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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 Ulysses Mission to the Sun

135990

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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 (ESA);

-- Magellan mission to Venus; and

-- Mars Observer mission.

This report provides the requested information on the Ulysses mission to the sun. 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 Ulysses mission is intended to investigate the sun in ways not previously possible to improve scientific understanding of the effects of solar activity on the

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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 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).

earth's weather and climate. Initially, the mission was to use two spacecrafts: one developed by NASA and one developed by ESA. At the start of the project in fiscal year 1979, NASA estimated the total cost of its share of the mission at about $215 million, assuming that there would be a single launch by the Shuttle for the two spacecrafts in February 1983 and that an Inertial Upper Stage (IUS) would be used to provide propulsion into an interplanetary trajectory. Each agency was to pay for its own spacecraft and scientific instruments. In addition, NASA was to pay for the Shuttle launch and support services and to share other costs with ESA. In October 1987, 9 years after the start of the project, NASA's share of the total project costs were estimated at $207.2 million.

The principal cause of mission cost increases before the Challenger accident in January 1986 was NASA's decision to postpone the launch date, which reduced the fiscal year 1982 budget by $53 million. However, this short-term cost saving contributed to an increase in estimated project costs to $315.8 million. Because of budget reductions, NASA canceled its spacecraft, and its estimate fell to $158 million.

Cost increases that occurred after the Challenger accident were a result of another launch delay and mission modifications and redesign.

At the start of the project in October 1978, the mission was scheduled to end in 1987. Since the project's inception, the launch date has been delayed three times. The first delay occurred in April 1980 when the launch date was postponed to April 1985 primarily to help reduce the fiscal year 1982 budget. The second delay occurred in July 1982 when the launch date was changed to May 1986 because of Shuttle launch delays and the replacement of the upper stage booster. The third delay occurred after the Challenger accident when the launch was postponed to October 1990. With the 1990 launch date, the mission will be extended until 1995, a delay of 8 years from its original schedule. Overall, the project has nearly doubled in its duration, from its initially estimated 9 years to 17 years.

The original mission objective will not be fully achieved, primarily due to the cancellation of the NASA spacecraft. As a result of the 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 this project. The NASA spacecraft was to provide simultaneous observations with the ESA spacecraft in opposite hemispheres, which would have been important for verifying the instrument readings. Also, several of the planned instruments for providing imaging information were unique to the canceled spacecraft.

As requested, we did not obtain official agency comments on this report; however, we discussed the report with NASA and Jet Propulsion Laboratory 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 and phrases 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.

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

Sincerely yours,

Harry R. Finley
Senior Associate Director

Contents

ABBREVIATIONS

ESA	European Space Agency
IUS	Inertial Upper Stage
IUS/PAM-S	Inertial Upper Stage/Payload Assist Module-Spin Stabilized
JPL	Jet Propulsion Laboratory
MO&DA	Mission operations and data analysis
NASA	National Aeronautics and Space Administration
RTG	Radioisotope Thermoelectric Generator

ULYSSES MISSION TO THE SUN

The Ulysses 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. As originally conceived, the mission was to use two spacecrafts: one developed by NASA and one developed by ESA. The first Announcement of Opportunity for the mission was issued in 1977. In February 1978, NASA and ESA jointly selected the scientific investigations to be performed by the two spacecrafts. In March 1979, a Memorandum of Understanding was signed by NASA and ESA. The Jet Propulsion Laboratory (JPL) manages NASA's portion of the project.

According to project staff, more than 200 scientists from 65 universities and research centers in 13 countries were chosen to participate in this mission. Each spacecraft was to carry a core of instruments to provide fundamental data on various aspects of the sun. NASA's spacecraft was also to carry other imaging instruments, namely, a white light coronagraph and an X-ray/extreme ultraviolet telescope.

