our work was performed at NASA Headquarters in Washington, D.C., and JPL in Pasadena, California. The results of our work were discussed with JPL and NASA officials, and their comments were incorporated where appropriate. As requested, we did not obtain official agency comments.

Our review was conducted from June 1987 to February 1988 in accordance with generally accepted government auditing standards.

COST, SCHEDULE, AND PERFORMANCE ISSUES

RELATED TO NASA'S DEEP SPACE MISSIONS

The deep space missions have experienced significant cost increases, and their launches have been delayed well beyond the initial schedules. The causes for the delays vary, for example, the lack of launch capability, development difficulties, and funding constraints. In some cases, mission funding was reduced to help achieve a short-term spending goal. This, in turn, contributed to increases in overall project costs because schedules were stretched out and scientific and engineering personnel had to be held over on the projects. On the other hand, the launch delays provided NASA with the opportunity to expand the objectives of the Galileo and Mars Observer missions.

PROGRAM AND PROJECT MANAGEMENT

NASA's Office of Space Science and Applications (OSSA) is responsible for the overall management of the space exploration program. The four deep space missions are managed by OSSA's Solar System Exploration Division. NASA's Office of Space Flight is responsible for providing spacecraft launch vehicles, upper stages, and launch services, and its Office of Space Operations is responsible for managing the Deep Space Network, a worldwide system for navigating, tracking, and communicating with spacecraft exploring the solar system. The system includes 11 antennae systems, a Network Operations Control Center, and other facilities operated by JPL.

The Galileo mission is managed for NASA by JPL, California Institute of Technology, Pasadena, California. JPL designed and built the orbiter spacecraft. NASA's Ames Research Center manages the development of the probe that will be released into Jupiter's atmosphere. The probe was build by Hughes Aircraft Company, California.

The Ulysses mission is a joint NASA/ESA project. The United States' portion of the mission is managed for NASA by JPL. The spacecraft was built for ESA by Dornier Systems of West Germany. ESA will also provide operations software and five instruments. NASA will provide, among other things, launch services, the upper stage, an RTG, tracking and data acquisition, and five instruments.

The Magellan project is managed for NASA by JPL. Martin Marietta Corporation is the prime contractor for the spacecraft, and Hughes Aircraft Company is the prime contractor for the Synthetic Aperture Radar (SAR).

The Mars Observer mission is managed for NASA by JPL, which will acquire the spacecraft and science instruments. NASA's Marshall Space Flight Center is responsible for managing the contract for this mission's upper stage, the Transfer Orbit Stage. The spacecraft is being built by Radio Corporation of America Astro-Electronics, and the Transfer Orbit Stage is being built by the Orbital Sciences Corporation.

MISSION OBJECTIVES

Galileo

This mission is a scientific descendant of the successful Voyager fly-by missions past Jupiter and its moons. JPL officials told us that the Galileo orbiter is the most complex spacecraft that JPL has ever developed. It is scheduled to carry 19 instruments, 12 by the orbiter and 7 by the atmosphere probe.

The primary objective of this mission is to investigate the chemical composition and physical state of Jupiter's atmosphere and satellites and the structure and physical dynamics of Jupiter's magnetosphere, which is an asymmetric region within which the magnetic field of Jupiter is confined by the solar wind.

Ulysses

This mission, previously known as the International Solar Polar Mission, is a joint NASA/ESA project. It is the first and only planned mission to observe the remote polar region of the sun. Originally, it was to use two spacecrafts: one developed by NASA and one developed by ESA. However, in fiscal year 1981, NASA canceled its spacecraft due to budget reductions; thus, this mission was reduced to a single ESA spacecraft, which will carry 10 scientific instruments.

The primary objectives of this mission are to study the solar chromosphere and corona, heliosphere, and interstellar medium.

