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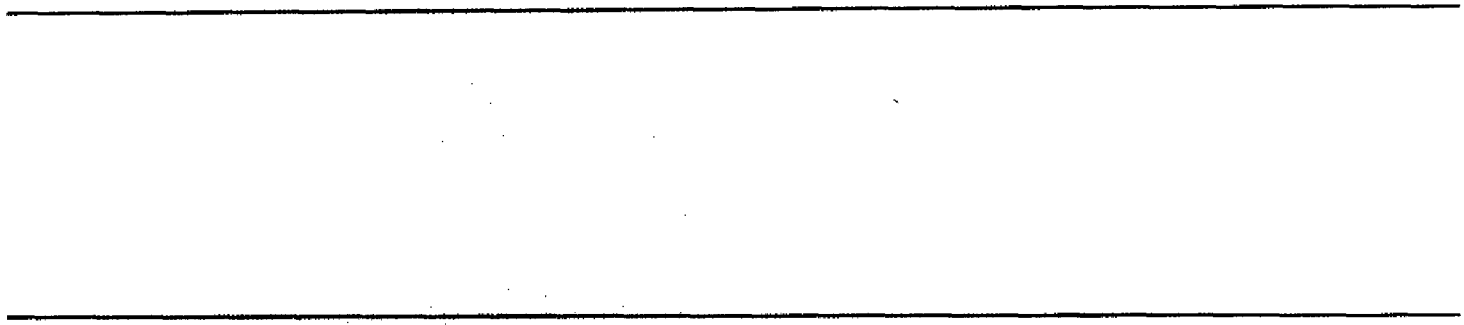
Report to the Chairman, Subcommittee on Investigations and Oversight, Committee on Science, Space, and Technology, House of Representatives

December 1993

SPACE SCIENCE

Causes and Impacts of Cutbacks to NASA's Outer Solar System Exploration Missions



GAO

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

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National Security and
International Affairs Division

B-254122

December 29, 1993

The Honorable James A. Hayes
Chairman, Subcommittee on Investigations and Oversight
Committee on Science, Space, and Technology
House of Representatives

Dear Mr. Chairman,

At the request of your predecessor, we reviewed the National Aeronautics and Space Administration's (NASA) Comet Rendezvous Asteroid Flyby (CRAF)/Cassini program to identify (1) the factors that led to cancellation of the CRAF portion of the project and (2) the prospects for continuation of the Cassini project.

Unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days after its issue date. At that time, we will send copies to the NASA Administrator and other interested congressional committees. We will also make copies available to others upon request.

If you have any questions, please call me on (202) 512-8412. The major contributors to this report are listed in appendix IV.

Sincerely yours,

Donna M. Heivilin
Director, Defense Management and NASA Issues

Executive Summary

Purpose

The Comet Rendezvous Asteroid Flyby (CRAF)/Cassini program was first funded by the Congress in fiscal year 1990. Since then, it has encountered difficulties that resulted in the cancellation of CRAF, reduction of Cassini's original scientific capabilities, and extension of its launch date.

At the request of the former Chairman of the Investigations and Oversight Subcommittee, House Committee on Science, Space, and Technology, GAO reviewed the program to identify (1) the factors that led to the cancellation of the CRAF project and (2) the prospects for continuation of the Cassini project.

Background

In 1981, the Jet Propulsion Laboratory began studies of a standard spacecraft design that could be used, with minor modifications, to conduct various missions to explore the outer solar system. In a 1983 study, the Solar System Exploration Committee of the National Aeronautics and Space Administration (NASA) Advisory Council set out a detailed strategy for continuing NASA's exploration of the solar system through the year 2000. Two of the Committee's highest priorities were missions to comets and asteroids and to Saturn and its moon, Titan. The Committee also recommended the development of a standard spacecraft for various outer solar system missions. The CRAF/Cassini project evolved from these studies.

NASA's original plans for the CRAF mission were to launch the spacecraft in August 1995, fly by and observe an asteroid, and then rendezvous with a comet, study its nucleus, and observe it as it traveled around the sun. At that time, Cassini was scheduled for launch in April 1996. NASA currently plans to launch the Cassini spacecraft in October 1997 and to arrive at and begin orbiting Saturn in 2004 to study the planet, its rings, moons, and magnetosphere for 4 years.

Results in Brief

A combination of factors led to the cancellation of CRAF. First, a large increase in the estimated cost for one of its important science experiments, the comet nucleus penetrator, led NASA to delete this, as well as another, experiment from the project. Next, large congressionally directed reductions in fiscal years 1992 and 1993 budgets led to a 2-year schedule extension and a significant increase in estimated cost.

NASA believed that its future budgets would not likely be large enough to fully fund all of its planned and ongoing activities, including CRAF/Cassini.

Therefore, NASA and the Office of Management and Budget deleted all funding for CRAF in NASA's 1993 budget request. The President's 1993 budget, reflecting this decision, proposed termination of CRAF, and the Congress provided no further funding for it. CRAF was canceled without thoroughly examining whether the scope of both CRAF and Cassini could have been reduced in order to preserve both missions.

After the termination of CRAF, NASA still anticipated that its future budgets could not fully fund all of its planned and ongoing projects, including the remaining Cassini project. Therefore, NASA directed that the Cassini project be restructured to further reduce its cost. The Cassini project is currently meeting its new cost and schedule goals, and NASA plans to exceed its new science goals, which were reduced as a result of the project's restructuring. However, several factors could adversely affect Cassini's future capability.

Principal Findings

Reduced Science Capabilities and Funding Problems Led to Cancellation of CRAF

Events early in the project combined to cause the cancellation of CRAF. In November 1990, a year after the Congress approved the CRAF/Cassini project, a cost increase estimated at $78 million to $98 million above the original proposed cost led NASA to cancel CRAF's comet nucleus penetrator experiment. This eliminated one of the project's primary scientific capabilities—the in situ study of a comet nucleus. At the same time, NASA canceled another CRAF science instrument to further reduce costs. In July 1991, the Senate Appropriations Committee, citing severe fiscal constraints, proposed terminating CRAF and capping Cassini's fiscal years 1992 and 1993 budgets at $215.7 million, $112.3 million and $167.7 million, respectively, less than NASA had planned.

In assessing the impacts of the proposed funding reductions, NASA estimated that the CRAF and Cassini launch dates would be delayed up to 2 years and that $254 million in additional funding would be required for the project's 1992 to 1998 budgets, increasing the estimated development cost from $1.60 billion to $1.85 billion. NASA anticipated that its future budgets would not be large enough to fully fund all of its planned and ongoing projects, including CRAF/Cassini. NASA and the Office of Management and Budget deleted funding for CRAF in NASA's 1993 budget request. Subsequently, the President's 1993 budget submission proposed

terminating CRAF, and the Congress provided no further funding for the project.

Alternatives to Canceling CRAF Were Not Evaluated

While NASA performed 9 years of studies before starting the CRAF/Cassini project, it canceled CRAF relatively early in the project's development in view of funding constraints and in response to congressional guidance. Before doing so, NASA did not perform any detailed analyses of alternatives that may have preserved both missions and did not ask the Jet Propulsion Laboratory to conduct such a study.

The President's 1993 budget submission stated that CRAF was proposed for termination because, with the cancellation of some of its instruments, its scientific benefits no longer justified the investment. However, the National Research Council reported shortly thereafter that the CRAF mission was still scientifically valuable, and, in an April 1992 report, the House Science, Space, and Technology Committee urged the agency to explore ways to reinstate a modified lower cost comet and asteroid mission.

Estimated Cost Reduction From Canceling CRAF

The cancellation of CRAF reduced the project's total estimated cost by about $698 million. Of this amount, about $163 million was a reduction from the estimated $1.85 billion development cost of both projects. This development cost reduction of 8.8 percent was relatively small because both spacecraft were to have used the same basic design with only minor differences. Thus, the development cost still had to be incurred to produce the Cassini spacecraft. Furthermore, the cancellation of CRAF caused the Federal Republic of Germany to cancel its share of development for spacecraft propulsion subsystems, which increased Cassini's estimated development cost by $55 million.