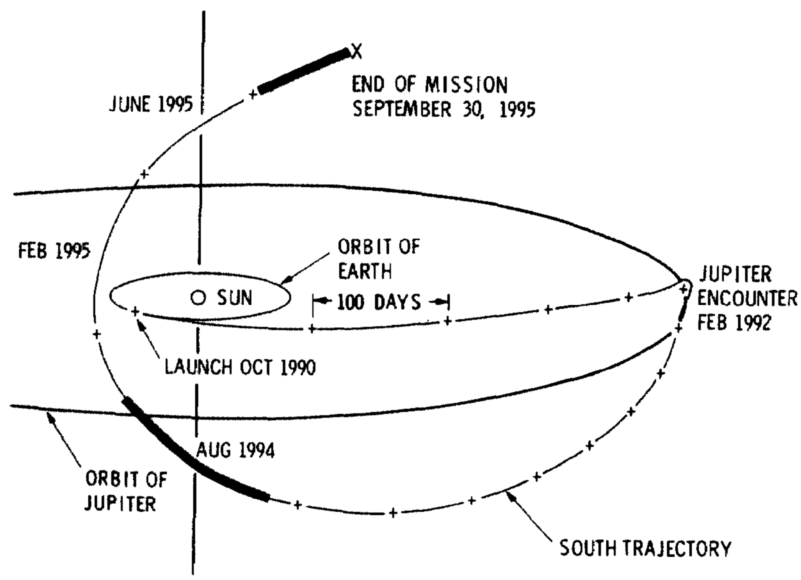
Because of budget reductions, NASA canceled its spacecraft. As a result of the cancellation, about one-half of the science instruments to be flown on this mission were not going to be used, and about 80 U.S. and European investigators were eliminated from the project. The cancellation also eliminated the opportunity to perform simultaneous observations in both solar hemispheres and stereoscopic observations from two vantage points in the heliosphere, since two spacecrafts are needed for these investigations. In addition, the spacecraft will not be able to perform white light, X-ray, and ultraviolet measurements of various coronal phenomena due to the cancellation of the white light coronagraph and X-ray/extreme ultraviolet telescope.

The objective of this mission is to study the three-dimensional structure and dynamics of the solar chromosphere and corona, heliosphere, and interstellar medium. According to NASA, this mission is intended to provide a better understanding of the effects of solar activity on the earth's weather and climate.

A unique aspect of this mission is that it will be the first solar exploration to use an out-of-ecliptic trajectory. Previous solar studies have been limited to solar observations in the ecliptic plane where solar wind phenomena is very complex and difficult to understand. According to JPL staff, previous interplanetary missions remained in the ecliptic plane because launch energy was limited and because target planets lie on the ecliptic.

A great amount of propulsion energy will be required to move a spacecraft out of the ecliptic plane, and scientists in the 1960s pursued the idea of using the gravity energy of Jupiter to put a spacecraft into an out-of-ecliptic orbit. The Ulysses spacecraft is scheduled to be launched in October 1990 by the Shuttle and to arrive at Jupiter about 17 months later. The spacecraft is then scheduled to be deflected south of the ecliptic plane and to pass over the sun's south pole about 2-1/2 years later. Subsequently, the spacecraft is scheduled to pass over the sun's north pole. The mission is scheduled to end in September 1995 when the spacecraft is below 70 degrees solar latitude. The planned trajectory for the spacecraft is shown in figure I.1.

Figure I.1: Ulysses Trajectory



Despite the cancellation of its spacecraft, NASA remains substantially involved in this mission. According to project staff, NASA is responsible for the launch, Radioisotope Thermoelectric Generator (RTG), tracking and data acquisition, navigation, parts procurement, integration and support, data records, and 5 of the 10 instruments aboard the spacecraft. NASA is also responsible for other activities jointly with ESA, including project management, mission design, mission operations, and science investigations. ESA's responsibilities include the spacecraft, operations software, and the other 5 instruments aboard the spacecraft.

The spacecraft's 10 instruments will support 11 investigations; 2 investigations will share data from one instrument. These investigations and the countries providing the principal investigator are listed below.

Investigation	Country
Magnetic field	Great Britain
Solar wind plasma	United States
Solar wind ion composition	Switzerland/ United States
Low-energy ions and electrons	United States
Energetic-particle composition and interstellar gas	West Germany
Cosmic rays/solar particles	United States
Unified radio and plasma waves	United States
Solar X-rays/cosmic gamma ray burst	United States/ West Germany
Cosmic dust	West Germany
Coronal sounding	West Germany
Gravitational waves	Italy

OBJECTIVES, SCOPE, AND METHODOLOGY

Our objectives were to describe this mission and to obtain information on its cost, schedule, and performance. To accomplish our 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).