Magellan

This mission was previously known as the Venus Radar Mapper. Its primary objective is to investigate the origin and evolution of Venus by using its single major instrument--the Synthetic Aperture Radar (SAR),which is a radar system utilizing an electromagnetic beam and the motion of a spacecraft to simulate a large antenna size to obtain high-resolution images--to obtain a global radar image of at least 70 percent of the planet. The spacecraft will provide global imagery with a resolution to 1 kilometer and will map global topography with a resolution to 50 meters.

Mars Observer

This mission is the first in a series of planned planetary observer missions. Its objective is to explore the geology, topography, and climatology of Mars. Specifically, the spacecraft will carry eight instruments that will determine the composition of surface materials; define the topography and gravitational field; establish the nature of the magnetic field; discover the distribution, abundance, and sources of volatile material and dust; and explore the structure and circulation of the atmosphere.

COST

Galileo

When this project started in fiscal year 1978, NASA estimated its total cost at approximately $410.1 million--$271.3 million for development and $138.8 million for mission operations and data analysis. By October 1987, the cost estimate had increased to $1,362.5 million--$878.3 million for development and $484.2 million for mission operations and data analysis.

The $952.4 million increase is primarily due to changes in the spacecraft hardware and mission characteristics caused by several Shuttle launch delays, changes in the upper stage, and the Challenger accident.

Ulysses

When this project started in fiscal year 1979, NASA had estimated its total cost at about $215 million. This estimate was based on a single launch for both the NASA and ESA spacecrafts using the Shuttle. NASA was to pay for the Shuttle launch and support services, and each agency was to pay for its spacecraft and scientific instruments and to share other costs.

NASA's decision to postpone the launch date from February 1983 to April 1985 to reduce the fiscal year 1982 budget contributed to the increase of the total estimated project costs to $315.8 million. Subsequently, NASA's total cost estimate dropped to $158 million when it canceled its spacecraft.

The Challenger accident forced NASA to further postpone the launch until October 1990 and to replace the liquid-fueled Centaur upper stage because of safety concerns about carrying liquid fuel in the Shuttle's cargo bay. The launch delay and the subsequent mission modifications and redesign were the primary reasons for the increase in NASA's October 1987 project cost estimate to $207.2 million.

Magellan

When this project started in fiscal year 1984, NASA estimated its total cost at $294.6 million. This estimate was based on the assumption that the spacecraft would be launched by the Shuttle with a Centaur upper stage in April 1988.

By October 1987, the mission cost estimate had increased about $219 million to $513.5 million. A significant portion of the cost increase was due to a 1-year launch delay and SAR development problems.

Mars Observer

When this project started in fiscal year 1985, NASA estimated its total cost at $292.5 million. Before the Challenger accident, the project cost estimate rose by approximately $48.2 million, principally as a result of the additional cost of future mission studies, JPL engineering and technical assistance in evaluating proposals, support of two altimeters, and communications band development.

After the Challenger accident, total project cost estimates increased from about $341 million to $513.8 million in October 1987, an increase of over $173 million--$163 million for development and over $10 million for mission operations and data analysis. The $163 million increase helped cover the estimated cost of mission rephasing, expanding the project's scope, additional project reserves, replacing the transponder (an electronic system that receives a radio signal, amplifies it, changes its frequency, and immediately and automatically retransmits it) and studying a dual-launch capability using either the Shuttle or an expendable launch vehicle. In total, the cost of this project has increased by $221.3 million since its inception.

SCHEDULE

Galileo

This project launch, originally scheduled for January 1982, has been delayed by more than 7 years. The current launch date is for October 1989. The mission was scheduled initially to end in 1987; however, it is currently scheduled to end in 1997, a delay of 10 years. Under previous launch schedules, the shortest cruise time--the amount of time it would take a spacecraft to reach its destination--to Jupiter was 26 months; now, under the current launch schedule, the cruise time to Jupiter will be 72 months, an increase of almost 4 years.