NASA's Overcommitted Budgets Required Restructuring of Cassini

After CRAF's cancellation, Cassini's estimated development cost was $1.68 billion. However, NASA anticipated that its future budgets would not be large enough to fully fund all of its planned and ongoing projects, including the remaining Cassini project. Therefore, NASA asked the Jet Propulsion Laboratory to restructure the Cassini project to further reduce its estimated cost. The result was that the standard spacecraft design was deleted in favor of a less expensive and less capable Cassini-unique design, about $94 million in development work was postponed until after the

mission was launched, and several management changes intended to improve the project's efficiency were implemented.

These changes reduced the Cassini project's estimated development cost to less than $1.5 billion, but they also reduced the amount and depth of scientific data to be collected during the mission. However, no instruments were deleted from the project and the National Research Council reported that the restructured Cassini project is still responsive to the planned science objectives.

Future Threats to Cassini Science

The Cassini project's most recent reviews indicate that the project is currently meeting its latest cost and schedule goals, and that NASA plans to meet or exceed the project's new, reduced science goals. However, there are several factors that could adversely affect NASA's plans. First, it is uncertain whether the new, more powerful solid rocket motor that is currently under development by the Air Force will be available in time to help launch the Cassini spacecraft. According to Jet Propulsion Laboratory project officials, the Air Force's development program for the upgraded solid rocket motor is meeting its current milestones and it should be available. However, if it is not, the Cassini mission will be launched using a less powerful rocket. If that happens, the mission's planned science will be reduced and NASA will not have the opportunity to exceed the project's current science goals. Second, the Jet Propulsion Laboratory's preliminary cost estimates for mission operations and data analysis costs need to be lower. One way of reducing these costs that is under consideration involves reducing the number of project personnel and accepting a higher risk of losing science data if a system fails. Third, significant delays in launching the Cassini spacecraft, for any reason, would further reduce the mission's science capabilities.

Recommendation

GAO is not recommending any specific actions on the CRAF/Cassini program. However, GAO believes that there are lessons to be learned from actions leading to the termination of CRAF. Specifically, NASA's future decision-making on any major project with a viable mission that becomes a candidate for termination could be based on more complete and authoritative information by assessing the advantages, disadvantages, and alternatives to termination. If NASA decides to terminate such a project or is asked by the Congress to consider doing so, congressional decision-making on the proposed termination could be more informed if NASA provided (1) the results of its internal assessment; (2) information on

the cost reduction from canceling the project, net of all termination-related costs; and (3) the views of any independent science advisory group(s) on the termination proposal.

Agency Comments

NASA said the GAO report was technically accurate and agreed that NASA should explain future project termination actions in a more comprehensive manner. NASA emphasized that, in its view, CRAF termination was primarily caused by lower than expected budget levels for planetary exploration. NASA stated that it was taking the steps necessary to ensure that when programs are started there is a realistic plan for annual funding.

Contents

Tables

Figures

Abbreviations

CRAF	Comet Rendezvous Asteroid Flyby
GAO	General Accounting Office
JPL	Jet Propulsion Laboratory
NASA	National Aeronautics and Space Administration
MO&DA	Mission Operations and Data Analysis
SRMU	Solid Rocket Motor Upgrade
SRM	Solid Rocket Motor

Introduction

The Comet Rendezvous Asteroid Flyby (CRAF) and Cassini missions originated in several studies that were conducted in the late 1970s and early 1980s by the National Aeronautics and Space Administration (NASA) and a NASA advisory committee. In 1981, the Jet Propulsion Laboratory (JPL) initiated studies of six missions to the outer solar system, each using a similar standard spacecraft design. In 1983, a report by the Solar System Exploration Committee of the NASA Advisory Council recommended a series of space science missions to continue NASA's exploration of the solar system.[1] In response to those recommendations, NASA directed JPL to intensify pre-project studies of missions to an asteroid and a comet, and to the Saturn system. These studies evolved into the CRAF/Cassini project.

Since the CRAF/Cassini project started in fiscal year 1990, many changes have been made and the project is now substantially different from the one envisioned by the committee. In particular, the CRAF mission was canceled, as was development of the Mariner Mark II spacecraft design that was intended to be used for various missions to the outer solar system.

Evolution of the CRAF/Cassini Project

In its 1983 report, the Solar System Exploration Committee described and recommended a detailed strategy for continuation of NASA's unmanned planetary exploration program through the year 2000. The committee defined a core set of solar system exploration missions as its highest priority. Its third- and fourth-priority missions—exploration of comets and asteroids, and of Saturn and its largest moon Titan—led to creation of the CRAF/Cassini project.[2]

The committee also recommended development and use of a standard multimission spacecraft design called Mariner Mark II. Using a standard spacecraft design that could be adapted, with minimal modifications, to many different missions was intended to reduce the cost of deep space exploration.

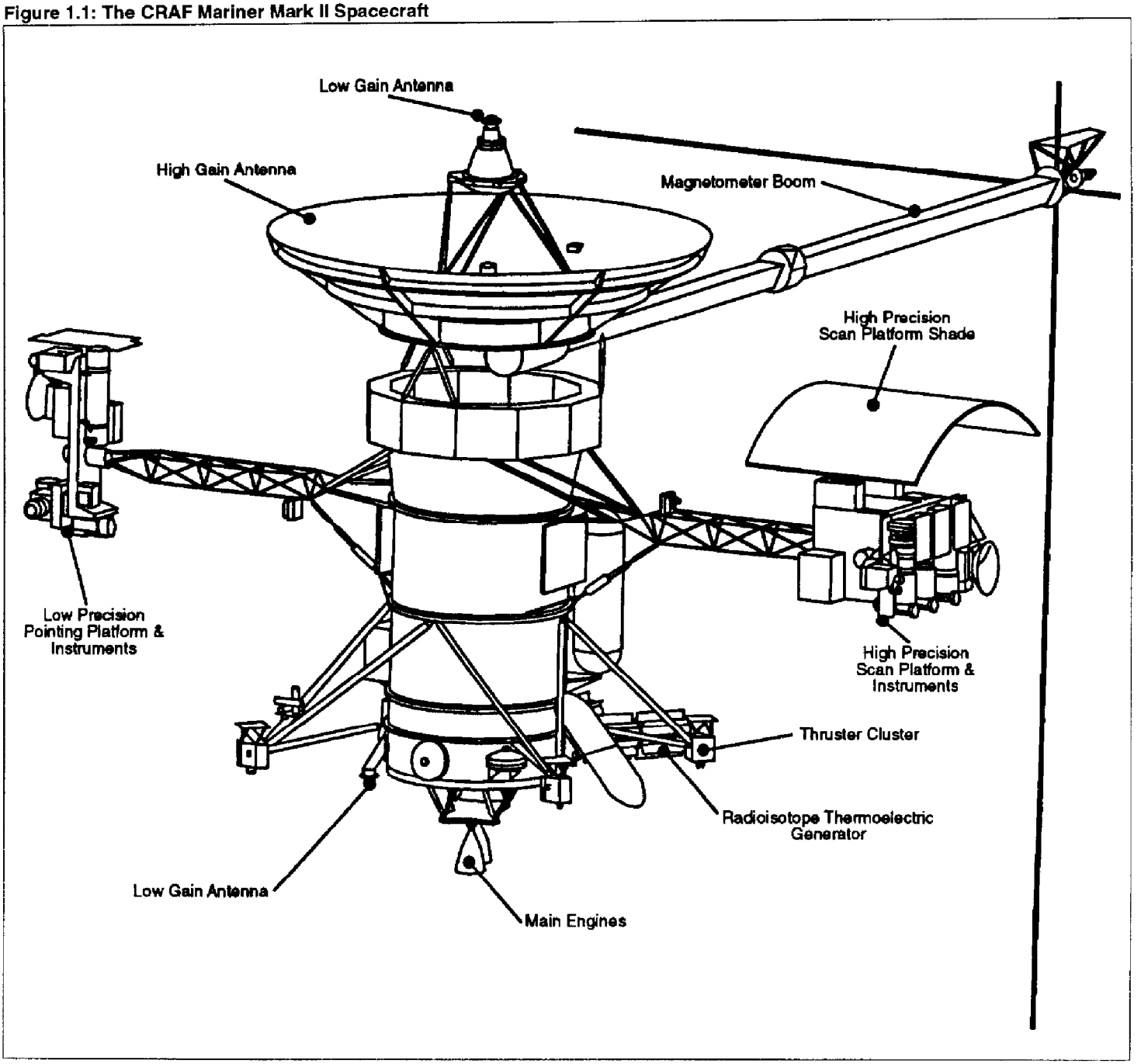
When NASA initiated the CRAF/Cassini project, it planned to save money by designing and building two Mariner Mark II spacecraft, one for each

[1]Planetary Exploration Through Year 2000: A Core Program (Washington, D.C.: GPO, 1983).