SPACECRAFT CONFIGURATION

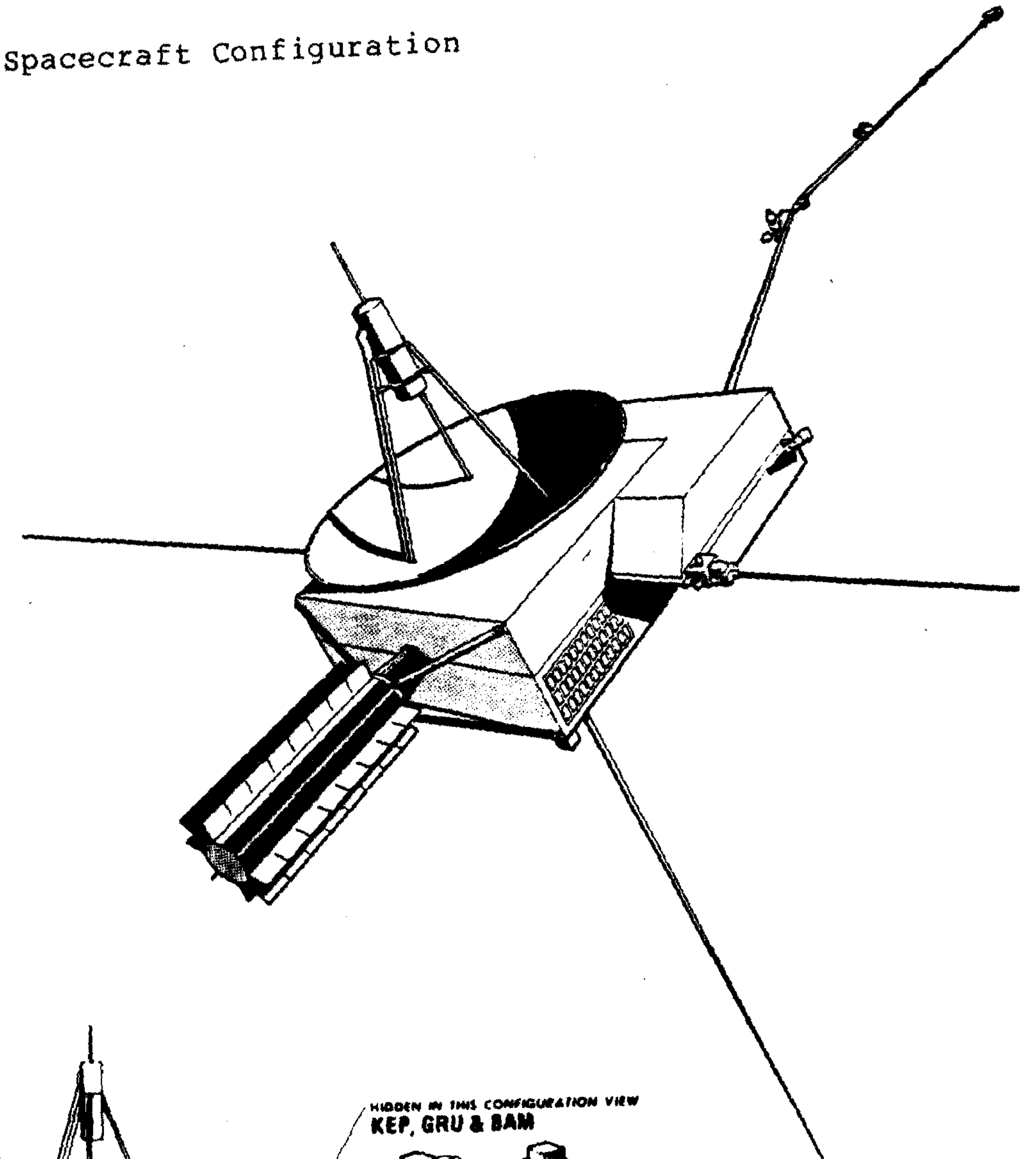
The spacecraft consists of a bus (a rectangular main body), an RTG, several antennae, and several instrument booms. The bus houses most of the scientific instruments and is designed to rotate at five revolutions per minute. The spacecraft's operational configuration and the location of its major components are shown in figure I.2.

