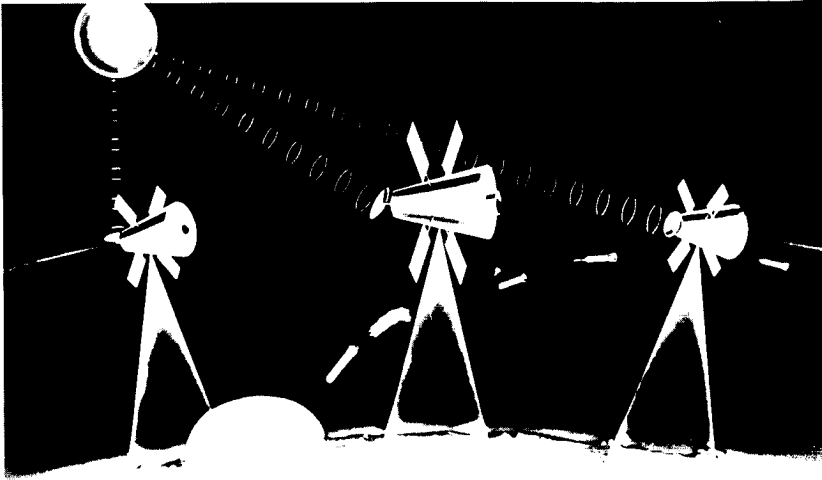


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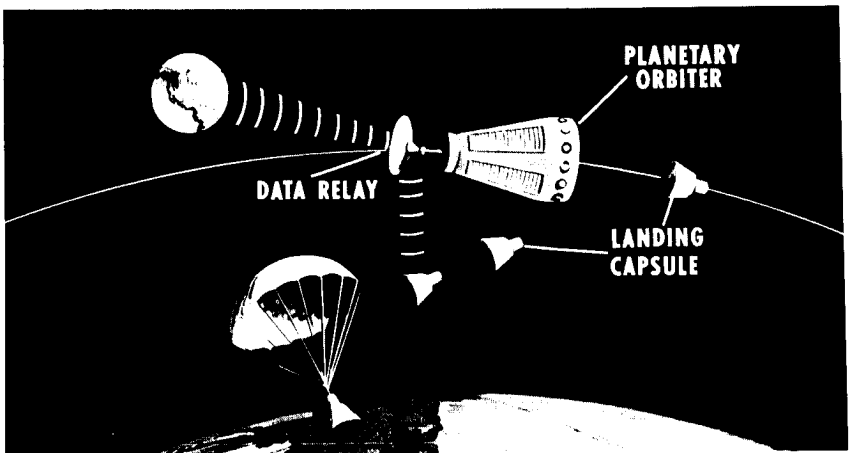
Voyager: Perils of Advanced Planning, 1960-1967

Voyager was an advanced mission concept first considered in the spring of 1960 when the NASA staff was beginning to define its long-range plans for lunar and planetary missions.¹ In their semiannual (1 April-30 September 1960) report to Congress, the agency managers reported that preliminary mission studies were under way for a second planetary series. The Voyager orbiters were to be designed to orbit Venus and Mars and were to be "phased in time and capabilities with the Saturn launch vehicle." Orbits of the planets for long periods would make possible excellent investigations of their environments, and landing capsules would be able to provide information on the lower atmospheres and surfaces.² In designing the Voyager spacecraft, NASA engineers and scientists hoped to use new data gleaned from the Mariner flights—information that would help them design Voyager's scientific instruments to answer the proper questions and solve technological problems posed by Voyager's large size.

Unfortunately, the real world of politics, with too many projects competing for too few federal dollars, is seldom as neat as planners hope. For the Voyager proponents, the real world was an unhappy one. Delays on the Atlas-Centaur launch vehicle during the early 1960s prompted many changes in the Mariner project, which in turn delayed the acquisition of information about the Martian environment essential to the designers of Voyager. But Kennedy's decision to mount a full-scale assault on the moon was an even bigger blow for the supporters of unmanned space exploration. Once the manned Apollo decision had been made, the Marshall Space Flight Center and its industrial contractors concentrated on the preparation and production of Saturns for the lunar missions. Launch vehicles for space science projects would become available only after the top-priority goal had been met. From the start, Voyager was by definition a second-class project. As Congress became restive over the increased expenditures for Apollo, monies originally marked for space science and Voyager were reallocated to help pay for the moon program. Added to this were a costly war in Vietnam and the domestic troubles of the late 1960s. All post-Apollo missions proposed by the space agency faced reduced appropriations, which put



One of the first conceptual views of Voyager, above, was published in the NASA-Industry Plans Conference, July 28-29, 1960. The artist concept below was described by Edgar M. Cortright during March 1961 NASA hearings before Congress: "This spacecraft, weighing about 2,400 pounds [1090 kilograms], would be designed to orbit the target planet and to inject a several-hundred-pound capsule capable of surviving atmospheric entry and descent. . . . Thus the orbiting spacecraft would observe the planet and its atmosphere . . . , while the landing capsule would make detailed measurements during descent and on the ground. . . . Numerous . . . developments are required to accomplish this difficult but fascinating and distinctly realistic mission, which may well include among its rewards the discovery of extraterrestrial life." Senate Committee on Aeronautical and Space Sciences, NASA Scientific and Technical Programs, hearings, 87th Cong., 1st sess., 28 Feb., 1 Mar. 1961.



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Voyager in deep fiscal trouble by summer 1967. A request in August from the Manned Spacecraft Center in Houston for proposals to study manned missions to Mars was the last bit of bad luck. Congress rebelled and terminated all Voyager work.

At first glance, it would appear that the Voyager project of the 1960s, like Mariner B and Mariner 66, was just another project that never progressed beyond the drafting table, but it was more than that. Voyager, with thousands of man-hours of work behind it, performed by dozens of specialists and costing many millions of dollars, helped to refine an understanding of the best approaches for a combination orbiter-lander investigation of Mars. Upon the solid foundations laid by Voyager personnel, the Viking team that followed them could construct a successful mission. The story of Voyager's troubles is essential to an understanding of Viking's accomplishments.

ORIGINS OF VOYAGER

For the duration of the Voyager project, there were two distinct perspectives of the enterprise—one view from NASA Headquarters and another from the Jet Propulsion Laboratory in Pasadena. As with Ranger and Mariner, Voyager was initially a JPL undertaking, with nearly all the early study and design done in the California lab. In contrast, JPL had contracted out to industry for the design and development of Surveyor, the lunar soft-lander. This difference may have been indicative of the Pasadena team's bias for planetary missions but, for whatever reason, the team had a particular attachment to Voyager. JPL staffers had very specific ideas about how Voyager should be developed (orbiters first, with the addition of landers much later) and managed (loosely knit organization of delegates from various laboratory divisions). Furthermore, JPL wanted to conduct the total project within the walls of the laboratory. The West Coast planners favored small "manageable" undertakings, while NASA Headquarters called for centralized management under one responsible individual, with centers assuming a supervisory role over industrial contractors. As Voyager became a pet project with headquarters managers, the differences between JPL and Washington became obvious. In Pasadena, JPL personnel muttered about pencil-pushers who had no understanding of the problems of engineering the nuts and bolts of a Mars-bound spacecraft, and not uncommon in the nation's capital were exasperated remarks about the single-mindedness and independence found at JPL. While these differences were not responsible for the cancellation of the project, they made the work of Donald P. Heath, responsible for Voyager at headquarters, and Donald P. Burcham, Voyager manager at JPL, more difficult. From the beginning, even Voyager's most optimistic supporters saw trouble ahead for the planetary spacecraft.

JPL planners began to study Voyager-class missions in 1961 to determine more clearly what flights with what size spacecraft would be a reason-

able step beyond Mariner B. In May 1962, the laboratory's Planetary Program Office commissioned a study of advanced missions and spacecraft. In addition to Voyager with flights to Venus and Mars, a second kind of advanced spacecraft was examined—Navigator, which would explore the sun, comets, Mercury, and Jupiter and require still more powerful launch vehicles. Under the direction of Philip K. Eckman, the advanced planetary spacecraft study group, with representatives from all the technical divisions of JPL, examined large orbiter missions for Voyager because it believed that too little was known about the Martian and Venusian atmospheres to permit the development of spacecraft landing systems for either planet. One of the most important results of this initial phase of the advanced study was the determination of "the maximum orbiter-spacecraft payload." One member recalled that the group had been "hard pressed to come up with an in-orbit payload in excess of 500 pounds [230 kilograms] of instruments" for the "ideal" payload.³ The group's work was the subject of three days of discussions by JPL and NASA representatives in early November 1962 (table 9).

Five men participated in the November Voyager review: Donald Hearth and Andrew Edwards, Jr., from headquarters; and Peter N. Hauran, manager of the JPL Voyager study, Philip Eckman, and Robert J. Parks from JPL. Hearth, with NASA since 1962, was chief of Advanced Programs in the Lunar and Planetary Program Office and the key headquarters representative at the winter meeting. He had been an aeronautical research engineer at the Lewis Flight Propulsion Laboratory (of NACA) in Cleveland in the 1950s and a project engineer for Marquardt Corporation, where he had managed research related to hypersonic ramjets and similar advanced power plants. Hearth believed that fiscal 1963 activities were "proceeding along logical lines" and that JPL was doing a good job. However, he was disturbed by the postponement of work on landers, as preliminary research was necessary for comparison studies of alternative missions. Hearth preferred to push ahead with a total mission study, refining the details as new information about the planets became available.

A more pressing concern, according to Hearth, was the work load the Pasadena laboratory was assuming. "It appears to me that JPL is planning on doing too much in-house starting in 1964. Their plans for bringing in contractors next year looks good; however, I question the relative in-house and out-of-house level." Providing some overlap (with the JPL effort) from contractors appeared advisable, and Hearth expanded his thoughts on the subject in a memorandum to Oran Nicks:

- 1.) JPL (Hauran) did not have complete information on Voyager expenditures thus far in FY63.
- 2.) JPL should have conducted mission capability comparisons (even on just a preliminary basis) earlier in the committee activity.

Table 9
Highlights of Advanced Planetary Spacecraft
Group Investigations, 1962

Missions Considered

Flyby—very short duration.

Planetary orbiter—longer duration but does not permit examination of planetary surface.

Direct landing—"most exciting" mission, but technological requirements for such a mission are quite severe.

Other—sample return, flyby or orbiter with landing capsule, flyby with multiple capsules, etc.

Conclusion—Advanced orbiter appears most feasible in period under study, 1966-1973.

General Mission Objectives

Acquire sufficient environmental information to permit confident design of large landing vehicle, both manned and unmanned.

Permit biological examination of the near planets.

Investigate planetary atmospheres.

Study planetary geology.

Major Technological Problem Areas

Launch facility limitations—not enough launch pads for quick turnaround required by launch window schedule.

Tracking system limitations—deep space network too limited to permit communication with multiple spacecraft.

Spacecraft power limitations—need to improve both solar-cell and radioisotope-thermoelectric-generator technology.

Sterilization—need to develop techniques for sterilization and develop hardware that can survive sterilization process.

Flexibility—need to develop capability to incorporate new knowledge from one mission into the next, even with short interval between planetary opportunities.