[2]The committee's first and second priorities, a mission to map Venus' surface using radar and an orbiting climatological and geoscience mission to Mars, have already been launched as the Magellan and Mars Observer missions, respectively. The Magellan mission is essentially completed. Communications with the Mars Observer spacecraft was lost as it approached the planet. Efforts to reestablish communications have been unsuccessful.

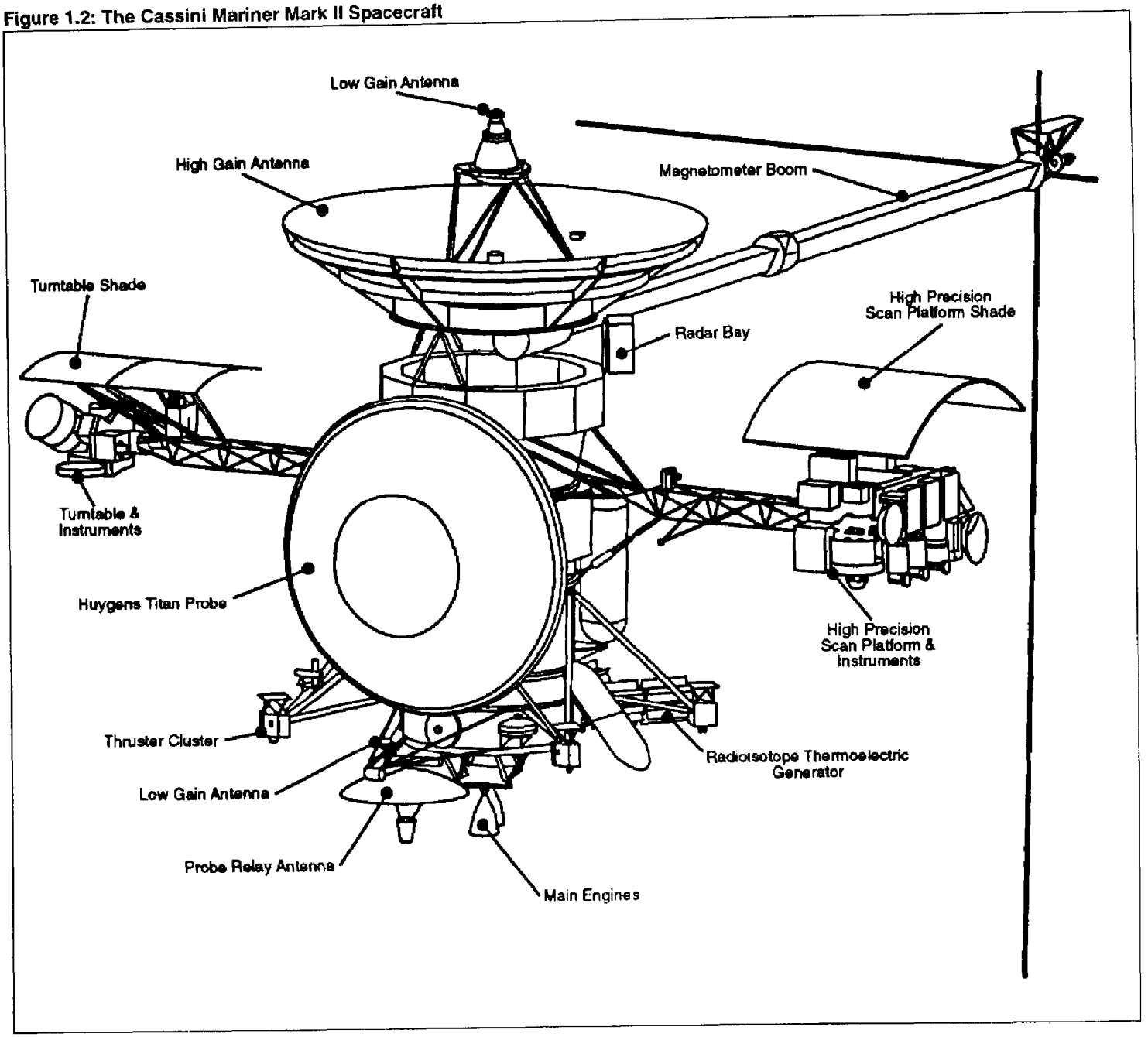
mission, in a single combined development project. Figures 1.1 and 1.2 illustrate how similar the two spacecraft would have been.

Figure 1.1: The CRAF Mariner Mark II Spacecraft



Source: NASA/JPL.

Figure 1.2: The Cassini Mariner Mark II Spacecraft



Source: NASA/JPL.

The project was approved by the Congress in November 1989 as a new start in fiscal year 1990 after 9 years of pre-project studies by JPL.[3] The CRAF mission was originally planned for launch in August 1995 to fly by and observe an asteroid and then rendezvous with a comet to study its nucleus and ejected gasses and dust as it traveled around the sun. The Cassini mission was originally planned for launch in April 1996. After launch, which is now planned for October 1997, the Cassini spacecraft is scheduled to begin orbiting Saturn in 2004 to study the planet, its rings, moons, and magnetosphere for 4 years. The CRAF/Cassini project included participation by the Federal Republic of Germany and the European Space Agency. The European Space Agency and the Italian Space Agency are participating in the remaining Cassini project. Major milestones and events associated with the CRAF/Cassini project from its inception through April 1993 are listed in appendix II.

Objectives, Scope, and Methodology

Our objectives were to identify (1) the causes of the cancellation of CRAF and (2) the prospects for continuing the Cassini portion of the project.

In conducting our evaluation, we interviewed NASA and JPL program and project management officials. We reviewed documents that describe the past, current, and future cost, schedule, and science goals of both the CRAF/Cassini and the Cassini projects. We interviewed the Chairman of the Space Studies Board of the National Research Council and reviewed the Board's reports on both projects. We also reviewed the Solar System Exploration Committee's 1983 report on planetary exploration, and the projects' legislative histories. The information in this report includes NASA estimates. We did not verify those estimates.

We performed our work at NASA headquarters, Washington, D.C., and at JPL, Pasadena, CA. We conducted our review from September 1992 to September 1993 in accordance with generally accepted government auditing standards.

[3]In approving the project, the Congress capped its development cost at $1.6 billion. Since that time, the cap has been at various levels. Through the completion of our fieldwork in September 1993, NASA's formal project budget commitments have been in line with any applicable cap.

CRAF Cancellation Caused by Reduced Science Capabilities and Funding Problems

A combination of factors contributed to the cancellation of CRAF, including an increase in its estimated cost, reductions to its science capabilities, large proposed reductions to the project's fiscal years 1992 and 1993 budgets, and NASA's overcommitted future annual budgets. CRAF's science capabilities were significantly reduced when a large increase in the estimated cost of its comet nucleus penetrator experiment led NASA to cancel the penetrator, one of CRAF's main scientific instruments. CRAF's scanning electron microscope and particle analyzer instrument was also canceled at the same time to further reduce costs.

Next, in its report on NASA's 1992 budget, the Senate Appropriations Committee proposed canceling CRAF and providing the project with fiscal years 1992 and 1993 budgets well below NASA's planned levels. Finally, anticipating constrained future budgets, NASA and the Office of Management and Budget deleted CRAF funding from NASA's 1993 budget request, and the Congress appropriated no funds for it.

Cost Increase Led to Reduced Science Capabilities for CRAF

A large increase in the estimated cost for CRAF's comet nucleus penetrator experiment led NASA to cancel this key instrument in November 1990, only about a year after the project began. At the same time, to further reduce costs, NASA also canceled CRAF's scanning electron microscope and particle analyzer.