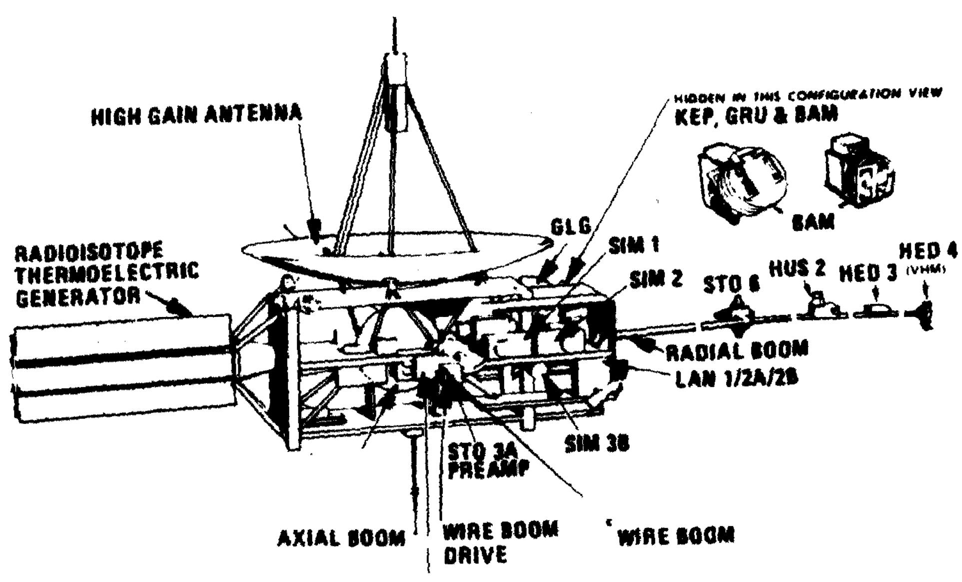
The spacecraft is dominated by three prominent features: a 5-foot parabolic high-gain antenna, an RTG, and long booms carrying several scientific instruments. The high-gain antenna is needed because the spacecraft will be operating at a long distance from the earth. The length of the radial boom is related to instrument requirements for electromagnetic cleanliness and shielding from the RTG. The spacecraft power is provided by an RTG, since the trajectory will take the spacecraft too far from the sun to rely on a solar power array. Two other booms, a 236-foot dipole wire boom and a 25-foot axial boom, serve as electrical antennae for one of the instruments.

The spacecraft's passage through Jupiter's radiation belts requires that all subsystems and experiments use radiation-hardened components.

APPENDIX I

Figure I.2: Spacecraft Configuration





Experiment code	Type of Investigation
HED	Magnetic field
BAM	Solar wind plasma
GLG	Solar wind ion
LAN	Energetic ions and electrons
KEP	Energetic particle composition and interstellar gas
SIM	Cosmic rays/solar particles
STO	Unified radio and plasma waves
HUS	Solar X-rays/Cosmic gamma ray bursts
GRU	Cosmic dust

COST

At the start of the project in fiscal year 1979, NASA estimated its total cost for development and mission operations and data analysis (MO&DA) of the mission at $215.1 million. This estimate was based on a single launch for the NASA and ESA spacecrafts using the Shuttle and a three-stage inertial upper stage (IUS), which provides propulsion into an interplanetary trajectory. Although each agency was to pay for its spacecraft and scientific instruments, NASA was to pay for the Shuttle launch and support service and to share other costs with ESA. In October 1987, 9 years after the start of the project, and 6 years after the elimination of the NASA spacecraft, NASA's total project costs were estimated at $207.2 million.

According to project staff, cost increases before the Challenger accident in January 1986 were mainly due to NASA's decision to delay the launch date, which reduced the fiscal year 1982 budget by $53 million. However, this short-term cost saving contributed to an increase in NASA's total estimated project costs from $243.5 million to $315.8 million.

When NASA canceled its spacecraft, its cost estimate was reduced from $315.8 million to $158 million in fiscal year 1982. During fiscal years 1982 and 1985, the project's estimated cost remained relatively stable, yet the fiscal year 1986 estimate increased to $167.3 million.

Cost increases that occurred after the Challenger accident were a result of NASA decision to postpone the launch date to October 1990 and to replace the liquid-fuel Centaur upper stage, which was canceled as a Shuttle safety- related measure, with a safer, solid-fuel IUS/Payload Assist Module-Spin Stabilized (PAM-S).