Most of the delays occurring before the Challenger accident were due to Shuttle launch delays and four changes in the upper stage that NASA had planned to use. In fiscal year 1981, NASA decided to use the more powerful Centaur upper stage instead of the three-stage inertial upper stage. Then, in fiscal year 1982, NASA canceled the Centaur's development because of budget problems and decided to use the Air Force's two-stage inertial upper stage (IUS). However, late in fiscal year 1982, the Congress directed NASA to reinstate the Centaur program. Subsequently, after the Challenger accident, NASA decided to replace the Centaur upper stage for safety reasons. Project delays since the Challenger accident have been due to the delay in the Shuttle program and the lack of an alternative launch vehicle.

Ulysses

At the start of the project in October 1978, this mission's launch was set for February 1983. Since then, the launch date has been delayed three times. First, in April 1980, the launch date was postponed to April 1985 to help reduce the fiscal year 1982 budget. Then, in July 1982, the launch date was postponed to May 1986 to allow for the additional time needed to replace the IUS with the Centaur. Last, as a result of the Challenger accident, the launch was postponed to October 1990. With the new 1990 launch date, the completion of this mission will be delayed a total of 8 years, and the project's duration has nearly doubled from its initially estimated 9 years to a current estimate of 17 years.

Magellan

At the start of the project in fiscal year 1984, this mission was scheduled for launch in April 1988, and the end of the mission was set for April 1989. Since the project's inception, its launch date has changed twice. First, as a result of the Challenger accident, the April 1988 launch was moved to October 1989. Second, in late 1986 the launch date was moved up to April 1989 so the Galileo spacecraft could be launched in October 1989. The current April 1989 launch date includes a change in trajectory that will increase the cruise time to Venus by about 1 year and will delay the spacecraft's arrival at Venus until August 1990, just over 2 years later than originally planned. The launch delay and the increase in cruise time has delayed the end of the mission to 1991.

Mars Observer

At the start of this project in fiscal year 1985, the launch date was scheduled for August 1990, and the mission was to be completed 3 years later, in 1993. In April 1987, NASA decided to postpone the launch to September 1992 because too many planetary launches were scheduled in 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.

Key information on some of the key events in the schedules of the deep space missions is summarized in table II.1.

Table II.1: NASA's Deep Space Mission Schedule

Event	Estimate Initial	Estimate Oct. 1987	Increase in years
Galileo			
Project start	1978	1978	-
Launch	1982	1989	7
End of mission	1987	1997	10
Project duration (years)	9	19	10
Ulysses			
Project Start	1978	1978	-
Launch	1983	1990	7
End of mission	1987	1995	8
Project duration	9	17	8
Magellan			
Project start	1984	1984	-
Launch	1988	1989	1
End of mission	1989	1991	2
Project duration	5	7	2
Mars Observer			
Project start	1984	1984	-
Launch	1990	1992	2
End of mission	1993	1995	2
Project duration	9	11	2

Some views on likelihood of meeting current schedules

According to the Director of Transportation Services in NASA's Office of Space Flight, the deep space missions are assigned a high launch priority, and they will likely be launched as scheduled. OSSA's Director of the Shuttle Payload Engineering Division noted that recent enhancements to the Shuttle system and the availability of two launch pads and three Shuttles reduces the risk of launch delays. However, according to a former OSSA Associate Administrator, the launch schedules for Galileo, Ulysses, and Magellan may be overly optimistic because the Shuttle has never launched within 60 days after a date scheduled 1 year ahead since the first Shuttle launch in 1981, and the launch window (a span of time during which a specific mission must be launched to achieve an optimal trajectory, orbit, or spacecraft arrival time) for the Magellan mission is open for only 20 days every 2 years. He believes that unless NASA places two Shuttles on a flight readiness status 60 days before the scheduled mission launch date, the probability of launching the Shuttle within the mission launch window is low; the Shuttle launch manifest and schedule are unrealistic; and the Shuttle is not an appropriate deep space mission launch vehicle--an expendable launch vehcile (ELV) with the Centaur upper stage is preferred.

