NASA

Technical Memorandum 78033

Cometary Exploration in the Shuttle Era

(NASA-TM-78033) COMETARY EXPLORATION IN THE SHUTTLE ERA (NASA) 24 p HC A02/MF A01 CSCL 03B

N78-15978

Unclas

G3/91 57921

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JANUARY 1978

National Aeronautics and Space Administration

Goddard Space Flight Center
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TM 78033

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IN THE SHUTTLE ERA

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ABSTRACT

A comprehensive program plan for cometary exploration in the 1980-2000 time frame is proposed. The proposal involves an observational program as well as a series of missions to comets. Plans for ground-based observations, a Spacelab cometary observatory, and the Space Telescope are included in the observational program. The cometary mission sequence begins with a dual-spacecraft flyby of Halley's comet. The nominal mission strategy calls for a simultaneous launch of two spacecraft towards an intercept with Halley in March 1986. After the Halley encounter, the spacecraft are retargeted: one to intercept comet Borrelly in January 1988 and the other to intercept comet Tempel-2 in September 1988. The additional cometary intercepts are accomplished by utilizing a novel Earth-swingby technique. The next mission in the cometary program plan, a rendezvous with Encke's comet, is scheduled for launch in early 1990. It is planned to rendezvous with Encke in September 1992 at a heliocentric distance of ~4 AU. Following this near-aphelion rendezvous, the spacecraft will remain with Encke through the next two perihelion passages in February 1994 and May 1997. The rendezvous mission will be terminated about seven months after the second perihelion passage.

COMETARY EXPLORATION
IN THE SHUTTLE ERA

INTRODUCTION

Comets are the least understood and the most puzzling objects in the solar system. Although they have been closely observed by Earth-based telescopes for many years, their basic nature is still a mystery. Further progress in cometary studies will almost certainly require in-situ data from instrumented space probes.

Literally hundreds of proposals for sending a spacecraft to a comet have surfaced over the last ten years, but to date, only two suggestions have ever been seriously considered for possible implementation. These two candidate missions were the 1977 fast flyby of comet Grigg-Skjellerup and the ballistic slow flyby of Encke's comet in 1980 (see References 1 to 3). Unfortunately, these proposals were not able to generate the broad-based support that is needed to initiate a flight project.

The prospect for a comet mission in the mid-1980's is more hopeful. It is rather obvious that the return of Halley's comet in 1985-86 will attract worldwide attention from the general public as well as the scientific community. Because Halley is the only dramatically bright comet whose return can be accurately predicted, it will offer scientists a once-in-a-lifetime opportunity to obtain in-situ measurements of a large comet. Furthermore, Halley's close association with important historical events of Western Civilization such as the Norman conquest of England in 1066 (see Figure 1) has helped to bring about an unusual public awareness of the unique character of this comet. In fact, a great many people actually believe that Halley's comet is a major body of the solar system on a par with the planets Mars, Venus, Jupiter and Saturn. For these reasons and many others, a mission to Halley's comet will have a strong popular appeal.

However, important as it is, a mission to Halley is only one element in a program of cometary exploration. The main purpose of this report is to present a specific plan for the total program. Building on the Halley opportunity, a logical sequence of flight projects is constructed. A coordinated schedule of remote observations from ground-based and space-based observatories in support of the cometary missions is also presented. The observational program includes plans for the utilization of two new systems that will be operational in the 1980's, Spacelab and the Space Telescope.

Figure 1. Halley's Comet in 1066 as Depicted on the Bayeux Tapestry

PROGRAM PLAN

In attempting to formulate a realistic program plan for cometary exploration, factors such as schedule, cost, and complexity must be considered as well as scientific return. The plan outlined in this section is one that gradually builds up to the most demanding mission. A two-step mission sequence is advocated: a ballistic fast-flyby followed by a rendezvous. Because of the great uncertainty about the environment of a comet, it is felt that this is the only sensible approach.