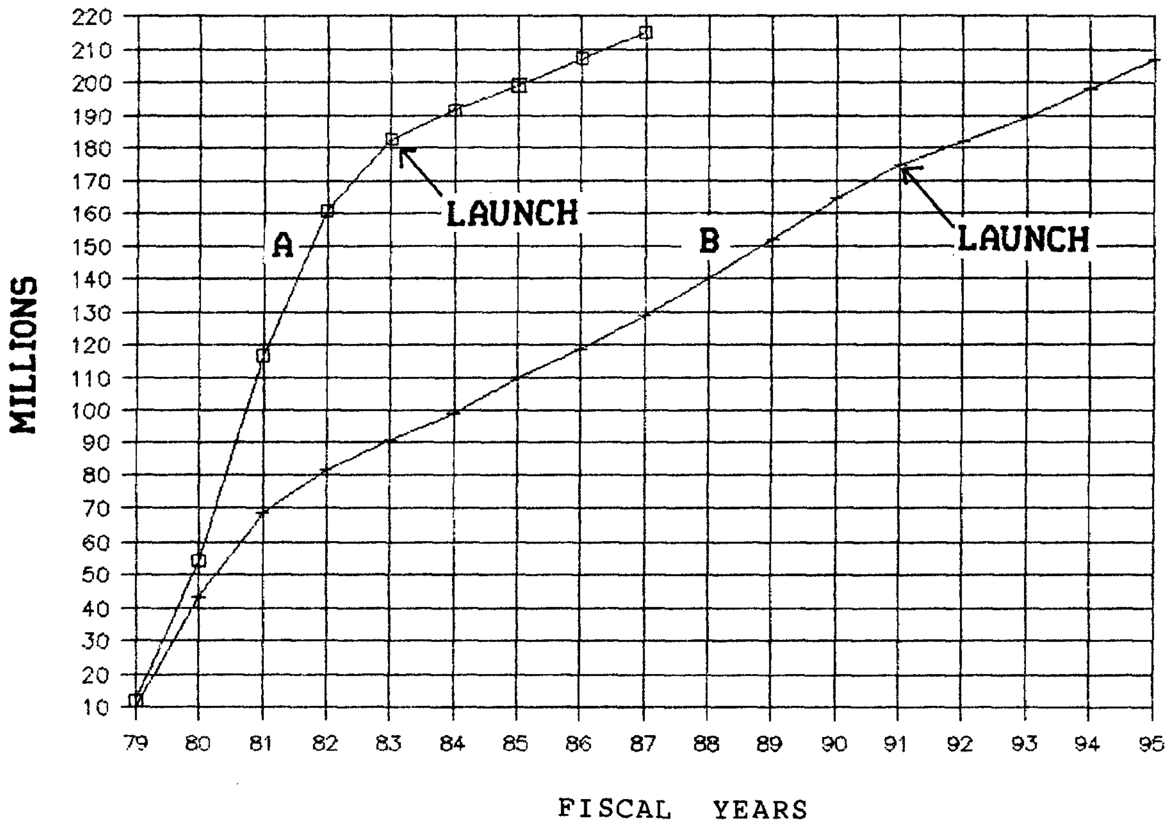
The cost increases by fiscal year are shown in figure I.3 and table I.1.

Table I.1: Cumulative Costs by Fiscal Year for Development and MO&DA Under Fiscal Year 1979 and October 1987 Estimates

FY	1979 Estimate Development	1979 Estimate MO&DA	1979 Estimate Total	October 1987 Estimate Development	October 1987 Estimate MO&DA	October 1987 Estimate Total
	(000 omitted)					
1979	$ 12,000	-	$ 12,000	$ 10,147[a]	-	$ 10,147[a]
1980	54,300	-	54,300	43,342[a]	-	43,342[a]
1981	116,900	-	116,900	68,409[a]	-	68,409[a]
1982	161,000	-	161,000	81,859[a]	-	81,859[a]
1983	178,100	$ 4,600	182,700	90,362[a]	-	90,362[a]
1984	-	13,600	191,700	98,805[a]	-	98,805[a]
1985	-	21,000	199,100	109,948[a]	-	109,948[a]
1986	-	29,000	207,100	118,810[a]	-	118,810[a]
1987	-	37,000	215,100	128,812[a]	-	128,812[a]
1988	-	-	-	140,213	-	140,213
1989	-	-	-	151,915	-	151,915
1990	-	-	-	164,396	-	164,396
1991	-	-	-	167,577	$ 7,290	174,867
1992	-	-	-	-	14,634	182,211
1993	-	-	-	-	21,891	189,468
1994	-	-	-	-	30,741	198,318
1995	-	-	-	-	39,591	207,168

[a]These are actual cumulative costs.

Figure 1.3: Development and MO&DA Costs



CUMULATIVE COSTS

CURVE A - INITIAL FISCAL YEAR 1979 ESTIMATE

CURVE B - OCTOBER 1987 ESTIMATE

The annual changes in the project cost estimate are shown in table I.2. Project costs are estimated at least twice a year by NASA and represent an estimate of total project cost through completion.

Table I.2: Annual Project Cost Estimate Change

Fiscal year	Estimated project costs	Annual cost change
	---(000 omitted)---	
1979	$ 215,100	-
1980	243,466	$ 28,366
1981	315,817	72,351
1982	158,019	-157,798
1983	147,300	-10,719
1984	151,000	3,700
1985	151,800	800
1986	167,322	15,522
1987	207,168	39,846
Total		$ -7,932

SCHEDULE

At the start of the project in October 1978, the mission was scheduled to end in 1987. However, the launch date has been delayed three times. The first delay occurred in April 1980 when the launch date was postponed from February 1983 to April 1985 to help reduce the fiscal year 1982 budget. The second delay occurred in July 1982 when the launch date was postponed from April 1985 to May 1986 because of the shuttle launch delays and the replacement of an upper stage. The third delay occurred after the *Challenger* accident when the launch was postponed from May 1986 to October 1990. With the new 1990 launch date, the mission will be extended until 1995, a delay of 8 years from its original schedule. Overall, the project has nearly doubled in duration, from its initial estimated 9 years to 17 years.