SOURCE: JPL, "Advanced Planetary Spacecraft Study Report," vol. 1, EPD-139, 28 Dec. 1962, pp. II-1 to II-8, V-1 to V-2.

3.) Hurlan and [Eckman] did not have definite schedules for committee activities . . . [and] schedule charts were not available. Between the three of us, we made up such a chart during my visit.

4.) JPL is thinking of doing more of the Voyager job in future years in-house than is reasonable.

Trying to maintain greater control over the progress of Voyager, Hearsh asked the study group to provide NASA with monthly reports, quarterly

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project reviews, and all back minutes of advanced planetary spacecraft study group meetings. Hearsh made a final point that would have discomfited the team in Pasadena. From "the current situation," it appeared likely that JPL could manage Voyager in future years, but there was the chance that NASA Headquarters might decide otherwise. "If another NASA Center or if a strong industry contractor [was] to manage the project," Hearsh thought that "they should be brought into the project *now* because the studies being conducted this year will establish the system design concept to be followed in future years."⁴

NASA had been considering broader industry participation in the Voyager project since early 1962,⁵ and eight companies had active, internally sponsored concept studies in progress:

Continuous study during the last 9-12 months	AVCO General Electric
Study during the last few months	Douglas, Santa Monica Convair, San Diego Convair, Fort Worth
Study just starting	Lockheed, Sunnyvale North American Aviation, Space and Information Systems Div. Space Technology Laboratories

In addition to the JPL exercise that would cost \$700 000, Hearsh recommended to Nicks that headquarters fund two industrial contractors (\$75 000 each) to conduct mission and predesign studies. From their findings, two systems would be selected for further study.

Industrial participation would have four advantages according to Hearsh. First, "it would provide a 'check' on the JPL results. This is important since a decision will, presumably, be made this year which will determine the approach to a system involving many millions of dollars." Second, NASA would have a wider base of "*funded* Voyager studies" in the event that Voyager management did not go to JPL. Third, by investing \$150 000, NASA "would provide encouragement to the management" of numerous companies by demonstrating that NASA was "serious about Voyager" and that a substantial part of the task would be assigned to industry. Finally, contracts with industry would allow NASA to direct the studies "along lines desired" by the agency, and Hearsh had no doubt that considerably more than \$75 000 would be expended by each company in its studies. "In addition, the agency would gain an "early insight into the firm's capability for Voyager."⁶

Whereas Hearsh had planned to contract with AVCO or General Electric for this short-term study, with a more elaborate preliminary design project in fiscal 1964, the lure of money brought a number of other contrac-

tors onto the scene.⁷ The original plan for a six-month contract starting 1 January was replaced by a 5 March 1963 competitive request for proposals for a formal design study.⁸ With an eye on a 1967 launch to Venus, Hearth decided that he could not afford to sacrifice six or seven months on a preliminary exercise. He told the NASA senior management at a February briefing for Administrator Webb that it would be difficult to meet the next Venus launch opportunity less than four and a half years away, but the undesirable alternative was to wait six years to launch the first planetary spacecraft (Mars 1969) "having the mission capability and scientific return possible with Voyager." Hearth believed strongly that they should set June 1967 as their goal.⁹

Request for Proposals—Voyager

Aiming for 1967 and 1969 launches to Venus and Mars, the NASA Headquarters staff decided to spend about \$200 000 in 1964 on two contracts to examine mission and predesign aspects of a Voyager flight.¹⁰ "Request for Proposal No. 10-929, Voyager Design Studies" was sent to 21 companies 5 March 1963. Potential contractors were to summarize their cost and scientific proposals—based on NASA's statement of work defining the projected studies—for developing an advanced spacecraft to perform "orbiter/lander missions to Mars and Venus from 1967 through 1975."¹¹ This Voyager-class spacecraft, launched by a Saturn booster, would be capable of more difficult missions than Mariner, carry more scientific instrumentation, collect and return more data, and have a longer operational lifetime.

Two contractors would be given six months to recommend their design concepts. Their proposals would consider both the orbiter and the lander and evaluate landers that could be released both before and after achievement of planetary orbit. Flight weight was set at 2700 to 3175 kilograms, the planetary payload for the Saturn IB booster, but smaller craft (1800 kilograms) would also be examined in case the Air Force Titan IIIC launch vehicle were employed instead. Growth of subsequent Voyager craft to weights as great as 27 000 kilograms was another area of study. Spacecraft in the heaviest class could be sized to fit the Saturn V, called the Advanced Saturn. Don Hearth was the technical director for this phase of the Voyager investigations.¹²

A total of 37 industrial organizations was represented at the Voyager preproposal briefing at NASA Headquarters on 11 March 1963, where delegates had the opportunity to ask questions before they finalized their proposals, due on the 25th.¹³ Of the 13 companies submitting proposals, 10 were judged acceptable. A technical evaluation team* met on 27 March to begin the selection process. Using an elaborate formula, the team decided that the Missile and Space Vehicle Division of General Electric, Valley

*D. Hearth, chairman, B. C. Lam, A. Edwards, E. A. Gaugler, F. D. Kochendorfer, P. N. Hauran, and L. E. Richtmyer.

Table 10
Ranking of Contractors Bidding on 1963 Voyager Study

Contractor	Overall Rank	Composite Score (of possible 600)	Total Estimated Cost (cost rank)	Fee Requested	Overhead Rate	Man Hours	G & A* Rate	Computer Time
Missile and Space Div., General Electric	1	524.5	\$125 000 (6)	8.0%	120%	6 100	10.5%	\$ 9 000
Research and Advanced Development Div., AVCO	2	443.4	144 546 (7)	7.0	105	9 131	8.0	13 200
Missiles & Space Co., Lockheed Aircraft Corp.	3	406.5	122 315 (5)	7.0	80	8 530	6.5	3 500
Space Technology Laboratories	4	358.6	169 189 (8)	8.5	103	10 850	9.9	-----
Space and Information Systems Div., North American Aviation Inc.	5	337.8	-----	-----	-----	-----	-----	-----
Aeronautics Div., Ford Motor Co.	6	334.4	96 109 (1)	0.0	131	4 284	0.0	-----
Martin Marietta Corp.	7	332.6	186 505 (9)	7.0	102	19 184	16.9	-----
Aerospace Div., Boeing Co.	8	301.9	-----	-----	-----	-----	-----	-----
McDonnell Aircraft Corp.	9	276.4	98 939 (3)	12.0	80	7 080	6.6	-----
Astronautics Div., General Dynamics Corp.	10	265.7	99 944 (4)	7.0	47	7 335	7.17	-----
International Telephone & Telegraph	11	-----	97 916 (2)	0.0	125	9 480	12.9	-----

----- = data not available.

*General and administrative expenses such as executive salaries.

SOURCE: Donald Hearth and Andrew Edwards to Carl M. Grey, "Technical Evaluation of Proposals Received in Response to RFP No. 10-929," 2 Apr. 1963; Hearth, note of conversation with Grey and R. W. Lord, 4 Apr. 1963; and Grey, "Technical Evaluation of Proposals," 4 Apr. 1963.

Forge Space Technology Center, Pennsylvania, was the clear first choice. While other companies were competitive from a cost standpoint, only AVCO Corporation,* Lockheed Missiles & Space Company, and Space Technology Laboratories, Inc., had submitted technically acceptable proposals. After careful scrutiny, the evaluation team favored awarding the second contract to AVCO. Although AVCO's "proposal was not as smooth and as well organized as the Lockheed proposal, it did demonstrate a better understanding of the scope of the technical study."¹⁴ The two contractors were notified of their selection in early April.

Contractor Proposals

Despite public and congressional scrutiny of Voyager, the contractor studies were conducted as planned during the summer months of 1963.¹⁵ General Electric secured the services of 20 distinguished scientists to review the company's progress and "suggest modifications which would increase the overall scientific value of the program." Several familiar names were on the list—Melvin Calvin, Joshua Lederberg, Wolf Vishniac, Carl Sagan, Harold Urey.¹⁶ Scientific community and industry were working together for their mutual benefit.

A host of technical questions were being examined by the contractors, as the following list sent to the Voyager project managers at AVCO and General Electric indicates:

1. What can Voyager do scientifically that Mariner B cannot do?
2. How large a Mars lander is required for long lifetime (one month or more)?
3. If a relay orbiter is employed, what is the trade-off between lander data rate, science payload weight, and lifetime?
4. How does Martian lander performance (data rate, science payload, and lifetime) and weight compare with and without a relay orbiter?
5. What are the problems associated with the use of a high-gain directional antenna on the Martian surface?
6. Can such an antenna be designed and developed for a '69 mission (without undue risk) based upon what we currently know and expect to learn about the planetary surface in the near future?
7. If the answer to question 6 is no, what type of additional scientific data is required?
8. Will a Voyager lander and *relay* plus science orbiter system be capable of obtaining the type of data indicated by the answer to question 7?
9. Once these data are obtained, how much time will be required for the design and development of a high-gain antenna (for landers) for use in a flight mission?

*Reentry research was a strong point with AVCO, since it had worked with the Air Force in 1956 and 1957 to develop the heat-sink reentry vehicle.

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10. How heavy must a Martian lander be if it is to use a high-gain antenna?
11. Is an orbiter really necessary? For science? For communications relay? If an orbiter is necessary, must it be used simultaneously with a lander? Can basic orbiter spacecraft be designed to be modified efficiently from a science plus relay orbiter to a pure relay orbiter?
12. What is the trade-off between orbiter science weight and lander science weight?
13. What is the *minimum* weight of a pure relay orbiter as a function of data rate? Of a pure science orbiter?
14. How does the weight of a science plus relay orbiter compare to a relay orbiter?
15. Can an orbiter be designed (with or without minor modifications) to perform both Mars and Venus missions? How much of a weight penalty results from designing an orbiter for both Mars and Venus compared to an orbiter for only Mars?
16. What are the critical technology problems associated with Voyager? What is the development time and cost? What will flight units cost? On what experience is this based?
17. Starting with the 1969 opportunity, what type of Voyager program for Mars is possible with the changing energy requirements between 1969 and 1975?¹⁷

Before any hardware could be developed for Voyager missions to the near planets, all these many complex technical issues had to be resolved by NASA and its contractors. Time, however, was an issue of equal importance. By early fall 1963, no one at the space agency still considered a 1967 launch to Venus practical, and a mission to Mars in 1969 seemed even less likely.¹⁸

Growing friction between Hearsh's office at headquarters and JPL's Advanced Planetary Spacecraft Study Group was another negative factor. The study group continued to stress the orbital portion of Voyager's mission and exclude the lander from its research. During the second phase of its study, which paralleled the AVCO and General Electric contracts, the team in Pasadena turned its attention to orbiter missions in the 2700- to 3175-kilogram class and during a third phase examined the technical aspects of joining and later separating an orbiter and lander. However, the work did not include studies of the lander itself. In fact, the engineers at JPL were growing increasingly skeptical about the desirability of an orbiter-lander spacecraft.¹⁹

Since NASA Headquarters had assumed control of Voyager, the laboratory managers had become resentful over the allocation of Voyager work and responsibility among the NASA centers. A memorandum for internal use only at JPL recorded that the laboratory had been directed by NASA

Headquarters to terminate its Advanced Planetary Spacecraft Study (APSS) as of September 1963. Later analysts explained JPL's perceptions of the controversy:

Many factors probably played a role in this decision; one of these was the reporting of recent Mars observations, indicating that the surface pressure was much less than had been previously estimated, making the problem of successful entry and descent more difficult. Another reason appears to be budgetary considerations. *A third reason, though never publicly expressed, may have been related to certain political questions related to the future of the Laboratory and whether or not it was to be directly involved in planetary landing missions.* The fourth and most pressing reason was the initiation of the Mariner 1966 project and the lack of available manpower to support APSS work concurrently.²⁰

Early in 1963, three JPL scientists—Lewis D. Kaplan, Guido Munch, and Hyron Spinrad—had revealed new data about Mars that had serious implications for proposed Mars landing studies. The new estimate for the surface level atmospheric pressure was 10-40 millibars, or one-third the previously estimated pressure.²¹ Homer Newell called a special colloquium for 1 October 1963 to discuss the subject. As Newell later told members of the Senate Committee on Aeronautical and Space Sciences, a dozen or so planetary astronomers could not agree on the best figure, and their estimates ranged from 10 to 115 millibars. While *Mariner 4* would resolve this issue in the summer of 1965, the uncertainty did cause concerns—though not insurmountable ones—for the Voyager team in the interim. AVCO and General Electric were given an extra month to examine the implications of the lower pressure for their proposed landers.²²

The JPL budget was not an inconsiderable issue. The space science budget was tied to the shuffling of the Mariner flights during 1963. As Oran Nicks pointed out to the Administrator in a 1963 year-end review, several flights planned for 1964 had been eliminated, including the Venus missions that would have duplicated the successful *Mariner 2*. Turning to the Mars aspect of the planetary program, Nicks told Webb that the two Mariner B flights planned for 1966 had been scrapped because of "recent budget problems for Fiscal Years 1964 and 1965." Mariner B with its small, biologically oriented landing capsule had begun to compete for Voyager dollars. Instead, a reincarnation of Mariner B—Mariner 1966—with a lighter and less expensive capsule had been scheduled for two Centaur-powered flights in 1966 to determine the constituents of the Martian atmosphere and obtain more accurate measurements of the surface pressure. While there was still time to prepare for a Venus mission in 1967, the fiscal 1965 budget crunch seemed to preclude such a flight. If Voyager funds were cut back or dropped entirely from the 1965 budget, a planetary mission would not be possible before 1971.²³

JPL's contention that the lab's future was inextricably bound to NASA politics over what center would manage the agency's planetary projects, had a hollow sound to it, as did claims about manpower shortage. Hearth and his associates in the headquarters Advanced Programs and Technology Office were the first to acknowledge the crucial and central role that JPL had played in the NASA planetary program, but in a late summer memo Hearth told Nicks that JPL was using Voyager as a hostage to induce the agency to increase its manpower levels. "As you know, JPL has been going through a detailed evaluation of their personnel assignments as a result of their current man-power ceiling." It appeared to Hearth that JPL would not be submitting a proposed project development plan for Voyager or the cost and schedule information that headquarters needed. Apparently, the lab would "dissolve the Advanced Planetary Spacecraft Study Committee which essentially [would] terminate the current Voyager activity at JPL."²⁴ Simply put, the managers in Pasadena had decided not to work on Voyager during 1964. This did not quite agree with JPL's position that the laboratory had been "directed to terminate its APSS work."

Hearth was sure it would mean trouble for the project if JPL were to use Voyager to garner more job slots, but he argued that without Pasadena's assistance his office would be crippled. "In addition, we cannot propose a program without a center ready and willing to accept project management." Although he could delay his Voyager recommendations to the NASA managers for six months while his team selected another center or for one year while they waited for JPL, either of those delays would "jeopardize the chance for a 1969 Voyager launch." Hearth frankly felt that JPL was being "short-sighted" and would be left "without significant programs in another 2 to 3 years without Voyager." But he also had an inkling that some people at NASA Headquarters also wanted to delay Voyager. "Obviously, NASA management may decide to defer Voyager indefinitely," but he did not want that to happen without their having "all the technical and scientific facts available."²⁵

Hearth presented the Voyager case at a December 1963 planetary program briefing for Administrator Webb. Summarizing first the Mariner program to date, he noted that the revised figures for the Mars atmospheric pressure, coupled with budget problems, had led to the termination of Mariner B. To survive a hard landing, a capsule would have to weigh at least 360 kilograms, and Atlas-Centaur could not be expected to deliver more than about 225 kilograms. The new Mariner 1966 would use a chassis like *Mariner 4*'s to transport a small atmosphere probe to Mars. Turning to Voyager, Hearth discussed the JPL, AVCO, and General Electric concepts as they had emerged during the April to October study.²⁶

Engineers for AVCO and GE had studied Mars and Venus missions, with AVCO giving Venus greater attention, but it was obvious to both contractors that Mars was NASA's primary target. General Electric recommended two identical landers carried aboard a single orbiter bus. Primary

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communications from the landers to Earth would be via a relay in the orbiter, with secondary links directly from the landers. Solar cells and batteries would be used to power the orbiter, while radioisotope thermoelectric generators would provide both electricity and heat for the lander. Having concentrated basically on Mars missions, the General Electric engineers emphasized "biological and geophysical-geological experiments," recommending Syrtis Major (10°N., 285° long.) as a landing site for one lander and Pandora Fretum (24°S, 310° long.) for the second. These were two of the more interesting areas for biological exploration. The appearance of Syrtis Major did not change much with the seasons. Its boundaries "are sharp and stable, and it is one of the darkest areas of the planet." Pandora Fretum did change with the seasons, the dark color developing in spring, deepening with summer, and becoming light in the fall for the duration of winter. While the choice of these sites would eliminate close examination of the polar regions and the "darkening wave," they considered their choices the best ones "in view of the high priority of the life detection [experiments] and the eventual requirements for choosing sites for manned landing missions."²⁷ GE would wait until after the first successful landings to define future sites, but AVCO made the proposals in table 11.²⁸

General Electric proposed a rather ambitious series of scientific investigations, considering the weight limits on instrumentation for both the orbiter (98 kilograms) and the lander (70 kg). Biological instruments would easily constitute a third of the payload projected for the lander. AVCO Corporation's landed science payload was greater (91 kg), but the proposed orbital instrumentation was less (61 kg). In either case, the weight was substantially more than the 23 kg of experiments that could have been landed with a Mariner B-class capsule. During more favorable Mars launch

Table 11
AVCO Proposals for Missions to Mars, 1963

Launch Opportunity	Lander	Landing Site	Latitude	Longitude
1969	1	Solis Lacus	28°S	90°
	2	Syrtis Major	15°N	286°
1971	1	South Polar Cap	83°S	30°
	2	Mare Cimmerium	18°S	235°
	3	Lunae Palus	15°N	65°
	4	Aurorae Sinus	15°S	50°
1973	1	Propontis	45°N	185°
	2	Elysium	25°N	210°
1975	1	North Polar Cap	78°N	220°
	2	Nepenthes-Thoth	25°N	225°

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opportunities—1971 and 1973—larger scientific packages could be landed using the same orbiter and launch vehicles.

Besides the weights of the landers (GE, 657; AVCO, 762), the major difference between the two contractors' approaches was the number of landers; one for AVCO and two for GE. AVCO's lander was encapsulated before launch for sterility and for protection during the descent. The blunt body of the aeroshell would protect the lander during entry and slow the descent. A parachute, deployed when the aeroshell and heatshield were discarded, would slow the craft further. At impact, the lander would be protected by aluminum crush-up pads (touchdown velocity 12 meters per second). After a relatively hard landing, the craft would roll and tumble until it came to a stop, and six petals, which when closed protected the internal parts, would open and erect the lander and raise it off the ground. AVCO also planned to use radioisotope thermoelectric generators to provide electricity. General Electric's capsules by comparison were much simpler. They consisted of "moderately blunt sphere cones," which entered point downward instead of blunt end down as with the AVCO approach. General Electric proposed to use rockets, tip bars, and explosive anchors to orient the cone once it was on the surface.

Hearth told Webb at the December briefing that "the areas of agreement were quite significant even though the studies were conducted independently and separately of one another." Both contractors called for similar scientific capabilities, and "they agreed quite well on cost and what the prime technical problems and development problems" were. But would NASA underwrite Voyager missions to the planets beginning in 1969?²⁹

Mariner 1966 and Advanced Mariner

Hearth's attempt to sell the NASA management on a 1969 Mars Voyager was unsuccessful. The administrator decided that the resources required—manpower and dollars—made it too ambitious for a 1969 mission. He preferred to defer the first Voyager launch until 1971. With the first manned lunar landings accomplished, the space agency would be under less political and financial pressure, and Voyager could proceed. To fill the gap between the 1964 Mariner C flyby and the 1971 Voyager orbiter-lander, NASA's planetary program staff proposed to add a 1968-1969 Advanced Mariner to the schedule to supplement a Mariner 1966 Mars atmospheric capsule mission.³⁰

A Mariner 1966 mission would "make maximum use" of Mariner 1964 technology.³¹ Plans called for a nonsurviving atmospheric capsule that would crash onto the Martian surface after it had relayed its scientific data. But not everyone favored the concept, since it added new technological problems in several areas—planetary atmosphere entry dynamics, communication links between a flyby craft and capsule, and sterilization. NASA planners began discussing a 1966 capsule in January 1964, and it quickly became apparent that JPL did not favor the idea.³²

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Table 12
Voyager System Weights from 1963 Contractor Studies

System	General Electric (kg)	AVCO (kg)
Orbiter		
Structure	190	147 (includes thermal
Harnessing	48	---- control)
Power supply	99	209
Guidance and control	103	84
Communications	131	128
Thermal control	40	---
Propulsion (dry)	212	209
Diagnostic instrumentation	13	---
Payload (scientific)	<u>98</u>	<u>61</u>
	934	838
Lander		
	2 landers	1 lander
Heatshield	41	204 (includes structure)
Structure	181	95 (adapter sterile can)
Retardation	72	
Thermal control	41	
Power supply	51	136
Orientation	26	
Communications	65	91
Payload deployment and installation	25	145 (touchdown and deployment)
Spin and separation	19	
Retrorocket	45	
Adapter and radiator	21	
Payload (scientific)	<u>70</u>	<u>91</u>
	657 each	762
	657	
Fuel		
Orbit insertion and midcourse	939	1361
TOTAL	3187	2961

SOURCE: General Electric Co., Missile and Space Div., Valley Forge Space Center, "Voyager Design Study," vol. 1, "Design Summary," 15 Oct. 1963; and AVCO Corp., Research and Advanced Development Div., "Voyager Design Studies," vol. 1, "Summary," 15 Oct. 1963, p. 111. All metric conversions are to the nearest kilogram.

By mid-March, Hearth told Oran Nicks that he was compelled to recommend eliminating the capsule from the proposed Mariner 1966 mission. JPL, understaffed and unenthusiastic, would not support the project if it included a capsule, and it was too late to assign the "entry probe" to another center. Considering the technical risks of the capsule, Hearth had to yield in face of the laboratory's intransigence.