The NASA Advisory Council[3] has voiced their concern about the lack of an alternative launch vehicle to the Shuttle:

> "The Council urgently recommends that NASA begin immediately, through a request for a supplemental budget, to provide sufficient ELV launch capability or services to achieve the robustness required for an effective space program. Without action now, the Nation's civil space program--especially that in space science, which has till now been a shining example of U.S. space leadership--will be damaged to a degree from

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[3]The NASA Advisory Council was established to advise the NASA Administrator on plans for work in progress and accomplishments of the space programs. The Council consists of a Chairperson and several members including the NASA Chief Scientist and the chairpersons of the National Research Council's Space Science Board, Space Applications Board, and Aeronautics and Space Engineering Board. The council also consists of a number of at-large members.

"which recovery will be extremely difficult and expensive."[4]

Recently, NASA officials described their plans to provide an additional backup for the launch of the deep space missions in the event of additional Shuttle launch delays. In a March 1988 congressional testimony, officials of NASA's Office of Space Flight stated that they were evaluating purchasing commercial launch services for the Mars Observer mission and using the Titan IV ELV as a backup launch system for the other deep space missions.

PERFORMANCE

Galileo

According to project staff, this mission is expected to achieve its original mission objective. In addition, because of launch delays, a redesigned trajectory, and extended cruise time, NASA has been able to expand the scope of the mission's scientific investigations to include one or more asteroid encounters, investigation of clouds and lightning on Venus, study of the hydrogen shell surrounding the sun[5], observations of portions of the earth's magnetosphere, and observations of the moon's farside, Mare Orientale, and polar regions. In addition, NASA added an Extreme Ultraviolet Sensor to the scientific instruments, which will enhance studies of the magnetosphere, and installed an instrument provided by West Germany for measuring elapsed flight time, which will improve ion composition measurements.

Ulysses

The original mission objectives for this mission will not be fully achieved, mostly due to the cancellation of NASA's spacecraft. As a result of this cancellation, about one-half of the science instruments to be flown on this mission were not going to be used, and about 80 U.S. and European scientists were eliminated from the project.

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[4]NASA Advisory Council Report of The Task Force on Issues Of a Mixed Fleet (final report), National Aeronautics and Space Administration Advisory Council Task Force, March 11, 1987.

[5]The hypothetical hydrogen shell located at the distance of 1 astronomical unit from the sun is thought to be created by the evaporation of small, unseen comets.

The NASA spacecraft would have provided simultaneous observations with the ESA spacecraft while they were in opposite hemispheres. The simultaneous observations were important for verifying the instrument readings. Also, several instruments that would provide imaging information were unique to the NASA spacecraft.

Magellan

According to project staff, this mission's objective is expected to be achieved, even though the launch date and the selected trajectory will place the spacecraft into Venus orbit shortly before the sun will be between earth and Venus. This will interrupt spacecraft communication with earth and create a gap in the mapping coverage.

Mars Observer

JPL staff expects this mission's initial objective to be fully achieved. In addition, the mission will be expanded in several areas. First, France is supplying an Electron Reflectometer to improve magnetic field measurements. Second, NASA decided to test Ka-band transmission over deep space distances and Deep Space Network antenna performance at Ka-band frequencies. Third, NASA plans to have the spacecraft take photographs that will be made available to the public because of the increased interest in Mars exploration, according to project officials.

STATUS

Galileo

The Galileo spacecraft is in storage at JPL, and the science instruments were returned to scientists for modifications and recalibration. The project staff is conducting aging studies, developing energy saving designs, and modifying the spacecraft's hardware to protect it from the sun, since its current trajectory will bring it much closer to the sun than previously planned trajectories. JPL is developing thermal protection for the heat-sensitive hardware.

Because of project delays, the aging of the spacecraft's hardware is of serious concern to JPL. Some of the spacecraft components are reaching the end of their lifetime and have to be replaced. The aging effects include loss of adhesion in conductive tapes, degradation of flexibility in electrical cables, corrosion of metal parts, and the fracturing of O-rings. Replacing parts can be an extensive task; for example, the orbiter's electrical systems contain nearly 25,000 feet of electrical cables and over 700 connectors.