Since project inception, mission design has been affected repeatedly by changes in the upper stage, which NASA changed five times. In fiscal year 1981, NASA canceled the three-stage IUS and decided to use the more powerful Centaur upper stage. However, in fiscal year 1982 NASA terminated the development of the Centaur because of budget problems and selected the U.S. Air Force's two-stage IUS as a replacement. In late fiscal year 1982, the Congress directed NASA to reinstate the Centaur program and to replace the two-stage IUS with the Centaur upper stage. After the *Challenger* accident, NASA canceled the Centaur upper stage because of safety concerns about carrying liquid propellants in the Shuttle cargo bay and returned to the solid propellant two-stage IUS.

The ESA project manager noted in 1982 that the spacecraft is probably considerably overdesigned for the environment it will ultimately encounter because ESA has had to estimate worst-case environments for many types of upper stages. Due to the launch delays, the spacecraft has also gone into storage on two separate occasions. Table I.3 shows the key events in this mission's schedule, as estimated initially in fiscal year 1979 and in October 1987, and a listing of the upper stage changes on the project.

Table I.3: Schedule and Upper Stage Changes

Event	Estimate Initial	Estimate 1987	Increase in years
Project start	1978	1978	-
Launch	1983	1990	7
End of mission	1987	1995	8
Project duration (years)	9	17	8

Launch type	Upper stage vehicle	Year constructed
Combined	Three-stage IUS spin	1978
Split	Three-stage IUS spin	1980
Split	Three-stage IUS 3 axis	1980
Combined	Centaur	1981
Single	Centaur	1981
Single	Two-stage IUS with injection module	1982
Single	Centaur	1982
Single	IUS/PAM-S	1986

PERFORMANCE

Original mission objectives will not be fully achieved, due primarily to the elimination of the NASA spacecraft. As a result of the 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 this project.

The NASA spacecraft, with its complement of instruments to the ESA spacecraft, was to provide simultaneous observations with the ESA spacecraft in opposite hemispheres. This would have been important for verifying the instrument readings. Also, several of the planned instruments for providing imaging information (white light coronagraph and X-ray/extreme ultraviolet telescope) were unique to the canceled NASA spacecraft.

ULYSSES PROJECT CHRONOLOGY

1959 The first mention of an out-of-ecliptic mission appears in a report of a round table discussion at the American Geophysical Union.

1960s Interest in an out-of-ecliptic mission arises largely as a consequence of the results obtained from Pioneer 6, 7, 8, and 9, which showed that the heliosphere in the vicinity of the earth orbit is highly structured and that a better understanding of the solar phenomena may be achieved through an out-of-ecliptic trajectory.

1974 This mission is conceived as a dual-spacecraft mission by a combined European Space Research Organization-NASA definition study team.

1975 The concept of this mission is reviewed at a symposium at Goddard Space Center.

1976 NASA and ESA plan a joint out-of-ecliptic mission called the International Solar Polar Mission that will use two spacecrafts: one developed by NASA and one developed by ESA. The project is reviewed by ESA, and officials hope to launch the spacecrafts in the December 1981 to January 1982 launch window.

1977 NASA and ESA issue a joint Announcement of Opportunity.

1978 Two hundred scientists from 65 universities and research centers in 13 countries are chosen, and 17 experiments are identified.

FY 1979 The project begins.

The launch of the spacecrafts by the Shuttle and a three-stage IUS is planned for 1983.

Mission science is confirmed, and NASA and ESA issue a Memorandum of Agreement.

TRW is selected as the contractor for the NASA spacecraft.

An additional medium-energy imaging detector, interdisciplinary scientists, and co-investigators for three instruments are added to this project.

FY 1980 The contract for the ESA spacecraft is awarded to Dornier Systems and the Star Industrial Consortium. NASA budget difficulties and an anticipated launch loading problem lead to a decision to launch the NASA and ESA spacecrafts as separate payloads.

The Congress proposes to cancel NASA's spacecraft.

The NASA-funded interdisciplinary scientists and radio science investigations, and portions of four instruments, are deleted by NASA.

FY 1981 NASA reinstates the interdisciplinary scientists as advisors to the project.