NASA's fiscal 1965 budget would not support the Mariner 1966 project either. The \$5.25 billion approved by Congress was \$195 million less than

Table 13
Experiments Recommended for Voyager 1969 in 1963 Contractor Studies

General Electric	AVCO
Orbiter	Orbiter
<ul style="list-style-type: none"> Biological <ul style="list-style-type: none"> Television survey Infrared spectrum survey Geophysical-geological <ul style="list-style-type: none"> Stereo-television mapping Magnetic field survey Charged particle flux survey Atmospheric <ul style="list-style-type: none"> Ionosphere profile Infrared emission Space environment <ul style="list-style-type: none"> Micrometeoroids Magnetic fields 	<ul style="list-style-type: none"> Biological <ul style="list-style-type: none"> Infrared spectra of surface Geophysical-geological <ul style="list-style-type: none"> Television mapping Magnetic field survey Radio absorption (lander to orbiter) Spectral albedo. Atmospheric <ul style="list-style-type: none"> Infrared radiometry of surface
Landers (2)	Lander (1)
<ul style="list-style-type: none"> Biological <ul style="list-style-type: none"> Growth Metabolic activity Existence of organic molecules Existence of photoautotroph Turbidity and pH changes Microscopic characteristics (TV) Organic gases Macroscopic forms (TV) Surface gravity Geophysical-geological <ul style="list-style-type: none"> Surface penetrability Soil moisture Seismic activity Surface gravity Atmospheric <ul style="list-style-type: none"> Temperature Pressure Density Composition Altitude Light level Electron density 	<ul style="list-style-type: none"> Biological <ul style="list-style-type: none"> Biological detection Microscopic examination of soil Chemical structure of soil Geophysical-geological <ul style="list-style-type: none"> Television mapping Magnetic field Solar optical absorption Atmospheric <ul style="list-style-type: none"> Temperature Pressure Density Composition Wind velocity

SOURCE: General Electric Co., Missile and Space Div., Valley Forge Space Center, "Voyager Design Study," vol. 1, "Design Summary," 15 Oct. 1963, p. 2-2; and AVCO Corp., Research and Advanced Development Div., "Voyager Design Studies," vol. 1, "Summary," 15 Oct. 1963, p. 9.

the agency had requested. Administrator Webb announced that NASA would maintain the momentum and direction of its programs despite the loss of anticipated funds, while meeting its lunar goals. Although the decision did not “involve the transfer to manned space flight of funds from space science,” those programs would “require some adjustments.” Mariner 1966, however, was doomed. According to the news release issued at NASA Headquarters, “the combination of a heavy workload at the Jet Propulsion Laboratory, the short lead time available, and the importance of applying our resources to a major advance beyond the limited Mariner” made it “unwise” to undertake a Mars mission in 1966 with the current Mariner spacecraft. Development of a spacecraft “with much greater scientific promise for launch to Mars in 1969” was being initiated.³³

Canceling the 1966 capsule called for changes in Mariner 1964 and the Advanced Mariner (Mariner 1969). Hearsh recommended flying the 1964 Mariner on an occultation trajectory—the spacecraft would fly behind Mars as viewed from Earth. A radio signal would be transmitted as the craft approached the planet, and that signal would be blocked as the craft passed behind it. Analysis of the behavior of the radio signal could determine more precisely the composition and density of the Martian atmosphere.*³⁴

At the loss of the 1966 Mars mission in July 1964, Hearsh called for an immediate study of the capsule for the 1969 Mariner. Early study was essential if Nicks’ Lunar and Planetary Programs Division was to coordinate its plans effectively with Orr Reynolds’ Bioscience Programs Division, which was working toward a 1 August 1964 deadline for a proposal for a “minimum acceptable” biological lander payload for 1969. Hearsh believed that should sufficient information be “obtained over the next three years on the Martian atmosphere, . . . a survivable biological lander is possible in 1969.” He also thought that a lander mission was “preferable over an orbiter mission although the orbiter will be given careful study.”³⁵ Hearsh explained this in detail for Nicks because he did not believe that JPL could handle the entire Advanced Mariner mission, even if industrial contractors were used. The problem as Hearsh saw it was choosing a NASA center to assist JPL. To assign Mariner 1969 to one organization and Voyager to

*“If all other factors producing apparent motion of the spacecraft were accounted for (e.g., the actual motion of the spacecraft, the motion of the deep space stations on the rotating Earth, the lengthening of the transit time of the signal, and the refractivity of the Earth’s lower atmosphere), the remaining unexplained changes in the radio signal could be attributed to refraction by the atmosphere of Mars. (For a successful experiment, it was necessary to account for the total change in frequency or phase of the signal due to all causes other than refraction by the Martian atmosphere to an accuracy of at least one part in 10^{11} .) Since the geometry obtained from the estimated trajectory is known, the measured changes could be used to estimate the spatial characteristics of the index of refraction (or refractivity) in the electrically neutral atmosphere and electrically charged ionosphere of Mars. Thus, by measuring and then analyzing the changes in the characteristics (frequency, phase, and amplitude) of the radio signals from the spacecraft, it was hoped to learn more about the composition, density, and scale height of the Martian atmosphere.” NASA, *Mariner-Mars 1964: Final Project Report*, NASA SP-139 (Washington, 1967), pp. 316–17.

another would be unwise, because “the missions and spacecraft are too closely related.” For Hearsh, the only solution was to assign another center the responsibility for some portion of either Mariner 1969 or Voyager. “It is logical that this be the capsule. There is no question that such an arrangement will be difficult, to say the least,” but he could see no alternative. Three centers could possibly assist JPL with its planetary work—Goddard, Langley, or Ames. Because of their earlier interest in the landing capsule for Mariner 1966, Hearsh recommended the Ames Research Center team at Moffett Field, California.³⁶

MISFORTUNES OF VOYAGER

During the financial belt-tightening related to the fiscal 1965 budget, there was growing pressure from Congress, the Bureau of the Budget, and the White House to hold down costs. Congressional concerns became particularly strong following the failure of *Ranger 6* to transmit any of its prescribed 3000 pictures of the lunar surface before it crashed into the moon on 2 February 1964. The representatives on Capitol Hill told Webb and his associates that no more failures would be tolerated.

Phased Project Planning

Joseph Karth, acting chairman of the House Subcommittee on NASA Oversight, was particularly bothered by the apparent weakness of the managerial chain between NASA Headquarters and Jet Propulsion Laboratory. Karth and other congressmen were rightly worried, since JPL was responsible for several key projects in addition to Ranger—Lunar Surveyor and the planetary Mariners, with Voyager likely to be the lab's next big project. Over the years, Karth and his staff had seen instances of JPL management resistance or reluctance to accept organizational and procedural changes recommended by NASA Headquarters. The *Ranger 6* failure gave everyone—congressmen, NASA managers, JPL staffers—the opportunity to reflect on the need for better program management in general and closer liaison between NASA managers and the California Institute of Technology-JPL team in particular.³⁷ One of the tools Administrator Webb chose to strengthen his managerial control over all new projects was Phased Project Planning.* This scheme played an especially important role in the subsequent life and death of Voyager.

In mid-July 1964, Associate Administrator Robert C. Seamans, Jr., advised that all “new projects should be planned on a phased basis with successful contracts for advanced studies, program definition, prototype design, and flight hardware and operations.” Phased development would

*It has been noted that Phased Project Planning bears remarkable resemblance to the Air Force approach to systems management—conceptual phase, definition phase, acquisition phase, operation phase—as set forth in the Air Force Systems Command's 375 manual series. Arnold A. Levine, *Managing NASA in the Apollo Era*, NASA SP-4102 (Washington, 1983).

permit projects to "evolve in an orderly manner with maximum realism."³⁸ Voyager was one of about half a dozen new projects on which the headquarters staff experimented with the new procedure months before the official guidelines were promulgated in October 1965.

After nearly three years of advanced Voyager studies by JPL and others, the NASA managers took the initial steps in December 1964 to place the planetary project on the phased track to a 1971 mission to Mars. The decision came after four months of hectic conferences in Washington, during which Mariner-Mars 69 was approved (12 August), agonized over (September through October), and terminated (20 November). The prolonged debate was the result of Homer Newell's belief that a 1969 mission was necessary to satisfy the scientific community and Congress but, knowing that fiscal year 1966 funds for both Mariner-Mars 1969 and Voyager 1971 were not likely to be appropriated, NASA finally canceled Mariner-Mars 69 in an attempt to preserve Voyager. No one was happy with the compromise.³⁹ Donald F. Hornig, President Johnson's special assistant for science and technology, was dismayed over the loss of yet another Mars launch window in 1969. Seamans assured him that, if at all possible, some kind of flight, perhaps a Mars flyby that would test the basic 1971 Voyager without a lander, would be attempted in 1969. Still, the associate administrator noted that the money for Voyager was going to be tight. Four flights, two in 1971 and two in 1973, were expected to cost \$1.25 billion. With that kind of price tag, a 1969 mission might have to be dropped in favor of less expensive test flights.⁴⁰

While various persons continued to express unhappiness about the loss of another Mars opportunity, Seamans signed the project approval document for Voyager on 16 December 1964. During that same week, Don Hearth, slated to become Voyager project manager at headquarters, submitted his suggestions for the Voyager office in Washington.⁴¹ Voyager was officially on its way. The first external step was the announcement on 15 January 1965 of requests for proposals from industrial contractors to work under JPL's direction on the preliminary design, phase IA of the phased program.⁴²

The 22 January proposers conference at JPL was attended by 113 representatives from 28 companies. Three months later, after an elaborate source selection process, three firms were selected to make 90-day preliminary design studies: the Aerospace Division of the Boeing Company, Seattle; the Missile and Space Division of General Electric, Valley Forge; and TRW Space Technology Laboratories, Redondo Beach, California.⁴³ As the contractors began their work, Seamans, Newell, and other top NASA managers went to the Congress to explain Phased Project Planning, their hopes for Voyager, and their projections for its cost. The fiscal 1966 appropriations hearings proved as difficult as those of the preceding year.

President Johnson on 25 January 1965 recommended a \$7.114-billion space budget for fiscal 1966. Of this amount, NASA would receive \$5.26

billion, the Department of Defense \$1.6 billion, the Atomic Energy Commission \$236 million, the Weather Bureau \$33 million, and the National Science Foundation \$3 million. Of the NASA request, \$43 million was earmarked for Voyager. Associate Administrator Seamans labeled the budget austere, but he said that the chances of landing Apollo's first crew on the moon on schedule were still good. He said that the \$43 million, to be spent on further defining the Voyager orbiter and lander, would allow the agency to meet its milestones—a Mars flyby test of the spacecraft in 1969 and complete missions in 1971 and 1973.⁴⁴

In testimony before Congress, Seamans, Newell, and Cortright explained phased planning and its applications to Voyager. Such planning gave design engineers the chance to refine project details incrementally, while the agency's managers maintained the big picture with all its critical milestones clearly delineated. Implicit in phased project planning was the assumption that the process would allow choice of the best technological alternatives. But phased planning was a double-edged management tool. By clearly delineating important decision points, it could be used to force the redirection or termination of a project. For Voyager it did both.⁴⁵

As the contractors worked on the first phase (3 May to 30 July), several factors came to the attention of NASA managers that affected the execution of phase IB, an in-depth study of the lander. Once again, the agency was called on to tighten its programmatic belts; the budget request for \$5.26 billion yielded an appropriation of \$5.175 billion for fiscal year 1966.