The spacecraft will be powered by two 285-watt RTGs fueled by plutonium-238 in the form of cylindrical pellets. Because some of this fuel has decayed, the RTGs will produce less power. Therefore, JPL is implementing numerous modifications to allow the spacecraft to function at reduced power levels without having detrimental effects on the objective of this mission.

Ulysses

After the Challenger accident, the ESA spacecraft was returned to the European Space Research and Technology Center. The instruments were removed and returned to the principal investigators. The spacecraft was sent to Dornier Systems in West Germany for storage. The RTG was returned to the Department of Energy.

The project staff is integrating the spacecraft with a new IUS in preparation for the October 1990 launch.

Magellan

The project staff is integrating this spacecraft with the IUS. The spacecraft and the SAR are being prepared for 6 months of functional and environmental testing.

Mars Observer

The contract to build the spacecraft for this mission is under a partial stop work order. The contract is being renegotiated so the spacecraft's activities can be rescheduled to accommodate the recent 2-year launch delay.

FACTORS CONTRIBUTING TO SCHEDULE DELAYS AND COST INCREASES

The schedule delays and cost increases for the four deep space missions can be mostly attributed to mission redesign and hardware modifications caused by delays in the Shuttle launch schedule, frequent upper stage changes, and funding reductions.

The delays in the Shuttle launch schedule often required extensive mission redesign (e.g., development of new trajectories), and retaining of project teams for extended periods. Also, NASA's frequent changes in upper stages, primarily because of problems in the upper stage programs, required extensive and costly mission redesign and hardware modifications to integrate the spacecraft with its new upper stage, redesign the mission trajectory to be compatible with the new upper stage's capabilities, and modify the spacecraft's hardware to recognize the new trajectory. Finally, NASA's budget cuts, although helping NASA deal with budget constraints for specific fiscal years, also increased long-term costs by contributing to launch delays and the need to redesign missions.

There are two categories of added costs associated with mission delays: monetary costs and human resource costs. In the first category, the $1.4 billion increase in the cost of the Galileo, Magellan, and Mars Observer missions is mostly needed to sustain the objectives of the original missions, thus making these resources unavailable to initiate additional deep space missions or for any other purposes. In the second category, highly skilled mission designers, engineers, and scientists spend extra time on mission and hardware redesign; therefore, they are not available to design other missions or to pursue other scientific opportunities.

GLOSSARY

Advanced studies	Studies on the feasibility of the technology, the instruments, and the mission conducted before the official start of a NASA project.
Altimeter	An instrument used for measuring altitude.
Asteroid	Any of a host of small rocky astronomical objects found primarily between the orbits of Mars and Jupiter. There are about 2,000 known asteroids in the solar system.
Centaur	An expendable, high-performance hydrogen-oxygen cryogenic upper stage used by NASA to launch interplanetary and earth orbital payloads.
Climatology	The branch of the atmospheric sciences that deals primarily with the study of weather and atmosphere.
Corona	The luminous irregular envelope of highly ionized gas outside the chromosphere of the sun; it is also called the solar corona.
Coronagraph	An instrument for photographing the corona of the sun at times other than solar eclipses.
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 used to measure the ratio of the energy of a reflected wave to that of an incident wave.
• Expendable launch vehicle (ELV)	A nonreusable rocket such as the Titan IV.

Extreme ultraviolet	Electromagnetic radiation with a wavelength between 10 and 185 nanometers.
Fly-by mission	An interplanetary mission in which the spacecraft passes close to the target planet but does not impact it or go into orbit around it.
Gravity or gravitational waves	Postulated extremely faint perturbations in the interstellar medium caused by stellar or galactic catastrophes. For example, the gravitational rippling caused by the collision of two black holes may be detected as an interference in the radio signal between a spacecraft and the earth.
Gravitational field	That region of space in which appreciable gravitational force exists.
Heliosphere	The region of the sun's influence on the space environment.
Inertial Upper Stage (IUS)	A rocket booster and associated guidance system designed for the Shuttle that is used to move heavy payloads from a low earth orbit into higher operational orbits or to move lighter payloads into deep space trajectories. The solid-fuel IUS was developed jointly by the U.S. Air Force and NASA, and the Boeing Aerospace Company was the prime contractor. The IUS family included (1) two versions (spin stabilized and 3-axis stabilized) of a three-stage IUS (canceled by NASA in 1982) and (2) a two-stage U.S. Air Force version that will be used to launch the Galileo, Ulysses, and Magellan missions.
Interstellar medium	The space between stars, permeated with gas and cosmic dust.
Ion	Any atom or group of atoms bearing one or more positive or negative charges.