NASA replaces the three-stage IUS with the Centaur upper stage augmented by a high-performance kick motor. This change requires major adjustments, since the two spacecrafts would have to be launched together rather than separate.

The launch is date changed from April 1985 to May 1986.

ESA protests NASA's decision to replace the three-stage IUS with the Centaur.

A budget reduction forces NASA to cancel its spacecraft so it could maintain funding for the higher-priority Magellan and Galileo missions.

ESA lobbies for the reinstatement of NASA's spacecraft, and it estimates its project cost at $150 million, with $100 million in nonretrievable costs.

ESA offers to replace the canceled U.S. spacecraft by providing NASA with a copy of its spacecraft at a cost of $40 million.

The white light coronagraph instrument is canceled by NASA.

A congressional committee recommends restoration of NASA's funding.

NASA advises the Office of Management and Budget that the ESA proposal to replace the canceled U.S. spacecraft is scientifically acceptable but additional funds will be required between 1983 and 1986 to pursue this option.

The Office of Management and Budget advises NASA that due to Shuttle cost increases, no additional funding would be available to replace the U.S. spacecraft.

NASA informs ESA that no request for the replacement spacecraft would be made in NASA's fiscal year 1983 budget proposal.

A panel convened by the Committee on NASA Scientific and Technological Program Changes (National Research Council) examines five options for the mission.

-- Option 1: A single ESA spacecraft with NASA and ESA instruments. Estimated NASA cost: $110 to $130 million.

-- Option 2: Buy a second ESA spacecraft by NASA for $40 million; use instruments planned for the NASA spacecraft except for those designed for the despun, or nonspinning, platform. Estimated NASA cost: $235 to $250 million.

-- Option 3: Buy U.S.-built spacecraft without imaging; ESA spacecraft would be provided as planned. Equip the U.S. spacecraft as planned, except for the white light coronagraph and x-ray/extreme ultraviolet telescope. Estimated NASA cost: $310 to $330 million.

-- Option 4: Buy U.S. spacecraft with minimum imaging. The equipment provided would be the same as option 3, except for the addition of a white light coronagraph. Estimated NASA cost: $380 to $430 million.

-- Option 5: Fully restore the two-spacecraft mission. Estimated NASA cost: $410 to $460 million.

The panel finds that the benefit-to-cost ratio of going from options 2 or 3 to option 5 is much greater than the benefit-to-cost ratio of going from option 1 to options 2 or 3.

The panel recommends option 1, which would still achieve scientific objectives recommended by the National Academy of Sciences.

FY 1982 As a result of the cancellation of NASA's spacecraft, about one-half of the science instruments to be flown on this mission will not be used, and about 80 U.S. and European scientists were eliminated from the project.

NASA replaces the Centaur upper stage with a two-stage IUS augmented by an injection module.

ESA formally announces its intent to proceed with the single spacecraft mission.

The Congress directs NASA to reinstate the Centaur program, and NASA replaces the two-stage IUS with the Centaur.

FY 1983 Dornier System completes testing of the ESA spacecraft and places it in storage until September 1985.

FY 1984 The International Solar Polar Mission is renamed the Ulysses mission.

FY 1985 The spacecraft is removed from storage, and experiments are integrated with the spacecraft.

Thermal vacuum, spin balance, recertification, and other system tests are conducted.

The spacecraft and ESA mission support pre-shipment reviews are conducted.

FY 1986 ESA control team moves to JPL.

Flight and ground safety reviews are completed.

The Centaur and JPL support hardware are shipped to the Kennedy Space Center. The RTG pre-shipment review is conducted.

Final launch integration activities are in process at the Kennedy Space Center to prepare the spacecraft for a May 1986 launch.

The Challenger accident occurs.

The Centaur is canceled and replaced with IUS/PAM-S.

ESA reassigns Ulysses project team to other projects pending the selection of a new launch date.

The spacecraft is returned to ESA for storage.

The instruments are returned to the principal investigators for storage and recalibration.

JPL and NASA evaluate alternative launch vehicles including the Titan III (now called Titan IV) expendable launch vehicle; however, none will be available until 1991-92.

The launch using the Shuttle is rescheduled for October 1990.

JPL and ESA initiate mission design activities to support a new mission profile and launch date.

FY 1987 JPL and ESA integrate the spacecraft with the new IUS/PAM-S.