MISSION STRATEGY AND OBJECTIVES

The simplest and least expensive way to begin a sequence of cometary missions is to use the ballistic fast-flyby technique. This mission mode is ideally suited to the scientific goals for the initial reconnaissance of a comet. It should be possible to determine the nature of the comet's nuclear condensation and possibly confirm the postulated existence of a halo of icy grains surrounding the nuclear region. Although a fast-flyby mission will only provide a "snap shot" of conditions in the comet, this should be adequate for

- Measuring the size and shape of the nucleus (or nuclei)
- Determining the abundance and spatial distribution of the neutral molecules and radicals in the coma

- Measuring the density, spatial distribution, and energy distribution of the charged particles

- Investigating the properties of the cometary plasma and magnetic field

- Determining the nature of the solar-wind/comet interaction and finding the locations of the bow shock and the contact surface (if they exist)

- Surveying the characteristics of the dust grains, especially size distribution, spatial distribution, and composition.

In addition, high-resolution spectrophotometric measurements can be made during the cometary approach and departure phases. These measurements should provide some information on the time variation of the coma's structure including its hydrogen halo.

Because of the exploratory nature of the first cometary mission, it is highly desirable to use a mission profile that includes encounters with more than one comet. Physical characteristics can vary substantially between different comets, and it will be necessary to obtain in-situ measurements from a variety of comets to fully understand cometary behavior. Fortunately, as will be shown in the MISSION DESCRIPTIONS section, it is possible to design ballistic trajectories that intercept two comets in less than three years.

The launch date for the second cometary mission, a rendezvous with a comet, should not be scheduled any earlier than two years after the first cometary flyby has taken place. This constraint is needed to allow sufficient time to make use of the flyby data in the selection and the design of a science payload for the rendezvous mission. The sequential strategy will maximize the science return from the very-expensive* rendezvous mission.

There is no question that the scientific payoff from a cometary rendezvous will be substantial. The long residence time and the ability to regulate the distance between the spacecraft and the nuclear region will permit detailed investigations of both the temporal and spatial variations of cometary features. The principal scientific objectives for a rendezvous mission can be summarized as follows:

- Investigate the nature and physical structure of the nucleus. Determine its mass, size, shape, albedo, rotation rate, temperature distribution, and surface features.

- Study the variable physical characteristics of the nucleus through at least one complete orbital cycle. Investigate the material ejection dynamics, the distribution of dust grains, and the lifetimes of icy grains.

*The cost of a rendezvous mission is likely to be five to ten times greater than the cost of a fast-flyby mission.

- Determine the surface composition of the nucleus by employing remote sensing techniques.

- Investigate the structure, composition, and motions of the cometary atmosphere. Identify the different species of parent molecules. Establish the abundance, spatial distribution, kinematic behavior, and production rate of all the constituents with particular emphasis on spatial resolution within the inner coma.

- Study the basic mechanisms which produce ions and radicals. Measure the time variations of the density and energy distribution of the charged particles. Find where and how the tail material becomes ionized, and determine the flux of charged particles through the tail.

- Determine the properties of the plasma and magnetic field. Establish whether the stylized variations of the tail structure are (1) associated with an imbedded magnetic field entrapped from the interplanetary medium, (2) related to waves along the contact surface, or (3) structures imbedded within the multiple neutral sheets that may exist in the cometary tail.