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 energy	Twice the energy per unit of mass imparted to a spacecraft, which is measured in relation to earth's hyperbolic escape trajectory. A hyperbolic escape trajectory resembles a hyperbola, which is a curve formed by the intersection of a double right circular cone with a plane that cuts both halves of the cone. A spacecraft on a deep space mission is typically launched by the Shuttle into a circular orbit and will require an additional propulsion burn to acquire sufficient velocity to leave the circular orbit and enter a hyperbolic escape trajectory toward the target planet.
Launch vehicle	A rocket used to launch a missile or space vehicle; it is also called a booster rocket.
Launch window	The span of time during which a specific mission must be launched to achieve an optimal trajectory, orbit, or spacecraft arrival time.
Magnetic field	A region of space in which there is an appreciable magnetic force.
Magnetic force	The physical force experienced by a magnetic substance when placed in a magnetic field or between magnetized bodies and electric currents.
Magnetometer	An instrument used for comparing the intensity and direction of magnetic fields.

Magnetosphere	An asymmetric region (generally spherical) within which the magnetic field of a planet is confined by the solar wind.
Mare Orientale	A circular plain made of basaltic material that fills the interior part of the Orientale basin on the moon.
Mars	The fourth planet from the sun, which has two known satellites, Phobos and Deimos.
Mission Operations and Data Analysis	A NASA term that denotes an operational phase of a mission, generally beginning with launch.
Nanometer	One-billionth of a meter.
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.
Out-of-ecliptic trajectory	A path to be used by the Ulysses mission that will take the spacecraft out of the ecliptic plane of our solar system. The Ulysses spacecraft will use Jupiter's gravity to execute a deflection maneuver and will eventually pass over the sun's poles.
Planetary Observers	A planned, low-cost series of spacecrafts intended for the exploration of the inner planets and small bodies, including Venus, the moon, Mars, near-earth asteroids, and comets. The planetary observers will be derived from existing earth-orbital spacecraft systems.
Probe	An instrumented device designed to gather data either during the descent and/or landing on a target planet.
Program Operating Plan (POP)	NASA's time-phased biannual projection of project resource requirements submitted by project centers to NASA Headquarters.

Radioisotope Thermoelectric Generator (RTG)	An electrical power generator consisting of a heat source and a system for the conversion of heat to electricity. The heat source contains a radioisotope (such as plutonium-238) that produces heat from its radioactive decay. The heat is converted to electricity by a thermoelectric converter.
Residual hardware	Spare hardware that is left after the launch of a spacecraft.
Shuttle	A U.S. Space Transportation System vehicle that places 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 chromosphere	A transparent layer of gas that rests on the photosphere (the intensely bright portion of the sun visible to the naked eye) in the atmosphere of the sun.
Synthetic Aperture Radar (SAR)	A radar system utilizing an electromagnetic beam and the motion of a spacecraft to simulate a large antenna size (synthetic aperture) to obtain high-resolution images.
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 solid-fuel 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.

Upper stage	A vehicle that is used to propel payloads into higher-than-earth orbit, interplanetary trajectories, or other high-energy orbital maneuvers.
Venus	The second planet from the sun.
Volatile material	Material that changes readily to a vapor.
Voyager	Missions to Jupiter and Saturn in which the Voyager I and II spacecrafts were launched in 1973 and 1975, respectively. Both missions returned a wealth of information on the planets and their satellites.

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