Table 14
NASA Budget Summary, Fiscal 1963 to 1966
(in billions)

Year	Budget Request	Authorization	Appropriation
1963	\$3.7873	\$3.7441	\$3.6741
1964	5.7120	5.3508	5.1000
1965 ^a	5.4450	5.2275	5.2500
1966	5.2600	5.1904	5.1750

SOURCE: NASA, "Back-up Book—FY 1976, Hearings," sec. 6.

^aIncludes \$141 million supplemental request; the appropriation includes a supplement of \$74.5 million.

Voyager, as a new start, was vulnerable, but other projects such as the adaptation of the Centaur to the Saturn IB were also at risk, since such development diverted money away from the completion of the Saturn V, Apollo's powerful booster.

The unfavorable budget was trouble enough without the additional bad news brought by the radio occultation experiment aboard *Mariner 4*.⁴⁶ The Martian atmosphere was much less dense than previously estimated.

All proposals for landing capsules had to be thrown out as new aerodynamic analyses were performed based on the much lower pressure range (4-7 millibars, rather than the earlier estimates of 10-30 millibars).

The latest Mariner findings also jeopardized use of the Saturn IB launch vehicle, on technical grounds, adding to its financial difficulties. Given the 3000-kilogram weight limit for the spacecraft, much of the scientific payload would have to be sacrificed to provide the lander with additional means for slowing its descent through the thin Martian atmosphere. No matter which approach to the problem was taken—larger aeroshell, braking rockets, larger parachutes—it would mean too much weight for the Saturn IB. The larger Saturn V could provide the extra booster power, but it was seemingly too powerful and too costly to be realistic.

Voyager Capsule Advisory Group

As early as March 1965, Oran Nicks and the Lunar and Planetary Program Office had begun plans for a Voyager Capsule Coordination Group to control studies being conducted at JPL and at the Ames and Langley Research Centers.⁴⁷ After preliminary meetings at which the centers exchanged information on their capsule activities, Homer Newell set up a panel of experts* to advise Don Heath, Nicks, and the space science office on two basic questions:

1. Is the Martian atmosphere and surface sufficiently well known at this time to permit the design of a survivable capsule to be included in the 1971 operational Voyager mission, or will the design of such a capsule have to be based upon the results of a non-survivable atmospheric probe and/or other measurements to be made during the 1969 opportunity?
2. If the Voyager Program is to proceed on the basis of a survivable capsule in 1971, what general size and type of capsule should be selected?⁴⁸

The concern at NASA Headquarters over the safe landing of Mars capsules was not totally spontaneous. For a number of months, this topic had been discussed throughout the U.S. space community. During the American Astronautical Society Symposium on Unmanned Exploration of the Solar System in early February 1965, the disagreements over priorities in Mars exploration bubbled to the surface. Some of the symposium participants wanted the 1969 atmospheric probe reinstated. Alvin Seiff, chief of the Ames Vehicle Environment Branch, was the leading proponent of an 11-kilogram Mars atmospheric probe. Others thought that 1971 was too early for a landing.

Implicit in this disagreement was a difference of opinion about the kinds of landers to be used and the best time to land the first life detectors. Whereas Seiff and his colleagues at Ames favored hard-landers, or “crash-

*J. E. Naugle, chairman, P. Tarver, E. Levinthal, U. Liddle, J. Hall, O. Reynolds, C. Goodman, R. F. Fellows, F. Johnson, H. M. Schurmeier, C. F. Capen, L. Lees, and G. Munch.

ers," Langley designers wanted soft-landers. Between them were men like Gil Levin, who wanted to get on with biological investigations at the very earliest opportunity, and Temple W. Neumann, program engineer for the NASA-sponsored automated biology laboratory being developed at the Aeronutronics Division of Philco. Neumann told the symposium participants that a biology laboratory could be hard-landed as part of a 1971 Voyager mission without prior detailed mapping of the Martian surface.⁴⁹ He, too, was ready to proceed.

Bruce Murray, a planetary astronomer at the California Institute of Technology and chairman of the Cal Tech-JPL planetary exploration study group, argued for a more evolutionary approach. At the Denver symposium, Murray remarked on the need for large-scale photographic mapping of Mars before landers could be safely deposited on the surface. Finding a satisfactory site, landing a craft there, and interpreting the biological instrument results would require a great deal of work and several hundred times more photographs than the 20 or so expected from *Mariner 4*.⁵⁰

Gil Levin, the father of the biological sampler Gulliver, put his finger on another recurring concern when he noted that the Soviet Union would probably beat the United States to a Mars landing. In addition to capturing yet another first in the international space sweepstakes, Levin feared that the Soviet Union would contaminate the Martian surface. He reported that the Soviet Academy of Sciences did not appear to have an interest in completely sterilizing its spacecraft, putting the American program in an awkward position. The NASA team wanted to reach Mars ahead of the USSR so it could be certain of examining an undisturbed, uncontaminated planet, but NASA needed more time to develop its own sterilization techniques.

Levin's remarks were sparked by Homer Newell's statement that only rugged experiments and small capsules that could withstand existing sterilization procedures would be flown at first. Initial studies had indicated that the larger and the more complicated the lander, the greater the technical difficulties of sterilization. Components and assemblies had to be developed that could withstand sterilization temperatures (135°-150°C) and still perform satisfactorily after months in the cold void of space. By early 1965, the Josh Lederberg-Elliott Levinthal team at Stanford was realizing that the biggest problem facing the multivator life detector was the creation of chemical compounds that would not be rendered useless when heated to such extreme temperatures. On the other hand, the radioisotopes used in Gulliver were not heat-labile (subject to breaking down when heated). Levin was ready to send a Gulliver to Mars, but other experimenters needed more time.⁵¹

Amid the controversy over the timing and nature of Mars capsules and landers, the formation of the Voyager capsule advisory group was a prudent act, as the initial scientific results from *Mariner 4* confirmed. Turning to the

questions posed by Newell when he established the panel, group chairman John Naugle reported at the end of August that new observations, including the Mariner occultation experiment, indicated that the lower limit for the surface pressure was in the region of 10 millibars. Furthermore, "in view of the agreement between the ground based and occultation studies, it appeared to the group that . . . the information that could be obtained from a 1969 atmospheric probe would not warrant its inclusion in the Voyager program." The 1969 atmospheric mission was eliminated once and for all.⁵²

The new atmospheric data raised questions of equal significance about the possibilities of safely landing a capsule in 1971. At NASA Headquarters, Newell and his associates decided to postpone the scheduled request for proposals on the preliminary design of landing capsules until "the implications of the apparent low Martian surface pressure are determined."⁵³ While delaying the next step of the phased project plan gave the NASA managers time to think, it also helped to blunt the momentum necessary to the survival of such projects.

Saturn IB-Centaur vs. Saturn V

After several weeks of study, accompanied by many leaks to the news media, NASA Headquarters officials announced in mid-October 1965 that development of the Saturn IB-Centaur would be terminated and that Voyager would be launched with the 33 360-kilonewton (7.5-million-pound-thrust) Saturn V booster.⁵⁴ The decision had a number of cascading results. First, since Saturn V was not scheduled to fly until 1967 and the early production was assigned to Apollo, there would be no 1969 Voyager test flight. The 1971 lander mission would have to be delayed until 1973, and the 1971 flight opportunity would be dedicated to an orbiter mission without a lander. Second, morale suffered. Within NASA and contractor circles, people were discouraged by another two-year postponement. Congressional and press reactions were equally gloomy. But more telling was the effect Saturn V had on the space science budget. Total costs for a rescheduled project based on the large Saturn soared, and some estimates ran as high as \$2 billion. Greater costs in a period of tightening agency budgets did not argue well for the survival of Voyager.⁵⁵

Since Voyager planners had resisted the use of the Saturn V launch vehicle for several years, the switch came as an unpleasant shock to many. During 1964, JPL had commissioned General Electric to study the possible use of the Air Force Titan IIIC or NASA's Saturn V in place of the Saturn IB-Centaur.⁵⁶ In evaluating these and other studies, Ed Cortright concluded that the Titan IIIC-Centaur launch vehicle would not be powerful enough. Whereas Saturn IB-Centaur could boost a 2700-kilogram payload, Titan-Centaur could lift only 1270 kilograms. NASA planners were also hesitant to use the Titan because it was an Air Force booster. In addition to pursuing the basic principle of not becoming involved with too many

different launch vehicles, Webb, Dryden, and Seamans—after their experiences with Atlas-Centaur—wished to stay clear of military boosters. And, although using the Titan IIC would have saved about \$10 million per Voyager launch, the dollars spent on Titan would have diverted money from the development of the Saturn family while purchasing an inadequate launch vehicle for Voyager.⁵⁷

Whereas the Titan IIC-Centaur combination was not powerful enough for Voyager, Saturn V was too powerful. In February 1963, Don Hearth had told Webb that the 18 000-kilogram payload capacity of Saturn V was 6.6 times that needed for first Voyager flights. "In addition," he noted, "we recognize that Apollo will place heavy demands on the Advanced Saturn launch vehicle during the time period of interest for Voyager."⁵⁸ By mid-1965, Saturn V was still too big for Voyager, unless two were flown at the same time, but the desire to keep that launch vehicle in production beyond the first lunar missions made it appear more practical for use in the planetary program.

The Saturn IB-Centaur combination was considered a diversionary project by many managers, diverting monies that could be used for the larger booster. Seamans wrote White House officials in late 1965 to that effect: "... the development cost of combining Centaur with Saturn IB would peak in FY 1966, 1967, 1968, while relatively little vehicle development effort is required to use Saturn V." Although the first flight of the advanced launch vehicle was still two years away, Seamans noted that "the projected cost of one additional Saturn V for 1971 and later Voyager flights is probably about equal to two Saturn IB Centaurs." As the year ended, the NASA managers believed that Saturn V was "a technically feasible and economic vehicle for Voyager [launching two spacecraft on one vehicle], with as great a probability of mission success as separate launches of smaller vehicles."⁵⁹

Management's acceptance of Saturn V was not enthusiastically received throughout the agency. Newell's "space science people were sort of horrified at the thought of using Saturn Vs."⁶⁰ There was no absolute certainty that two spacecraft could be launched by one of the big boosters at about the same cost as two Saturn IB-Centaur combinations. There was surely less flexibility. If budgets tightened further, at least one flight could be made at each opportunity with the smaller vehicle. With Saturn V, two very large spacecraft were required for each launch.