Representative science payloads for both the rendezvous mission and the fast-flyby mission are listed in Table 1. Knowledge gained from the initial cometary

Table 1

Science Instrumentation for Cometary Missions

Class	Instrument	Fast Flyby	Rendezvous
Remote Analysis	Imaging: Narrow Angle		X
	Imaging: Wide Angle	X	X
	UV Spectrometer	X	X
	IR Radiometer		X
	X-Ray Fluorescence Spectrometer		X
Mass Spectrometry	Neutral Mass Spectrometer	X	X
	Ion Mass Spectrometer	X	X
Fields and Particles	Magnetometer	X	X
	Plasma-Wave Detector	X	X
	Electron Analyzer	X	X
	Plasma Analyzer	X	X
Dust Studies	Dust Counter	X	X
	Dust Composition Analyzer	X	

flyby could change the composition of the rendezvous payload somewhat, but the present list is adequate for planning purposes. It should be noted that the dust composition experiment was omitted from the rendezvous payload because existing instruments use an impact ionization technique which requires relative velocities in excess of 10 km/sec for efficient operation. Detailed discussions of potential scientific instruments for cometary missions can be found in References 4 and 5.

TARGET SELECTION

In spite of the fact that there are approximately 100 known short-period comets, choosing the prime targets for the mission sequence recommended above is relatively easy. The two outstanding candidates are clearly comets Halley and Encke. Both comets have been observed extensively during their previous appearances, and their orbital behavior can be predicted with great accuracy. Furthermore, these comets are ideal representatives of the two major types of comets. Halley has exhibited many of the characteristics of bright long-period comets, while Encke has displayed features that are associated with more-evolved comets. Of course, as noted earlier, Halley's comet is exceptional in ways that go beyond its scientific importance.

Halley is the obvious choice for the first cometary mission. Its return in 1985-86 is only eight years away, and serious planning must begin in the near future or a truly unique mission opportunity will be lost. The next return of Halley's comet will not occur until the year 2061.

Because of Halley's retrograde orbit, flyby speeds at encounter will be ~58 km/sec. This high encounter velocity will put severe constraints on the imaging science, and the spatial resolution will be degraded somewhat for all experiments. Nevertheless, there is every reason to believe that all of the major scientific goals for the first cometary mission can be achieved.* Even at this high flyby speed, the spacecraft will be inside the visible coma region for over an hour and will remain within the extended hydrogen atmosphere for about two days.

Following the Halley encounter, it is planned to retarget the spacecraft to a typical short-period comet. The secondary targets are much smaller than Halley, but the flyby speeds will be under 20 km/sec. Because of Halley's unique status among short-period comets, a multi-comet mission that includes a Halley encounter will provide definitive scientific data for comparative studies of comets.

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*The development of a science payload that will yield satisfactory data at a flyby speed of 60 km/sec is not expected to be a serious problem. With the exception of the neutral mass spectrometer, flight-proven instrumentation or slightly modified versions of current instrument designs would be able to satisfy the Halley mission requirements. Furthermore, neutral mass spectrometers that can operate at flyby speeds up to 100 km/sec are already in a developmental phase and should be ready for implementation in the early 1980's.

Encke's comet is the logical choice for the rendezvous mission. Its short orbital period of only 3.3 years enhances the likelihood of obtaining data through at least two perihelion passages. Moreover, Encke's orbit covers an interesting range of heliocentric distances as far as cometary activity is concerned (just enough, not too much). Although Encke has been in its present orbit for thousands of years, it is still quite active and produces a broad range of cometary phenomena.

Coordination between local measurements by spacecraft instruments and remote measurements by Earth-based telescopes will undoubtedly play an important role in the Encke rendezvous mission. Comprehensive coverage for about six months before and after Encke's perihelion passage is highly recommended. In selecting an appropriate apparition for the Encke mission, this critical factor must be taken into account.

Favorable Earth-based viewing conditions can easily be determined by examining the bipolar plot of Figure 2. This plot depicts Encke's motion with respect to a fixed Sun-Earth line for each apparition from 1980 to 1997. It is readily apparent that the best geometry occurs during the 1984 and 1994 apparitions. In both cases, excellent viewing conditions will exist for an extended period before and after perihelion. Notice that the orbital geometry for the 1987 apparition is very poor.