Development of the comet nucleus penetrator was initially estimated to cost $22 million in 1986.[1] However, by the end of the CRAF/Cassini project's first year of development, technical problems had increased its estimated cost to between $100 million and $120 million, $78 million to $98 million above the original estimate. NASA then terminated further development. Termination of the penetrator significantly reduced CRAF's science capabilities by eliminating CRAF's ability to analyze a comet's nucleus in situ.

CRAF's penetrator experiment would have enabled the project to exceed the science goals established by the NASA Advisory Council's Solar System Exploration Committee for the first comet mission—conducting detailed observations over time without directly sampling the comet's nucleus. However, with the penetrator, the spacecraft could have directly sampled and analyzed a comet's nucleus. Nevertheless, the National Research Council, in a March 1992 report, stated that the CRAF mission had great scientific merit even without the penetrator experiment.

[1]Work on CRAF science began several years before the CRAF/Cassini program officially began in 1990.

Proposed Budget Reductions Led to Schedule Slips and Cost Increases

Proposed reductions to the CRAF/Cassini project's fiscal years 1992 and 1993 budgets, in conjunction with NASA's overcommitted future budgets, were the major factors in the cancellation of CRAF. The actual reductions to the project's budgets were $117.3 million and $173.4 million, respectively. While the project was able to absorb the 1992 reduction without changing its overall cost and schedule goals, the 1993 reduction caused the CRAF and Cassini launch dates to slip by 1 year and 2 years, respectively, and the total development cost estimate to increase from $1.6 billion to $1.85 billion. Because NASA's future annual budgets were expected to be smaller than previously planned, NASA anticipated that it could provide the additional funding for the CRAF/Cassini project only by taking funds from other projects in future years. Rather than doing that, NASA and the Office of Management and Budget decided to delete CRAF from NASA's 1993 budget request. Subsequently, the President proposed cancellation of CRAF in his fiscal year 1993 budget submission and the Congress appropriated no funds for it, effectively canceling it.

Before reductions were made to the Cassini project's fiscal years 1992 and 1993 budgets, NASA estimated that the project would need $328 million and $383.4 million, respectively, for those years. Then, in July 1991, the Senate Appropriations Committee's Report on NASA's 1992 budget proposed that, due to severe fiscal constraints, CRAF be cancelled and Cassini's 1992 and 1993 budgets not exceed $215.7 million for each year—$112.3 million and $167.7 million less, respectively, than NASA estimated would be needed. Because NASA, the Office of Management and Budget, and the Congress made further changes to the project's fiscal years 1992 and 1993 budgets, the amounts actually provided were different than those proposed in the Senate report. Table 2.1 shows NASA's 1992 and 1993 budget requests before the proposed reductions, and the amounts that were actually provided.

Table 2.1: Comparison of NASA's 1992 CRAF/Cassini Project Budget Estimates for 1992 and 1993, and the Appropriated Amounts

Real-year dollars in millions

	1992	1993
1992 NASA estimates	$328.0	$383.4
Appropriated amounts	210.7	210.0[a,b]
Reduction	$(117.3)	$(173.4)

[a]NASA transferred $5.6 million from the project to the Planetary Mission Operations and Data Analysis (MO&DA) budget, and $0.5 million to the project for reallocation of Research Operation Support. These transfers reduced the project's actual 1993 funding to $204.9 million.

[b]This appropriation was for Cassini only.

In order to conform with the proposed reductions to the CRAF/Cassini project's fiscal years 1992 and 1993 budgets, NASA delayed some development work. According to NASA and JPL project officials, this caused delays of up to 2 years in the launch dates. Those delays, in turn, increased the project's estimated development cost by about $254 million due to (1) the funding of 2 more years of project development work, (2) the additional funding required to perform some of the delayed work concurrently with previously scheduled work, and (3) 2 more years of inflation costs. Table 2.2 shows the project's estimated budgets prior to and after the proposed 1992 and 1993 funding reductions.

Table 2.2: NASA's CRAF/Cassini Project Budget Estimate Profiles Before and After the Proposed 1992-93 Cuts

Real-year dollars in millions

	Project budget estimate profiles		
Fiscal year	Before cuts	After cuts[a]	Anticipated change
1990	$29.5	$29.5	$0
1991	143.0	143.0	0
1992	328.0	210.7	(117.3)
1993	383.4	266.2	(117.2)
1994	380.1	413.7	33.6
1995	252.6	392.5	139.9
1996	76.1	257.5	181.4
1997	5.0	138.9[b]	133.9
Total	**$1,597.7**	**$1,852.0**	**$254.3**

[a]These are internal NASA planning estimates, not formal budget commitments. NASA later submitted a smaller fiscal year 1993 project budget request, reflecting the decision to cancel CRAF.

[b]Includes funding for project development activities associated with the launch of the Cassini spacecraft in October 1997.

Before the proposed fiscal years 1992 and 1993 budget reductions, NASA estimated the CRAF/Cassini project's development cost to be $1.598 billion, slightly less than the estimate when the project started. After evaluating the anticipated impacts of the proposed reductions, NASA's internal planning estimate of the project's cost increased to $1.85 billion. NASA estimated that the project would have been able to accommodate the 1992 reduction without changing its overall cost and schedule goals by delaying some work to later years and reducing the financial reserves portion of its budget. However, the project would not have had enough financial and schedule reserves left to absorb the 1993 funding reduction and still meet

its overall cost and schedule goals, thus making schedule slips and cost increases necessary.[2] Table 2.3 summarizes the changes to the project's estimated launch dates and development costs before and after the proposed 1992 and 1993 funding reductions.

Table 2.3: Selected Development Cost Estimates and Launch Dates for the CRAF/Cassini Project

Real-year dollars in millions

Project milestones or events	Project cost estimates	Changes to cost estimates	Launch dates	
			CRAF	Cassini
Project start	1,599.0	[c]	8/95	4/96
Preliminary design	1,597.7	(1.3)	2/96	11/95
After proposed 1992 and 1993 budget cuts	1,852.0[b]	254.3	5/97	10/97
Cassini-only after CRAF cancellation	1,689.4[b]	(162.6)	[c]	10/97
Cassini-unique design	1,453.7	(235.7)	[c]	10/97

Note: Excluded from this table are (1) launch vehicle costs; (2) MO&DA costs; (3) tracking costs; (4) most NASA personnel costs; (5) Department of Energy's share of costs for radioisotope thermoelectric generators, radioisotope heater units, radioisotope fuel for the generators and heaters, and other related activities; and (6) costs borne by foreign participants.

[a]During Preliminary Design Review, a project is evaluated to determine that its mission requirements and preliminary hardware designs are well-enough defined for the project to proceed into the critical design phase.

[b]These are internal NASA planning estimates, not official budget commitments.

[c]Not applicable.

Alternatives to Canceling CRAF Were Not Evaluated

There is little documentation of the reasons and decision process behind the cancellation of CRAF. Further, no studies or analyses were done to evaluate whether to cancel CRAF or pursue an alternative means of accomplishing CRAF's mission.

NASA's Project Status Reports to the Congress in March and July of each year are intended to describe the progress, changes, and status of NASA's major projects. The July 1991 Project Status Report, issued at about the same time as the Senate Appropriations Committee's Report on NASA's 1992 funding, did not discuss possible termination of CRAF. The March 1992 Cassini Project Status Report was issued after NASA and the President had

[2]Project financial reserves are funds set aside from current budgets or estimated as part of future budgets for financing efforts to solve unanticipated technical problems and preventing cost overruns. Project schedule reserves are composed of unscheduled time set aside until needed to solve unanticipated technical problems and prevent schedule delays.

decided to cancel CRAF, but it did not discuss possible alternatives and reported only that the 1992 and 1993 budget cuts resulted in termination of the CRAF mission.

The cancellation of CRAF was not fully supported by the space science community. For example, the National Research Council's Space Studies Board reported in March 1992, after NASA's decision to cancel CRAF, that the mission remained scientifically valuable and that such a mission should be pursued at the earliest opportunity. Further, in its April 1992 report, the House Science, Space, and Technology Committee urged NASA to explore restructuring options that might allow the reinstatement of a modified, lower cost comet and asteroid spacecraft program. However, according to NASA and JPL project officials, NASA did not pursue any alternatives and did not ask JPL to study alternatives, such as reducing the scope of both missions to bring them in line with NASA's budget constraints. At the time, project officials at JPL were not aware that NASA had been asked to consider an alternative lower cost comet/asteroid mission.