At JPL and elsewhere, the launch vehicle switch was viewed with some suspicion. JPL staffers "felt Headquarters used the finding of [new data on the Martian atmosphere] as a rationalization for concepts they were already 'enamored of' such as out-of-orbit landing and mammoth scientific payloads, without adequately considering either the feasibility of some reasonable alternatives or the effects at the project level." There was also the belief that Webb had decided to force Saturn V on Voyager to maintain the Saturn production line and keep the Marshall Space Flight Center team "happy

and working." Many persons at the project working level were afraid that headquarters did not understand how disruptive the decision could be for Voyager.⁶¹

Angered and dismayed because it had not been properly consulted about the decision, the JPL team believed there were several explicit reasons for not using Saturn V. Although launch vehicle cost was usually a small part of a planetary mission cost, the team feared use of the Saturn V would make the program too costly because increased payload capability would "escalate the cost of the spacecraft." It also would be too big a technological leap over the Mariners. And it might lead to a program "too big for JPL to handle alone or perhaps even to oversee."⁶²

If the change from Saturn IB-Centaur to Saturn V was bad news in Pasadena, the cancellation of the 1971 Voyager mission was worse. On 22 December 1965, a little more than two months after the October launch vehicle decision, Homer Newell's office notified JPL that there would be no 1971 mission. On the 22d, NASA announced publicly that Voyager would not fly until 1973. To replace the 1971 orbital Voyager, the agency planned a 1967 flight to Venus using the *Mariner 4* backup spacecraft modified for this new purpose. In 1969, a pair of heavier Mariner-class craft would be launched by Atlas-Centaur boosters. In 1973, after passing up the 1971 opportunity, two identical Voyager craft would be launched to Mars by a single huge Saturn. According to this plan, both spacecraft would orbit Mars and release large landing capsules that would search for evidence of Martian life. Under the revised phased plan, capsule procurement would begin in late 1966 or early 1967.⁶³

The 22 December 1965 decision was more than just another delay; it was the death knell for Voyager. In a published interview, Hearsh admitted that work on Voyager spacecraft would "go on a low back burner basis for the next year and a half to two years before [it was picked] up again."⁶⁴ JPL would continue design work on landing capsules with support from Langley and Ames, but the next phase of the procurement cycle would be delayed "for some time."

The immediate reason for canceling the 1971 flight was a lack of funds. NASA had hoped to obtain \$150 million in the 1967 budget with which to start hardware development for Voyager, but the Bureau of the Budget slashed the \$5.6-billion overall request to \$5.012 before it went to Capitol Hill. Since Apollo and Surveyor were reaching critical periods in their maturation, the planetary program took the greatest cuts. Voyager was allocated only \$10 million. As Webb subsequently informed Sen. Clinton P. Anderson, chairman of the Committee on Aeronautical and Space Sciences, "The President specifically rejected the initiation of the Voyager program in the FY 1967 budget. In his consideration of the requirements of the space program for FY 1967, the President specifically included limited funds to permit continued study of the Voyager system aimed toward a 1973 Mars landing mission."

Looking back, Homer Newell concluded that NASA could not have managed two large programs simultaneously—there was just not enough money for the moon and the planets.⁶⁵

For the next 22 months, Voyager continued at a reduced pace. The paperwork multiplied for all concerned, but the avalanche of correspondence and reports was misleading, for the agency's money and enthusiasm went elsewhere. Some dollars were reprogrammed to begin work on the 1967 Mariner Venus flyby and the twin 1969 Mariner Mars flybys. NASA could finally fall back on Mariner missions launched by Atlas-Centaur, since that vehicle was approaching flight readiness. To all concerned, it was apparent that in times of tight budgets it was easier to rely on existing and proved hardware, like Mariners, than to take the step up to more advanced technology.⁶⁶

Mission Guidelines and Management Assignments

From January through September 1966, the JPL Voyager team under Don Burcham's direction prepared more than a dozen Voyager project estimates. Each of these lengthy documents detailed alternative missions and the technological and scientific tradeoffs required to execute a planned series of four Voyager flights for 1973, 1975, 1977, and 1979. These estimates were given to the JPL managers, the Voyager capsule advisory group, and the space science office team during a series of reviews from July through October. In mid-September, Voyager Project Estimate-14 was presented to Newell and his staff. This document, called a "feedback VPE" because it included many space science office recommendations, was approved in a revised set of Voyager project guidelines sent to JPL by Newell on 5 October. But some of the modifications of the plan upset JPL. The big change was that headquarters wanted the lab to examine the pros and cons of launching two orbiter-lander combinations that carried different—rather than identical—experiment payloads, with the possibility of a direct-entry landing instead of delivering the lander from an orbiting bus.⁶⁷

In an attempt to secure approval for the development of the capsule systems (phase B of the procurement plan), JPL managers made their VPE-14 presentation to Associate Administrator Seamans on 17 October 1966.⁶⁸ But before any action was taken on phase B, considerable discussion on the best management arrangement for Voyager had to take place during the winter months. When finally signed on 27 January 1967, the project approval document for phase B called for a Voyager Program Management Office to parallel the Lunar and Planetary Program Office within Newell's Office of Space Science and Applications. Like Apollo, the Mars project had grown enough in size, duration, and cost to be called a program.⁶⁹

Other changes proposed in the approval document were more significant, and from the JPL point of view revolutionary. Von Braun's Marshall Space Flight Center would be established as the management organization for both the Voyager spacecraft and the Saturn V launch vehicle. JPL and

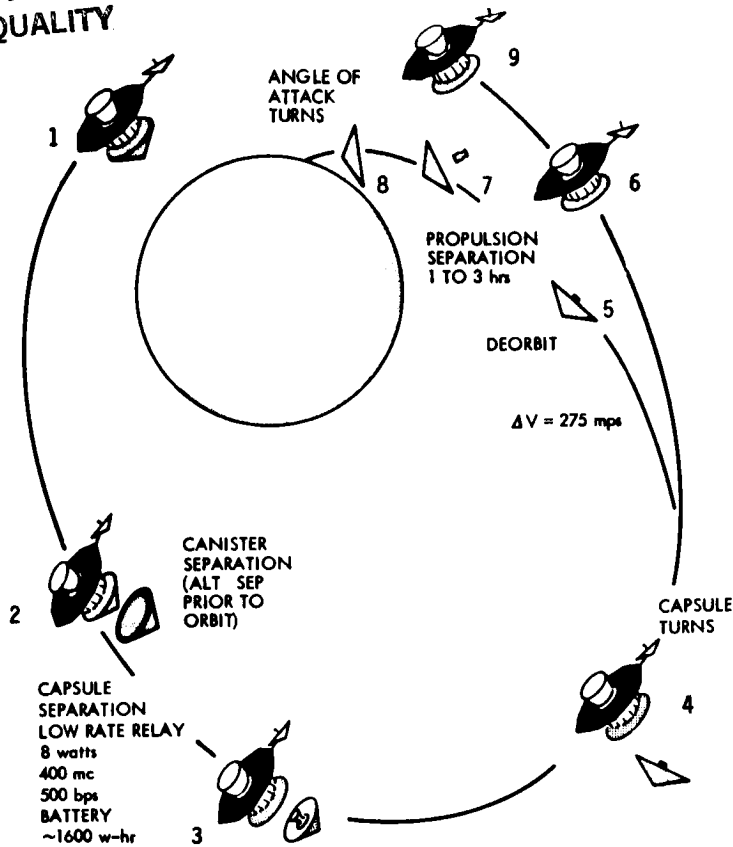
Langley would work together on the development of lander systems and report to Marshall. This plan was never executed because a disaster in the Apollo program diverted NASA's attention from planetary missions. On 27 January, the day the project approval document was signed, a flash fire killed three astronauts during a test of the Apollo 204 spacecraft. The tragedy profoundly unsettled the American space program. As the agency investigated the awesome fire, Webb decided in early February to delay assigning responsibility for Voyager to Huntsville. In the interim, the administrator approved the creation of a Voyager Program Office in Newell's organization and a Voyager Interim Project Office in Pasadena. Oran Nicks would be program director and Hearsh his deputy and acting project manager. The California office would be abolished once the project was assigned to another center.⁷⁰

In discussing these changes with Webb and Seamans, Newell remarked that the transfer of project management from JPL to the Interim Project Office had been made because the next nine months were critical in preparing Voyager for its 1973 launch date. He also noted that they must "continue to draw heavily upon the existing project management team in JPL during the transition." Hearsh's team of 77 persons began operation in a downtown Pasadena bank building on 20 March 1967.⁷¹

In Washington, meanwhile, Seamans, Newell, Cortright, and Nicks were explaining the agency's Voyager decisions to Congress. After the Apollo fire, the congressmen tended to be even sharper in their questioning, and they no longer accepted as readily the rationale of a race with the Soviet Union for first place on Mars. Representative Karth questioned the wisdom of assigning Voyager tasks to different organizations. Pursuing rumors that JPL was being deprived of Voyager management so that Marshall would be certain to have an adequate workload in the post-Apollo period, Karth asked if the split in responsibility had come about "as a result of certain" NASA centers running out of work for the future. He did not really expect the NASA officials to answer such a question in the affirmative, but he confessed that the new arrangement appeared suspect after "some 5 or 6 years of experience with the Voyager program." Ed Cortright responded that it would not be in the government's interest to enlarge JPL, a contractor, at a time when the agency's centers were likely to be cut back, especially when Marshall had personnel available from a phased-down Saturn program and Langley had pertinent, valuable skills developed from its management of Lunar Orbiter.⁷²

Several years later, a Harvard Graduate School of Business Administration team studied the Voyager management shift and, while reflecting something of a JPL bias, questioned NASA's judgment:

... as of the middle of 1967, the Voyager Program had an unusual and complex management structure. Much of the actual work was still being done at JPL, which was technically a contractor associated with OSSA [Office of Space Science and Applications], even though its official role



The September 1966 JPL Voyager Project Estimate-14 briefing gave a profile of the planned orbital operations of the Voyager spacecraft. 1—The Voyager craft approaches the point of insertion into orbit of Mars. 2—After orientation of the orbiter (capsule), the lander in its aeroshell (canister) separates from the orbiter. 3—The orbiter and lander continue around the planet. 4, 6, 9—The orbiter is turned to achieve the attitude for communications with Earth. 5—A retrorocket impulse alters the velocity of the lander by 275 meters per second, causing it to deorbit. 7, 8—One to three hours after deorbit, the propulsion unit on the lander canister is released and the canister is oriented for final approach to the Mars surface. VPE-14 Project Study, September 1966.

was much reduced. Two [Office of Advanced Research and Technology] centers, Ames and Langley, were involved in capsule work with Langley being given responsibility for the capsule bus system. Kennedy and Marshall, two [Office of Manned Space Flight] centers, were also on board. . . . On top of this structure was the [Voyager Interim Project Office] an arm of OSSA but staffed from the centers, and of course there was the program office at Headquarters in Washington.⁷³

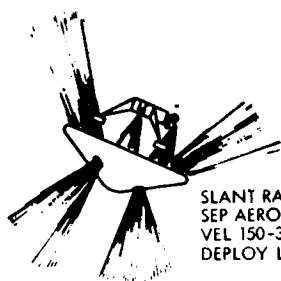
Voyager Terminated

The viability of the new management arrangement became a topic only for conjecture because Voyager was canceled in 1967 (see appendix B

VOYAGER: PERILS OF ADVANCED PLANNING

for a summary of Voyager project highlights, 1966-1967). The cancellation was only one of a series of interlocking circumstances, which taken together remind us that 1967 was an unhappy year for the United States at home and abroad. Foremost among the problems facing the nation was the war in Southeast Asia. More than a half million Americans were on military duty in Vietnam. By 1967, nearly 25 000 had died in a conflict that was costing taxpayers at home \$2 billion monthly. With each new expenditure in Vietnam, the Johnson administration was faced with a growing budgetary deficit, which forced the president to reduce nondefense expenditures and raise taxes. If no other factors had conspired to undermine the planetary projects NASA wanted to pursue, the cost of the Vietnam war alone would have diminished the chances for a big Mars mission. But other factors did also conspire against Voyager.