GLOSSARY

Announcement of Opportunity	A formal announcement that is issued by NASA to advise scientists about an opportunity to participate in a scientific mission.
Bus	A spacecraft carrier vehicle for various payloads; it is also a part of a spacecraft housing various avionics and scientific instruments.
Centaur	An expendable, high-performance hydrogen-oxygen cryogenic upper stage used by NASA to launch interplanetary and earth orbital payloads.
Combined mission	A mission that will launch two spacecrafts as a single payload.
Corona	The luminous irregular envelope of highly ionized gas outside the chromosphere of the sun; it is also called the solar corona.
Cosmic dust	Small particles found in space that are probably meteoric fragments.
Cosmic rays	Any class of energetic particles traveling through space at speed nearly equal to that of light. They tend to coincide with solar flares and supernova explosions.
Despun platform	A platform designed to keep scientific instrument pointed in a specific direction.
Dipole antenna	An antenna approximately one-half radio wavelength long, split at its electrical center for connection to a transmission line whose radiation pattern has a maximum at right angles to the antenna.
Ecliptic plane	The intersection of the plane of earth's orbit with the celestial sphere, which is an imaginary sphere of infinite radius against which the celestial bodies appear to be projected and of which the apparent dome of the visible sky forms half.

Energetic particles detector	An instrument that measures energetic electrons and protons, determines their spatial distributions, and measures particles trapped in a magnetic field.
Expendable launch vehicle	A nonreusable rocket such as the Titan IV.
Gravity assist	A technique to give a spacecraft sufficient added velocity by aiming the spacecraft toward a planet to use its free gravitational pull.
Hardware	A general term for all mechanical and electrical component parts of a computer or data processing system; it is also applied to spacecraft components.
Heliosphere	The region of the sun's influence on the space environment.
High-gain antenna	A highly sensitive antenna capable of receiving and transmitting radio signals at great distances.
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.
Injection Module	A JPL-developed kick motor.
Interdisciplinary investigations	Investigations beyond the principal experiments in which scientists work with the data from several experiments and provide a broad link among many disciplines.
International solar polar mission	The initial name for the Ulysses mission to the Sun.

Interstellar medium	The space between stars, permeated with gas and cosmic dust.
Ion	Any atom or group of atoms that bear 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). Jupiter has 16 known satellites, with the four largest known as the Galilean moons (Io, Europa, Ganymede, and Callisto).
Kick motor	A supplemental upper stage usually integrated with a spacecraft.
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.
Mars	The fourth planet from the sun, which has two known satellites, Phobos and Deimos.

Memorandum of Understanding	A diplomatic agreement between governments signed at a cabinet level that is often used to describe an agreement for a joint venture or project.
Mission Operations and Data Analysis (MO&DA)	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.
Payload Assist Module-Spin Stabilized (PAM-S)	An upper stage motor system developed by McDonnell Douglas Astronautics Company that is designed to boost a medium-class spacecraft to geosynchronous orbits. The Ulysses spacecraft will use PAM-S to supplement the launch energy provided by an inertial upper stage.
Payload	The useful or net weight that is placed into orbit in a space mission.
Radiation hardening	A procedure to protect computer hardware and other sensitive electronic equipment from highly energetic particles in a severe radiation environment.
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.
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.
Software	A general term for programming or compiling accessories used for computing or data processing systems.
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.
Solar power array	A large assembly of photovoltaic (solar) cells.
Solar wind	A constant plasma stream of protons moving radially away from the sun at a speed of 250 to 800 kilometers per second. It affects the earth's magnetic field and also causes acceleration in the tails of comets.
Solar wind plasma instrument	An instrument that will detect and analyze particles in the solar wind to determine variations in the particles from the equator to the poles.
Split mission	A mission that will launch two spacecrafts as two separate payloads.
Stereoscopic observations	Observations that allow objects to seem three dimensional through the use of observations from two different vantage points.
Trajectory	The path traced by a rocket or spacecraft moving as a result of an externally applied force, considered in three dimensions.
Ultraviolet radiation	The portion of the electromagnetic spectrum located beyond visible light with wavelengths between 400 and 10 nanometers. Radiation with a wavelength below 10 nanometers is classified as extreme ultraviolet.
Ultraviolet spectrometer	An instrument that studies the composition and structure of an upper atmosphere by analyzing the intensity of ultraviolet emissions triggered by the destruction of complex molecules by solar ultraviolet light.

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.
White light coronagraph and X-ray/extreme ultraviolet telescope	An instrument designed to provide an image of the solar atmosphere from the chromosphere to outer corona in white light (400 to 650 nanometers), X-rays (0.3 to 6 nanometers), and extreme ultraviolet light (1.71 to 55 nanometers).
X-ray	A penetrating form of electromagnetic radiation that is nonnuclear in origin and has a very short wavelength (10 to 0.001 nanometers).

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