Estimated Cost Reduction From CRAF Cancellation

The project's estimated development cost was reduced by about $163 million by canceling CRAF, or 8.8 percent, of the total estimated $1.85 billion development cost for the CRAF/Cassini project. After adding launch vehicle and MO&DA costs, canceling CRAF reduced estimated project costs by about $698 million, or about 19 percent, of the $3.64 billion total estimated cost of the CRAF/Cassini project. Table 2.4 shows the estimated differences between the major project cost elements just before and just after CRAF was canceled.

Table 2.4: Estimated Cost Reduction by Cancellation of CRAF

Real-year dollars in millions

Major project cost elements[a]	Estimated project costs		Estimated reduction	
	CRAF/Cassini	Cassini only	Amount	Percent
Development	$1,852.0	$1,689.4	$162.6	8.8
Launch vehicle	686.9	352.0	334.9	48.8
MO&DA[b]	1,100.0[c]	900.0[d]	200.0	18.2
Total	**$3,638.9**	**$2,941.4**	**$697.5**	**19.2[e]**

Note: Excluded from this table are (1) most NASA personnel costs; (2) Department of Energy's share of costs for radioisotope thermoelectric generators, radioisotope heater units, fuel for the generators and heaters, and other related activities; (3) costs borne by foreign participants; and (4) tracking costs.

[a]Tracking costs are not shown because the CRAF/Cassini estimate was too preliminary for comparison with the Cassini only estimate.

[b]MO&DA cost estimates are preliminary.

[c]The amount is the mid-point of an estimated range from $1 billion to $1.2 billion.

[d]The amount is the mid-point of an estimated range from $800 million to $1 billion.

[e]This calculation is of an estimated cost reduction, not a potential savings; therefore, it includes funds already spent on the project.

According to NASA and JPL project officials, the reduction in estimated development costs from the cancellation of CRAF was relatively small because the large investment required to design and build the first spacecraft would have already been made, making it possible to build the second spacecraft at relatively low cost. CRAF's cancellation also caused the Federal Republic of Germany to withdraw from the project, increasing Cassini's cost by an estimated $55 million to pay for spacecraft propulsion subsystem work that Germany was to have performed.

Conclusions

NASA performed 9 years of studies before gaining congressional approval to start the CRAF/Cassini project. In a relatively short time, an increase in the estimated cost of the CRAF portion of the project, large proposed and actual reductions to the CRAF/Cassini project budgets, and NASA's overcommitted future budgets combined to cause the cancellation of the CRAF portion of the project. However, the decision to cancel CRAF was made without thoroughly examining the alternative of reducing the scope of both missions in order to pursue them at a reduced level.

We believe there are lessons to be learned from the actions leading to CRAF termination. Specifically, we believe that NASA's future decision-making on any major project with a viable mission that becomes a candidate for termination could be based on more complete and authoritative information by assessing the advantages, disadvantages, and alternatives to termination. If NASA decides to terminate such a project, or is requested by the Congress to consider doing so, congressional decision-making on the proposed termination could be more informed if NASA provided (1) the results of its internal assessment; (2) information on the cost reduction from canceling the project, net of all termination-related costs; and (3) the views of any independent science advisory group(s) on the termination proposal.

Agency Comments

NASA said the report was technically accurate and agreed that the agency should explain future project termination actions in a more comprehensive manner. NASA emphasized that, in its view, CRAF termination was primarily caused by lower than expected budget levels for planetary exploration. NASA stated that it was taking the steps necessary to ensure that when programs are started there is a realistic plan for annual funding. NASA's comments are in appendix I.

Cassini Project Restructuring Reduced Cost but Provides Less Science Capability

After canceling CRAF, the estimated development cost of $1.68 billion for the remaining Cassini project still exceeded what NASA officials believed could be provided.[1] NASA instructed JPL to restructure the Cassini project, primarily to further reduce the project's estimated development cost—especially the estimated costs for fiscal years 1994 and 1995. As a result, the original multimission Mariner Mark II spacecraft design was replaced with a less expensive, less capable one, Cassini's science capabilities were reduced, some development work has been postponed until after the mission is launched, and project management procedures intended to increase the project's efficiency were implemented. As shown in table 2.3, this restructuring effort reduced the Cassini project's estimated development cost to its current estimate of $1.45 billion.

While the science capabilities of the Cassini mission were reduced, the National Research Council, in an October 1992 report by its Space Studies Board, stated that the restructured mission remained responsive to its scientific priorities and does not substantially compromise the primary mission objective to intensively study the Saturn system.

Change to a Less Capable Spacecraft Reduced the Amount and Quality of Science

NASA's cost-reduction efforts for the Cassini project included replacing the Mariner Mark II multimission spacecraft design with a less expensive, less capable Cassini-unique design. While no science instruments were deleted from the project and the mission's primary science objectives were not changed, the new spacecraft design reduced the amount and quality of some of the project's planned science investigations. According to project officials, the breadth of the science coverage of the Saturn system was not reduced in the redesign process, but the depth of some of the investigations was reduced. Table 3.1 summarizes the most important changes to the Cassini project's science capabilities resulting from NASA's cost-reduction efforts.

[1]NASA was also becoming increasingly concerned about whether the Air Force's Titan IV Solid Rocket Motor Upgrade (SRMU) would be available to launch the Cassini spacecraft. The effects of SRMU availability on the Cassini project are summarized in table 3.1 and discussed in more detail in chapter 4.

Table 3.1: Changes to Cassini Science Capabilities

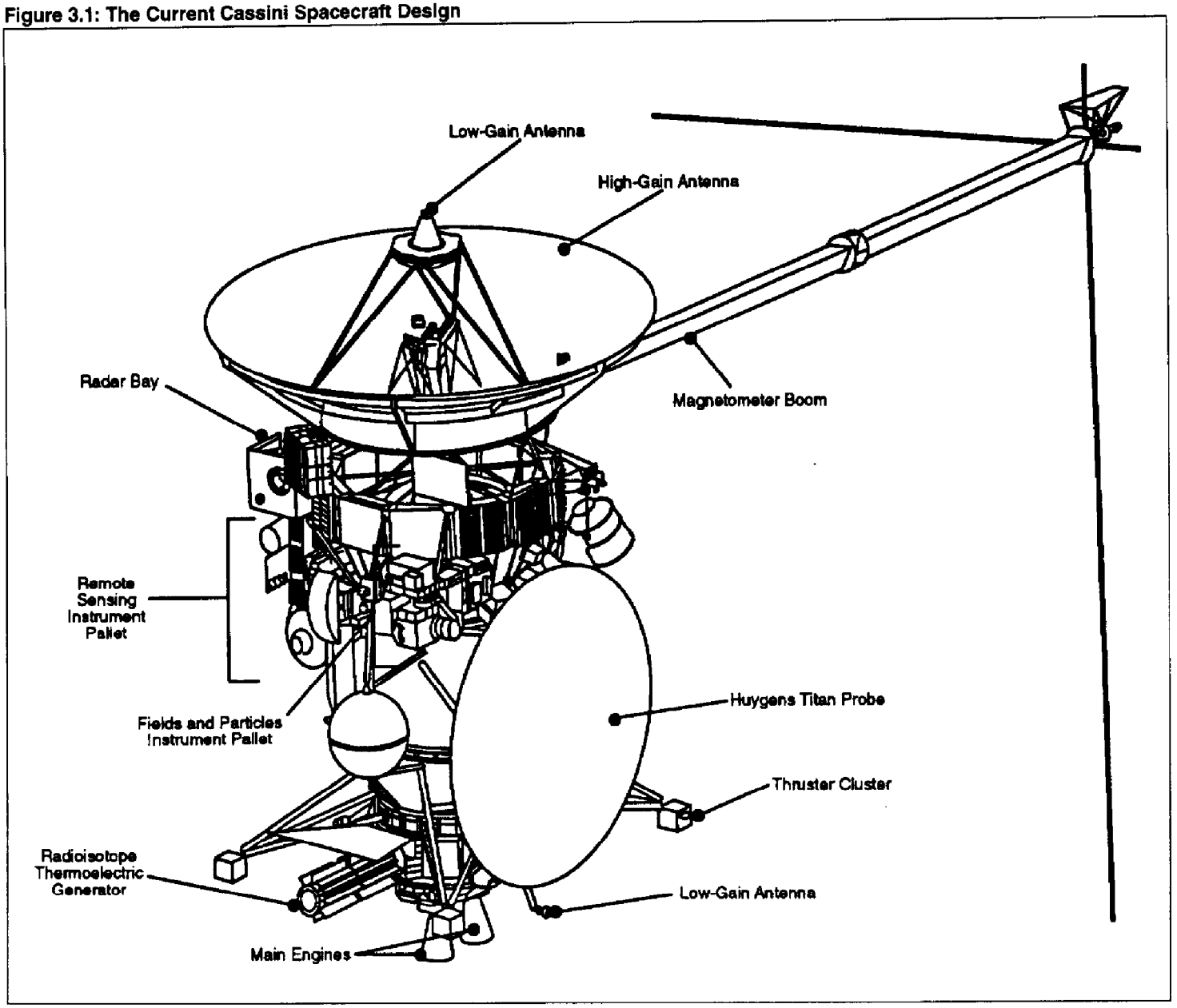
	Science capabilities		
Cassini science goals	**Original mission**		**Current mission**
Cruise-phase science[a]			
Interplanetary fields and particles observation	*About 7 years*	*About 2 years*	
Venus observations	2 sets	Deleted	
Earth and moon observations	1 set	Deleted	
Potential asteroid observations	1 set	Deleted	
Jupiter observations	1 set	Deleted	
Saturn system science		SRM[b]	SRMU[b]
Estimated number of Saturn orbits	59	50	60
Times crossing magnetopause (maximum number)	119	101	127
Required particle observation time (in seconds)	20	1380	1380
Titan flybys	36	23	33
Estimated flybys of other moons	20	15	20
Radar coverage of Titan (percent)	30	10	15
Optical resolution (percent)	100	80 to 100	80 to 100
Optical instrument operations (in hours per day)	24	15	15
Simultaneous instrument operations	6 of 12	10 of 12	10 to 12