JPL engineers also outlined their plan for landing Voyager. At about 6100 meters, the craft would be traveling 140-335 meters per second, depending on the density of the Martian atmosphere. To slow the lander canister, braking rockets would fire. At about the same time, the inertial guidance system and the radar altimeter would be activated to control the final approach. At a slant range of 610 meters, the lander would be pyrotechnically separated from the aeroshell. By this time, the craft would have slowed to 45-105 meters per second. At 25 meters from the surface, it would stabilize at 1.5 meters per second by firing the terminal descent engines. The engines would shut down at 3 meters to prevent undue alteration of the terrain. At touchdown, the lander would be traveling 3-8 meters per second. VPE-14 Project Study, September 1966.



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SEP AEROSHELL
VEL 150-350 fps
DEPLOY LEGS



SLANT RANGE MARK 20,000 ft
ALT 11,000-20,000 ft
VEL 450-1100 fps
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IGNITION
INERTIAL ATT. STAB.
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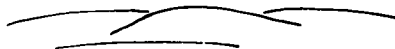
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DESCENT



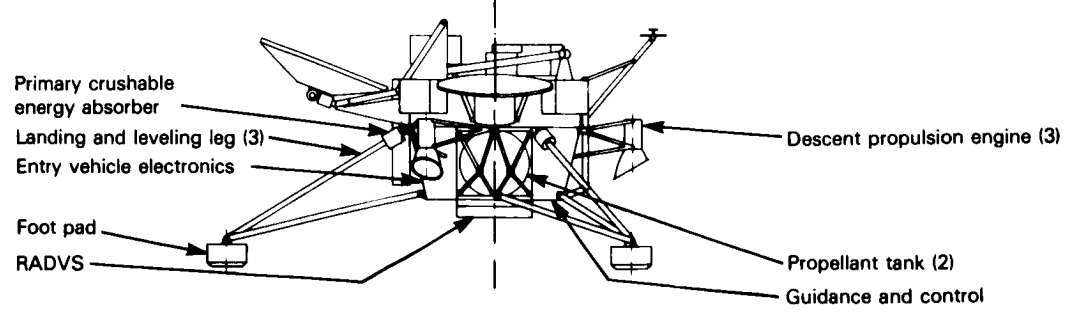
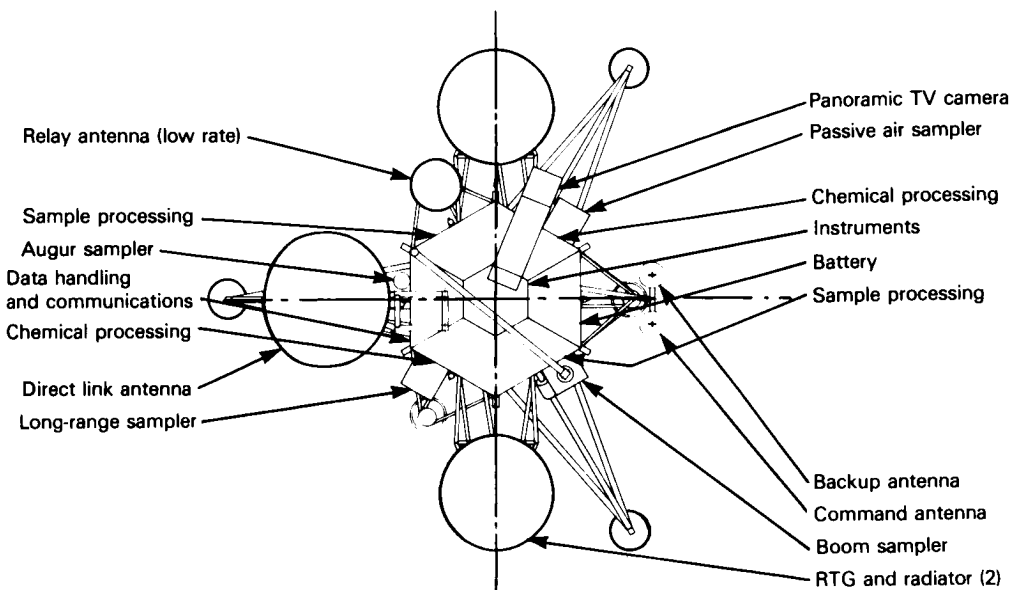
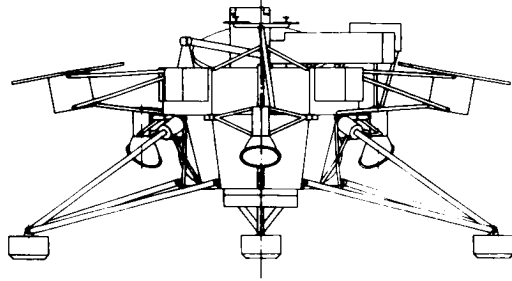
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There were the growing costs of Apollo, escalated further by the fire. As one reporter deduced, "The explosive spacecraft fire that killed three Apollo astronauts . . . may seriously delay unmanned spacecraft space projects as well as those involving man." The Apollo setbacks would cost more money—money that had been earmarked for Voyager and other planetary projects. The Office of Space Science and Applications had asked for \$695 million for 1968 (an increase of \$88 million over 1967) to provide funds for Voyager (\$71.5 million). Now, noting that the orbiter-lander project had been "on NASA's back burner for about three years as a result of one budgetary crisis after another," the newspapers reported that the proposed 1973 landing date was "no longer realistic in view of the added costs likely to be imposed as a result of the Apollo accident."⁷⁴

A secondary budget problem for Voyager was growing cost projections within the program itself. In House and Senate hearings, NASA representatives were questioned about the total estimated cost for Voyager. Sen. Margaret Chase Smith of Maine asked Webb for his best total cost figure. He responded with \$2.2 billion for research and development through fiscal 1977. On top of that were "administrative operations costs—that is the salaries of our civil service personnel," as well as \$40 million for facilities and \$55 million for two additional 64-meter radar tracking antennas for the Deep Space Network, which could be used for other projects, too.⁷⁵ Voyager's growing price tag and the general record of NASA's cost predictions prompted Representative Karth to lecture the space agency's managers, noting that over the years, when project failures and budget overruns had occurred, NASA had used a by now too familiar excuse—youth and inexperience. Karth believed that the committee had been very understanding, but it would not excuse or accept any more mistakes. "We have grown up now." He added that the Subcommittee on Space Science and Applications would "pay particular attention" to Voyager. "If it is authorized and moneys are appropriated by the Congress, I would hope that we will set a different standard by which to gauge ourselves and to which we testify before committees that are responsible for raising the money for the program."⁷⁶

When Congress considered the NASA authorization bill in June 1967, the House and Senate committees both made deep cuts in the agency's requests (table 16). While sustaining the pace of the Apollo program, the House reduced the Voyager budget by \$21.5 million and the nuclear rocket

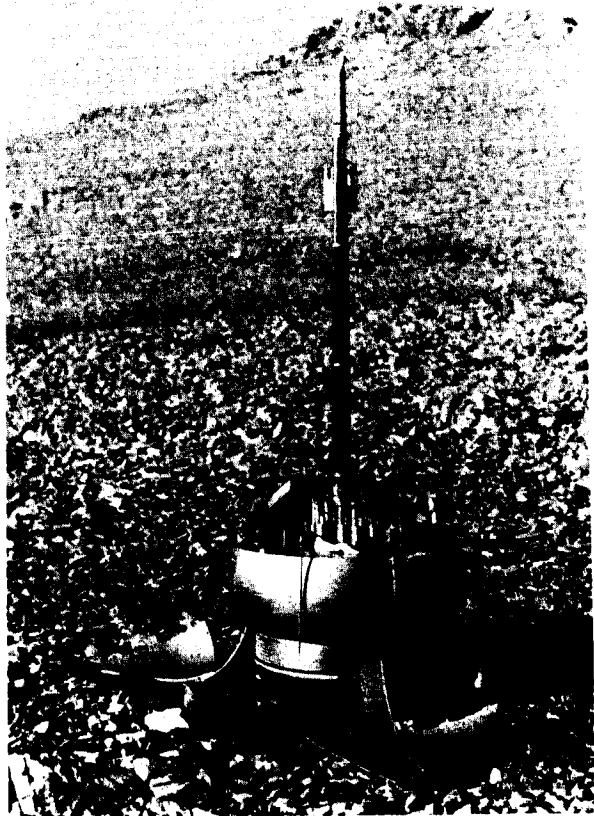
The Voyager lander proposed in September 1966 for 1977-1979 landings on Mars was quite similar to the Viking lander that would reach the Red Planet in 1976. Similar elements included the tripod landing gear, large direct-link high-gain antenna, smaller relay antenna, and radioisotope thermoelectric generators. The 1966 design already had a boom soil sampler and a television camera, but the scientific experiments would need more definition for a biological mission. The span across the legs of the proposed Voyager lander was nearly twice that of the Viking. Proposed weight was about twice that of Viking. VPE-14 Project Study.

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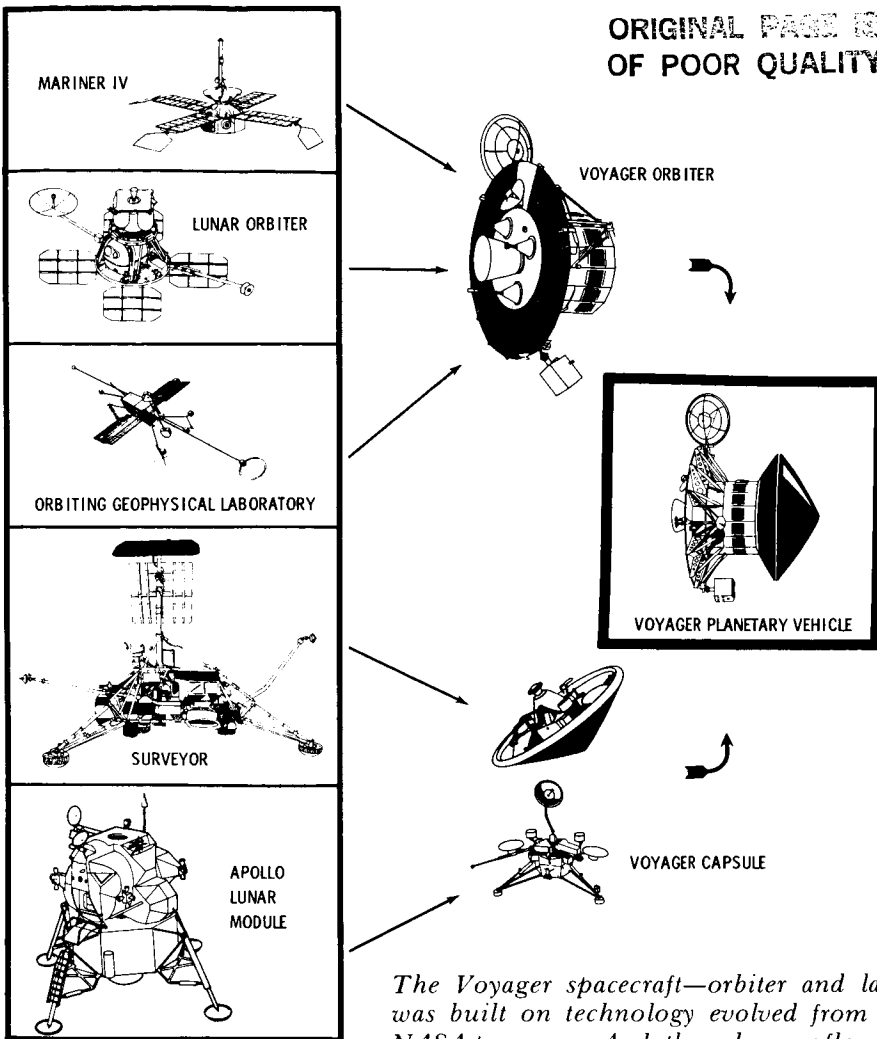
ON MARS