[a]Limited science operations during the spacecraft's 7-year trip to Saturn were not formal project objectives, but were included in the mission plans before the project was restructured.

[b]The mission's Saturn system science opportunities are different, depending on whether NASA uses the Solid Rocket Motor (SRM) or Solid Rocket Motor Upgrade (SRMU), with the Titan IV rocket to launch the Cassini spacecraft.

Comparison of the current Cassini spacecraft design in figure 3.1 with the original Mariner Mark II design shown in figure 1.2 illustrates one of the most important changes that affected the project's science capabilities: deletion of the two booms and movable instrument platforms on which many of the science instruments were to have been mounted. As shown in figure 3.1, these instruments are now mounted directly on the spacecraft's body.

Figure 3.1: The Current Cassini Spacecraft Design



Source: NASA/JPL.

Mounting the science instruments on the booms would have provided greater operational capability and flexibility for conducting science observations. For example, in many cases, instruments on the boom with the scan platform could have been pointed at their targets without changing the orientation of the whole spacecraft and the other instruments. The ability to point and operate science instruments independent of the spacecraft and other instruments would have provided greater operational flexibility and more observing time than is possible using the new Cassini spacecraft design.

In the new design, instruments will be mounted on the spacecraft's body and, in many cases, the entire spacecraft will have to move in order to point them. This reduces the amount and quality of science data that can be obtained because body-mounting of the instruments eliminates the ability to simultaneously point the instruments at different targets, and reduces available viewing time because of the time required to move the spacecraft.

Some Development Work and Costs Were Postponed

In order to reduce Cassini development costs, NASA also postponed development of some of the spacecraft's flight software, ground control systems, and science operations capabilities until after it is launched, and transferred the estimated funding requirements for the postponed work from the project's development accounts to its MO&DA accounts. NASA mentioned the postponed work in its March 1993 Cassini Project Status Report to the Congress, but did not specify the amounts transferred. According to NASA program officials, congressional and Office of Management and Budget officials were briefed by NASA on the delayed work and transferred funding estimates and did not expect the amounts to be shown in the Project Status Report.

As of June 1992, JPL estimated that $94 million in development phase work had been postponed to the project's MO&DA phase. As a result of this delay, the cost to perform this work has increased by $59.3 million, making the total cost of the postponed work $153.3 million.

NASA and JPL officials believe that postponing development work until after launch may benefit the mission's operations. For example, during the postponement period, advancements in technology and experience in operating the spacecraft are expected to increase the efficiency of project personnel in developing and using the science instrument operations software. Also, project technical and scientific personnel will be needed to

complete the deferred development tasks during the Cassini spacecraft's 7-year trip to Saturn. According to NASA and JPL project managers, without the delayed development work, many of these personnel would have to be reassigned until the spacecraft approaches Saturn. By then, their project-related technical skills would have degraded somewhat. By keeping some of them working on the project during the long trip to Saturn, their Cassini-specific technical skills would be maintained at a higher level, they would be more readily available to respond to potential spacecraft problems, and they would be better prepared to conduct science operations when the spacecraft reaches Saturn.

Postponements Significantly Reduced Cassini Cruise-Phase Science Capabilities

NASA's postponement of development work until after launch eliminated most of the science operations that were planned for the 7-year trip to Saturn, as summarized in table 3.1. Science operations during the spacecraft's trip to Saturn were not part of the mission's formal science objectives. However, the project had been planning to conduct some cruise-phase science operations, and these plans were strongly supported by the National Research Council's Space Studies Board. They included planned observations and measurements of Venus, earth, the moon, an asteroid (if feasible), Jupiter, and the fields and particles environments around and between the planets. The only science observations now planned during the spacecraft's 7-year cruise to Saturn are three sets of gravity-wave observations of 40 days duration each, and magnetic fields and particles observations that will begin about 2 years before arrival at Saturn.

After launch, the Cassini spacecraft will swing by Venus twice, the earth and moon once, and Jupiter once in order to obtain gravity-assists to increase its speed for the trip to Saturn. This route presents opportunities to make scientific observations of each of these planets, earth's and Jupiter's moons, and of the interaction between the sun's energy and the planets' magnetospheres. Observations of Jupiter and measurements of its magnetosphere would be especially useful because the Cassini spacecraft is planned to arrive at Jupiter at about the time NASA's Galileo mission to Jupiter will end. Thus, Cassini's measurements could be compared with Galileo's and used to calibrate Cassini's science instruments in preparation for science operations at Saturn. Further, Cassini's trajectory will provide the longest duration inside Jupiter's magnetotail of any spacecraft and place the spacecraft in regions of the magnetotail that have not previously been visited. Also, since Jupiter and Saturn are similar, Cassini's Jupiter

data could be directly compared with Galileo and Voyager mission data, enhancing the scientific return from all three missions.

While the Cassini spacecraft is enroute to Saturn, it will spend most of its time between the planets where it could measure and map interplanetary magnetic fields and particles and the sun's effects on them. This information would enable scientists to increase their understanding of the sun and the interactions of its particle streams with the planets.

The Cassini spacecraft will also pass through the asteroid belt on its way to Saturn, and could collect and analyze dust samples. Cassini's measurements of dust in space would improve scientific understanding of the origin and evolution of the solar system and provide engineering design information for building future spacecraft.

The space science community did not fully agree with NASA's reduction of the project's cruise-phase science operations. The National Research Council's Space Studies Board recommended in an October 1992 report that NASA should, if possible, reinstate the cruise-phase science objectives and capabilities for the Cassini project. While NASA and JPL project officials believe that some of the deleted cruise-phase science capabilities could still be reinstated, there are no formal plans or funding to do so. According to a JPL project official, it would take 2 to 3 years to develop the capabilities for cruise-phase science operations during the trip to Saturn. The cost to reinstate the mission's cruise-phase science capabilities has not been estimated.

New Project Management Procedures Implemented

JPL also implemented new project management procedures as part of the restructuring of the Cassini project. The new procedures, aimed at streamlining the project's development process and reducing costs, included collocation of project personnel, a new product-oriented project structure, a new work monitoring system, reduced oversight of contractor work, and reduced project staffing. The new procedures, as described by program and project officials, are summarized in appendix III.