development program by \$24 million. An additional \$75 million was cut from Apollo Applications, which had been established to provide follow-up activities in the manned program once the first lunar expeditions had been achieved. The Senate denied NASA its entire Voyager request and cut \$120 million from Apollo Applications, but authorized the entire amount for NERVA (nuclear engine for rocket vehicle application). Senator Anderson and his colleagues on the Aeronautical and Space Sciences Committee believed that Voyager should be further postponed because the project would use too much of the space science budget. Whereas 21 space science missions were planned for 1967, the number would decrease to 13 in 1970 and to only 2—the Voyagers—in 1973. "It is clear, therefore, that to have a varied mission space flight program in the early 1970's comparable to that now existing in OSSA there would have to be a substantive increase in funding for that Office."⁷⁷ Additional dollars would not be forthcoming, and NASA would have to reevaluate its space science activities. In late June, a joint House-Senate Conference Committee worked out a compromise budget that restored \$42 million to Voyager for 1968. Excluded from NASA's budget altogether were funds for the proposed Mariner 1971 with the atmospheric probe.⁷⁸

An automated biological laboratory was developed by Philco Aeronutronic Company to study the possibility of a hard-landing entry probe to make simple assays of the Martian environment. One of several studies for Voyager in the mid-1960s, it grouped science instruments that could be programmed for numerous experiments. None of the projects was flown, but they provided understanding of extraterrestrial biology detectors.



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The Voyager spacecraft—orbiter and lander—was built on technology evolved from several NASA programs. And, though never flown, Voyager orbiter and lander designs provided a substantial foundation for the Viking teams.

Though far from lavish, the funds suggested for Voyager would have been sufficient to begin basic development of the orbiter for a 1973 flight, but this was just the authorization. The appropriation still had to be moved through Congress. Between June and August 1967, while the NASA appropriations were being finalized, riots or violent demonstrations associated with the civil rights movement occurred in 67 American cities. Combined with the unpopular, costly war in Vietnam, the summer of disorder—the third since the burning of Watts in 1965—forced congressional attention to concerns more pressing than sending spacecraft to Mars.⁷⁹ At the end of July, as Webb was resolutely refusing to choose between Apollo Applications or Voyager, a Harris survey indicated that the American public no

Table 15
Voyager Projected Costs

(in millions)

Date of Estimate	Missions	Projected Cost
8 Mar. 1963	Four flights with SIB-Centaur	\$ 700
7 Aug. 1964	Two flights with SIB-Centaur	450
Dec. 1964	1969 test flights, and orbiter- landing capsule mission in both 1971 and 1973 with SIB-Centaur	946
14 Dec. 1964	Four flights with SIB-Centaur	1250
Project Operating Plan 65-1	1969 test flights, and orbiter- landing capsule missions in both 1971 and 1973 with SIB-Centaur (JPL estimate)	1107
Mar.-Apr. 1965	Above missions reviewed by Office of Space Science and Applications; kept earlier estimate pending completion of project definition	946
10 May 1965	Above missions	946
Sept.-Oct. 1965	1969 test flights deleted, 1971 landing changed to capsule test, one 1973 mission, and launch vehicle changed to Saturn V (headquarters)	1000
POP-65-1	JPL estimate for one 1973 flight and 1971 capsule test	1300
Dec. 1965	Landing capsule flights deferred until 1973 and 1975: JPL estimate Hearth estimate	1578 1200
End of Jan. 1966	1973 and 1975 Voyager estimate (Office of Space Science)	1800
25 Oct. 1966	1973 and 1975 lander missions; cost for spacecraft and lander without launch vehicle	1429
18 Apr. 1967	1973 and 1975 lander missions with cost of launch vehicles (\$400 million); does not include operations costs or \$40 million for facilities or \$55 million for additions to Deep Space Network	2200

SOURCE: House Committee on Science and Astronautics, *1964 NASA Authorization*, hearings before Subcommittee on Space Sciences and Advanced Research and Technology, 88-1, pt. 3(a), Mar.-May 1963, p. 1621; Donald P. Hearth, "Voyager Cost Estimates," memo for record, 7 Aug. 1964; Robert C. Seamans, Jr., to Donald F. Hornig, 14 Dec. 1964; Hearth to Oran W. Nicks, "FY67 Funding Requirement for Voyager," 10 May 1965; Hearth, "History of Voyager Cost Estimates," memo for record, 15 Feb. 1966; and Hearth, "Estimates of Voyager System Contractors Cost," memo for record, 25 Oct. 1966; Senate Committee on Aeronautical and Space Sciences, *NASA Authorization for Fiscal Year 1968*, hearings, 90-1, pt. 1, Apr. 1967, p. 30.

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Table 16
NASA Fiscal 1968 Budget

(in millions)

Program	Authorization			Appropriation
	House	Senate	Conference	
Apollo Applications (Skylab)				
Requested	\$ 454.7	\$ 454.7		
Approved	379.7	334.7	\$ 347.7	\$ 315.5
Voyager				
Requested	71.5	71.5		
Approved	50.0	0.0	42.0	0.0
Nuclear rockets program				
Requested	74.0	74.0		
Approved	50.0	74.0	73.0	46.5
Total NASA budget				
Requested	5100.0	5100.0		
Approved	479.7	4851.0	4865.8	4588.9

SOURCE: NASA, *Astronautics and Aeronautics, 1967: Chronology on Science, Technology, and Policy*, NASA SP-4008 (Washington, 1968), pp. 17-18, 192, 194-95, 237, 320; and NASA, "Chronological History, Fiscal Year 1968 Budget Submission," 8 Nov. 1967.

longer supported large expenditures on space. Detroit Mayor Jerome P. Cavanagh voiced the public's concern: "What will it profit this country if we . . . put our man on the moon by 1970 and at the same time you can't walk down Woodward Avenue in this city without some fear of violence." Cavanagh and others thought "our priorities in this country [were] all out of balance."⁸⁰

Considering the political climate, Voyager still might have survived, but only if NASA were very careful about how it promoted its planetary program. Unfortunately, the Manned Spacecraft Center in Houston chose the first week of August 1967 to send 28 prospective contractors a request for proposals to study a manned mission to Venus and Mars.⁸¹ While not the first such investigation to be suggested, in the summer of 1967 proposing a "Planetary Surface Sample Return Probe Study for Manned Mars/Venus Reconnaissance/Retrieval Missions" for 1975-1982 was a grave mistake.⁸² The request infuriated Congressman Karth, who had been fighting an uphill battle to preserve Voyager. He told one reporter that he was "absolutely astounded," especially in view of repeated congressional warnings against "new starts. Very bluntly, a manned mission to Mars or Venus by 1975 or 1977 is now and always has been out of the question—and anyone who persists in this kind of misallocation of resources at this time is going to be stopped."⁸³ While such advanced study proposals were commonplace

among most government agencies, the timing of Houston's request could not have been worse, since previous exercises of this kind sponsored by the Office of Manned Space Flight centers in Houston and Huntsville had been billed as logical extensions of the Voyager missions. This cast Voyager in the role of a "foot in the door" for manned flights to the planets—flights that would cost billions of dollars.

The Manned Spacecraft Center's request for proposals may have been the proverbial last straw, because on 16 August the committee voted down *all* monies for Voyager and the Houston study. On the 22d, the House approved a \$4588.9 million budget for NASA, \$511 million less than the agency's request. President Johnson did not care to fight the reduction: "Under other circumstances I would have opposed such a cut. However, conditions have greatly changed since I submitted my January budget request." While Johnson went on to say that "these [budget] reductions do not signal a lack of confidence in our space venture," they did signal the end of Voyager.⁸⁴

Despite last minute attempts in October in both the Senate and the House to save Voyager, the program died in the final deliberations of the appropriations conference committee (see table 17 for 1968 budget).⁸⁵ After seven years of work, the planetary project had been killed, leaving NASA with no program for the exploration of the solar system. The 1969 Mars Mariner was the last approved flight, since the 1971 Mariner had been cut with Voyager. Much of the responsibility for planning a reduced and revised space science program fell on John E. Naugle, who succeeded Newell as associate administrator for space science and applications. Newell had been appointed in late August to the number three position, NASA associate administrator (see organization chart in appendix G), and Seamans had become deputy administrator on 28 January 1966, having occupied that office in an acting capacity since Hugh Dryden's death the previous December.

When asked what he would do in his new job, Newell responded, "My first assignment will be to develop an orderly, routine planning approach for the agency." The major problem he saw was "defining the major new objectives of the space program." While Newell and his colleagues publicly held out hope for a resurrection of Voyager—"My only hope is that we've sold Voyager and that we're just experiencing a delay because of war and problems on the homefront"—privately they knew that future planetary projects would have to be on a smaller scale, in both physical size and budget.⁸⁶ NASA was embarked on a new era—one of ever-tightening budgets and closer congressional scrutiny.

VOYAGER: PERILS OF ADVANCED PLANNING

Table 17
Final NASA Budget, Fiscal 1968

(in millions)

Program	Request	Authorization	Appropriation
Apollo	\$2546.5	\$2521.5	\$2496.0
Apollo Applications	454.7	347.7	315.5
Advanced missions	8.0	2.5	0
Physics and astronomy	147.5	145.5	130.0
Lunar and planetary	142.0	131.9	125.0
Voyager	71.5	42.0	0
Bioscience	44.3	41.8	40.0
Space applications	104.2	99.5	88.0
Launch vehicles	165.1	157.7	145.0
Space vehicles	37.0	36.0	35.0
Electronics	40.2	39.2	35.0
Human factors	21.0	21.0	21.0
Basic research	23.5	21.5	20.0
Space power	45.0	44.0	44.0
Nuclear rockets	74.0	73.0	46.5
Chemical propulsion	38.0	41.0	35.0
Aeronautics	66.8	66.8	65.0
Tracking & data acquisition	297.7	290.0	270.0
University program	20.0	20.0	10.0
Technology utilization	5.0	5.0	4.0
Research & development			
total	\$4352.0	\$4147.6	\$3925.0
Construction	\$ 76.7	\$ 69.9	\$ 35.9
Administrative operations	<u>\$ 671.3</u>	<u>\$ 648.2</u>	<u>\$ 628.0</u>
TOTAL	\$5100.0	\$4865.8	\$4588.9

SOURCE: *Space Business Daily*, 27 Oct. 1967.