Some of the new project management techniques involve accepting somewhat higher levels of risk for the project. A Cassini project official said that he and his management staff maintain proper cognizance of how the work is being accomplished and ensure that appropriate engineering judgment is being applied in the project's technical decision-making processes. NASA and JPL are monitoring the results of the new management

techniques, and NASA plans to apply them to other NASA projects where appropriate. Because the Cassini development project is not scheduled for completion until the end of 1997 and the new project management procedures have only been in place for about a year, it is too early to judge their ultimate success or failure.

Cassini Is Currently Meeting Its Goals, but There Are Future Threats to Its Capability

NASA's most recent reviews indicate that the Cassini project is meeting its current cost and schedule goals and, according to JPL project officials, NASA plans to exceed the project's current science goals.[1] However, several factors threaten the project's ability to ultimately achieve its current goals. First, the Cassini mission is planning to use a new and more powerful Titan IV launch vehicle being developed by the Air Force. Although JPL project officials believe that the more powerful rocket will be available when needed, JPL is planning to reduce the amount of propellant on board the Cassini spacecraft, and thereby lower the spacecraft's weight, if the less powerful version of the Titan IV launcher must be used. While JPL's back-up plan to use the less powerful launcher increases the likelihood that the Cassini spacecraft will be launched on time, use of the less powerful launcher would reduce the amount of science that could be done.

Second, the mission's preliminary MO&DA cost estimate is too high, according to JPL and NASA officials. Finally, a significant delay for any reason in Cassini's currently scheduled October 1997 launch will adversely affect mission science.

Goals Are Currently Being Met

NASA's recent Cassini budget review and Project Status Report indicate that it is currently meeting its cost, schedule, and science goals. NASA's March 1993 project budget review did not show any increase in the project's estimated development cost since it was restructured in May 1992. Table 4.1 shows NASA's current estimates for the project's major cost elements.

[1]As discussed in chapter 3, the current science goals are lower than those originally set for the project in 1990.

Table 4.1: Total Estimated Restructured Cassini Project and Mission Costs

Dollars in millions

Major project element	Estimated cost
Development	$1,453.7
Launch vehicle	417.0
Tracking	112.0
MO&DA[a]	1,150.0[b]
Total	**$3,132.7**

Note: Excluded from this table are (1) most NASA personnel costs; (2) Department of Energy's share of costs for radioisotope thermoelectric generators, radioisotope heater units, fuel for the generators and heaters, and other related activities; and (3) costs borne by foreign participants.

[a]The MO&DA estimate is preliminary.

[b]The amount is the mid-point of a range from $1 billion to $1.3 billion.

According to its March 1993 Cassini Project Status Report, NASA expects to meet the project's current schedule goal and launch the Cassini spacecraft in October 1997. The project's Critical Design Review was held in December 1992 and, according to JPL project officials, did not disclose any major technical problems.[2]

Threats to the Project's Future

Several factors could affect the project's ability to continue to meet its current cost and schedule goals, and to exceed its science goals. First, if a less-powerful rocket than planned has to be used to launch the Cassini spacecraft, the mission's science return will be reduced. While use of the less powerful rocket would enable the mission to meet its current science goals, its science return would be reduced and not exceed the current goals, according to NASA's current plans. Second, the project's preliminary MO&DA cost estimate has increased. Finally, any significant delays in the mission's currently scheduled October 1997 launch will further reduce the quality of the mission's science return.

Contingency Plans for Cassini Weight Reduction and Its Impact on Mission Science

NASA plans to launch the Cassini spacecraft on a Titan IV launch vehicle equipped with a new and more powerful booster rocket—the SRMU—that is still under development. According to JPL project officials, the Air Force's Titan IV SRMU development program is currently meeting its schedule and performance goals, and the SRMU should be available to launch the Cassini

[2]During Critical Design Review, a project is evaluated to determine that it is ready to begin actual fabrication of flight hardware.

spacecraft in October 1997.[3] If the Cassini spacecraft is launched with the SRMU, NASA plans to exceed the project's current science goals.

However, there is uncertainty over whether it will be available to launch the Cassini spacecraft on schedule. As a result, JPL has a contingency plan that would permit the Cassini spacecraft to be launched on a Titan IV equipped with the less powerful solid rocket motor boosters. JPL's contingency plan to use the SRM boosters, if needed, increases the likelihood that the spacecraft will be launched on schedule whether or not the SRMU is available. However, use of the less powerful SRM boosters would require reductions to the Cassini spacecraft's weight.

NASA would reduce the spacecraft's weight by only partially filling the Cassini spacecraft's on-board propulsion fuel tanks. However, with less propulsion fuel available, the spacecraft would make fewer orbits of Saturn and fewer flybys of Saturn's moons, thus reducing the quality and amount of science data that could be obtained. Despite the reductions in science that would occur, the National Research Council reported in October 1992 that the Cassini mission will remain responsive to the science priorities established for the mission even if the less powerful launcher is used. Table 3.1 lists the project's science capabilities with and without the more powerful solid rocket motors.

Ways to Reduce Preliminary MO&DA Cost Estimates Currently Under Study

In July 1992, NASA estimated that the MO&DA phase would cost between $800 million and $1 billion. By March 1993, this estimate had increased to between $1 billion and $1.3 billion, due to launch delays, longer mission duration, and the rephasing of work. The MO&DA cost estimate is still preliminary, and NASA and JPL are currently studying ways to reduce it. According to JPL project officials, JPL's goal is to hold total MO&DA costs to about $1 billion. A final MO&DA cost estimate is scheduled for release in March 1994.

One way JPL is planning to lower the project's estimated MO&DA cost is to reduce the number of project personnel during the MO&DA phase. While personnel reductions would lower costs, a NASA program official noted that it would also increase the risk of losing science data during a system failure because more time would be required to solve technical problems. NASA and JPL officials said that the reduced costs make it a risk worth taking. JPL Cassini project officials also said that risk mitigation measures,

[3]A production decision on the SRMU is scheduled for fiscal year 1994. If the decision to produce the SRMU is made on schedule, it could be ready for operational use in 1995.

similar to those described in appendix III for the new project management techniques, would be applied when MO&DA personnel reductions are implemented.

Launch Delay Impact on Cassini Science Data Quality

While the Cassini project is currently meeting its schedule goals and the spacecraft is expected to be launched in October 1997, any significant delay in meeting the launch date, for any reason, would further reduce the quality of the project's science data.

For example, a launch delay could reduce the quality of observations of Saturn's rings. The sun provides the light needed by some of Cassini's instruments to observe Saturn's rings. The position of Saturn's rings relative to the sun changes over time, and the amount of solar illumination of the rings will be just past optimum when the Cassini spacecraft arrives at Saturn. As Saturn's rings change position from face-on to the sun to edge-on to the sun, the amount of sunlight falling on the rings will decrease. Thus, the longer Cassini's arrival at Saturn is delayed, the less sunlight will be available to illuminate Saturn's rings when the spacecraft arrives. Decreased illumination of the rings will reduce the quality of the science observations. After the Cassini spacecraft's scheduled arrival at Saturn in 2004, it will be about 8 years before Saturn's rings again begin to more optimally face the sun.

A significant launch delay could also affect the Cassini spacecraft's electrical power supply and reduce the quality of science data that can be obtained, if it occurs after the nuclear fuel for the spacecraft's three radioisotope thermoelectric generators is manufactured. Once produced, the fuel decays at a rate that results in a reduction of 3 watts of electricity per generator per year. If the launch was delayed for 2 or more years after the fuel was made, then decay would be sufficient to reduce the availability of electricity for operating the spacecraft and science instruments at Saturn. This, in turn, would reduce the amount of science data that could be obtained.

Comments From the National Aeronautics and Space Administration

NASA
National Aeronautics and
Space Administration
Washington, D.C.
20546
Office of the Administrator

NOV 5 1993

Mr. Frank C. Conahan
Assistant Comptroller General
National Security and International Affairs
General Accounting Office
Washington, DC 20548

Dear Mr. Conahan:

Thank you for the opportunity to comment on your draft report, "Space Science--Causes and Impacts of Cutbacks to Outer Solar System Exploration Missions." We have reviewed your draft, and it is technically accurate. You and your staff are to be complimented for the very thorough and perceptive review of the CRAF/Cassini funding history.

With regard to your recommendations, we agree that NASA should be prepared to explain any future termination decision in a more comprehensive manner. It is important, however, to understand that the basic CRAF/Cassini problems that led to the termination of the CRAF mission were primarily due to the less than anticipated budget availability for planetary exploration. We are taking the necessary steps at NASA to ensure that any new start program can expect to be funded in accordance with a realistic plan for annual funding. We must avoid the past practice of cutting program costs and stretching schedules which only increase the program costs. As your report indicates, when the cost of the launch vehicle and the MO&DA were included, the CRAF cancellation was necessary to remain within the anticipated FY 1993 funding.

Sincerely,

John R. Dailey
Associate Deputy Administrator

Chronology of the Comet Redezvous Asteroid Flyby/Cassini Project Major Milestones and Events

1981	The Jet Propulsion Laboratory (JPL) began studies of a spacecraft with a standard design that could be readily adapted for use on six different robotic missions to the outer solar system. JPL personnel briefed the National Aeronautics and Space Adminstration's (NASA) Solar System Exploration Committee on their work.
1983	Part one of Planetary Exploration Through Year 2000 was issued by the Solar System Exploration Committee of the NASA Advisory Council. As part of its highest priority missions, the report recommended, among other things, initiation of a comet and asteroid mission and a mission to Saturn and its moon Titan, both using a standard multimission capable Mariner Mark II spacecraft design.
1983	JPL intensified pre-project studies of a comet/asteroid mission and a mission to Saturn and Titan. These studies evolved into the Comet Rendezvous Asteroid Flyby (CRAF) /Cassini project.
Nov. 1989	NASA's proposed CRAF/Cassini project was approved and funded by the Congress, with a $1.6 billion cost cap. NASA planned to use Mariner Mark II multimission spacecraft for both the CRAF and Cassini missions.
Nov. 1990	NASA deleted CRAF's comet nucleus penetrator experiment because its estimated cost had increased up to $120 million, $98 million over its originally estimated development cost. NASA also deleted the scanning electron microscope and particle analyzer from CRAF at the same time to further reduce project costs and because it duplicated some of the observations planned for another instrument.
June 1991	The CRAF/Cassini project's Preliminary Design Review was successfully completed.
July 1991	The Senate Appropriations Committee's fiscal year 1992 report stated that the Cassini project budget for 1992 and 1993 would be capped at $215.7 million for each year.
Sept. 1991	The Congress provided $210.7 million for the project in 1992, $117.3 million less than NASA had requested. NASA's 1993 budget estimate sent to the Office of Management and Budget terminated funding for the CRAF portion of the project and requested $215.7 million for the Cassini-only project for 1993.

Oct. 1991	After the 1992 and 1993 cuts were factored in, the project's schedule slipped about 2 years and NASA's internal estimates increased the CRAF/Cassini project's estimated development cost to $1.85 billion.
Dec. 1991	The Congress' 1992 authorization legislation increased the cost cap for the CRAF/Cassini project from $1.6 billion to $1.9 billion.
Jan. 1992	The President's 1993 budget submission to the Congress proposed cancellation of the CRAF portion of the project, noting that its reduced science capabilities no longer justified its cost. The project's 1993 request included $210 million for the Cassini-only project.
Feb. 1992	NASA instituted an agency-wide review of project costs to reduce agency outlays and bring them more into line with the agency's expected future budgets. Because the Cassini project's estimated cost still exceeded what NASA's budget could fund, NASA directed JPL to restructure the project to further reduce its cost. During the restructuring, the Mariner Mark II spacecraft design was replaced by a less expensive Cassini-unique design.
Mar. 1992	The Space Studies Board of the National Research Council reports that it was dismayed by the proposal to cancel CRAF, which was still considered a scientifically valuable mission.
May 1992	NASA approved JPL's restructured Cassini project plans, with an estimated development cost of $1.45 billion.
Dec. 1992	The project's Critical Design Review was held. There were no significant technical problems.
Apr. 1993	The President's 1994 budget submission included $266.6 million for the restructured Cassini project. The Congress subsequently provided the requested amount.

New Cassini Project Management Procedures

According to project officials at JPL, as part of the Cassini "redesign," the project has taken the following significant steps to improve internal project communication, control costs, streamline the process for resolving technical development issues, and increase accountability at all levels of project management.

Increased Collocation

The project has collocated its subsystem work teams, comprised of various hardware, software, and support disciplines, to improve their efficiency by making it easier to meet and interact on a daily basis. For example, the JPL division responsible for designing the structure, cabling, packaging, propulsion, and thermal control system had been located in nine different buildings. It is now housed on a single floor in one building, and related work groups are close to each other.

Product-Oriented Project Structure

The project is emphasizing a product-based management structure to (1) more closely match the project's organizational structures with its hardware work plans, (2) facilitate managers' knowledge of the status of spacecraft and instrument hardware development costs, and (3) increase the uniformity of the content, scope, and size of the various work elements. The product-based structure is intended to provide efficiencies by enabling delegation of authority and responsibility for work elements to the technical managers making day-to-day resource allocation decisions.

Improved Task Monitoring

The project has developed and implemented a computerized system for tracking all work products (e.g., hardware, software, designs, analyses, etc.) at the subassembly level and higher. The system is intended to enhance both the planning and control of development tasks by (1) accelerating the process of reconciling the development schedules of the project's various work elements and (2) through weekly reports on the status of product deliveries, providing managers with the capability to track tasks at various levels of management and to identify potential problem tasks.

Science Management Plan

The Science Management Plan's goal is to obtain balanced science within the given cost constraints. Under the plan, each science instrument receives, at the beginning of the instrument development process, its total allocation of resources to build the instrument (funding, mass, power, data, and reserves), and each science team is responsible for developing

the best instrument possible within these resources. Such allocations are adjusted only to compensate for new requirements.

The project does not hold resource reserves to assist instrument teams in trouble and there are strict performance and reliability requirements for all instruments. Since instruments delivered within their allocations would be recommended for flight, the teams have incentive to make realistic design decisions early in the development process. The plan permits the instrument and spacecraft teams to trade resources among themselves. The only constraint is that these trades not cause the violation of any system, subsystem, subassembly requirement, or interface control drawing. A computerized resources trading system has been developed to assist in the trading process.

Reduced Procurement Risk

The project has taken several steps to reduce the potential for cost growth and failure of its key hardware procurements. One innovative procedure involved submitting draft proposals to industry for comment prior to release of the formal Request for Proposal. This action was then followed up by JPL/contractor meetings where the combined expertise of the group clarified the package content to remove any ambiguities. The final results have been well-defined equipment specifications without open items and clear and unambiguous criteria for design analysis and review.

Clear specifications and criteria enabled an emphasis on fixed-price contracts. These actions have permitted a reduction in the in-house work force traditionally needed to assist contractors in their "getting up on the curve" and assuring their compliance with JPL-imposed practices.

Requirements for contractor qualification testing of engineering model hardware, acceptance testing of delivered hardware, and negotiated contractor warranties for delivered hardware have also been put in place.

Employee Empowerment

As the Cassini project was undergoing its rescoping, JPL was beginning to offer instruction in and take advantage of the principles of total quality management. For Cassini this has resulted in the following benefits: (1) resource control and decision-making has been pushed down to lower levels in the organization, eliminating the need to achieve top-to-bottom consensus on every issue; (2) design team meetings are now attended by individuals possessing broad knowledge and skills, resulting in meetings that tie up fewer people, run shorter, and accomplish more; and

(3) engineering changes are authorized with only the data necessary for the decision, rather than requiring that all the detailed work be accomplished first, thus, decisions are more timely and unnecessary work is avoided. The efficiencies resulting from these new ways of doing business have enabled modest work force reductions across the project.

Major Contributors to This Report

National Security and International Affairs Division, Washington, D.C.	Frank Degnan, Assistant Director
Los Angeles Regional Office	Allan Roberts, Assistant Director Jeffery Webster, Evaluator-in-Charge Gary Wiggins, Evaluator

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