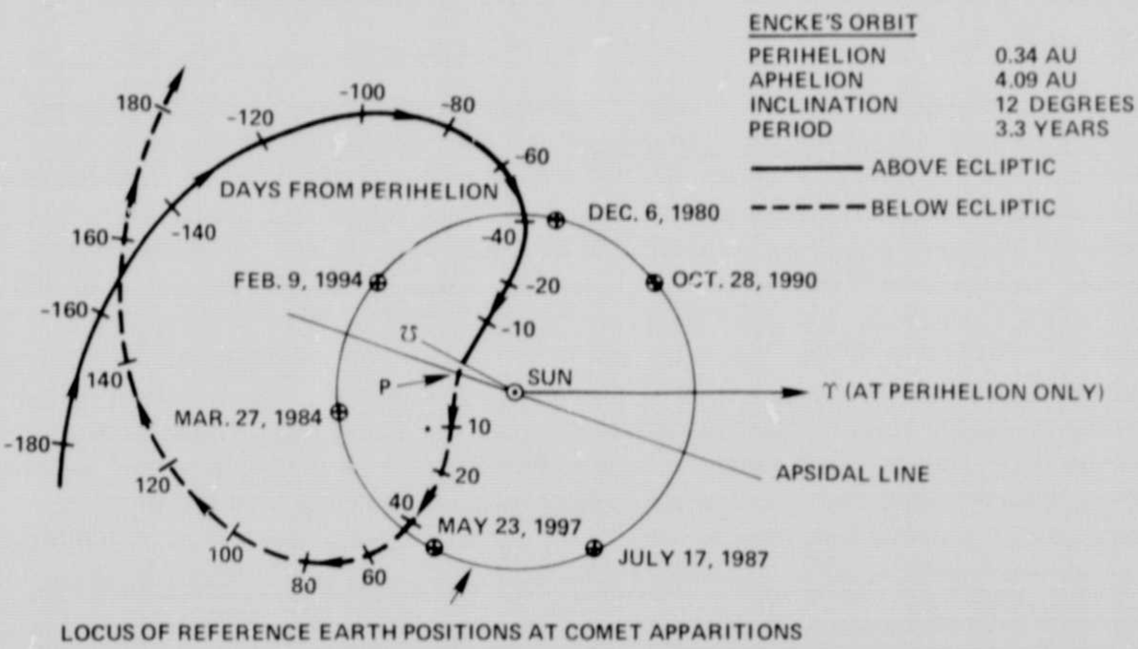

Figure 2. Orbit of Comet Encke in Bipolar Coordinates

For reasons that will be discussed in the MISSION DESCRIPTIONS section, the fast flyby of Halley's comet is planned for March 1986. Therefore, the best Encke apparition after the Halley flyby would occur in 1994. However, the viewing geometry for Encke's 1990 apparition would also be satisfactory during the pre-perihelion phase.

OBSERVATIONAL PROGRAM

A greatly expanded schedule of cometary observations from telescopes in Earth orbit and at ground-based observatories will be needed to carry out an effective cometary exploration program. Increased coverage is desirable for all short-period comets with a particular emphasis on comets that have been selected as targets for future missions. A large number of observations over an extended interval of time will be required for studies concerning the evolutionary behavior of comets.

Remote observations are also important for mission support. Astrometric measurements will be needed to update cometary ephemerides. For fast-flyby missions, at least one set of measurements every five days should be a minimum goal. To be useful during the mission, these measurements should be processed within a few days time.

However, the most essential task for the observational network will be to monitor the physical characteristics of the target comet at the same time that in-situ measurements are recorded. Photographs of the coma and tail regions should be taken at frequent intervals to track the motions of nuclear fragments and tail condensations. Spectral coverage of cometary activity in the ultraviolet and infrared can be obtained by Earth-orbiting telescopes. The remote observations will provide complementary and correlative data that will be needed for the interpretation of the in-situ measurements.

A wide variety of instruments and observing techniques will be used in the cometary observational program. The principal elements of this program will be ground-based observatories, Spacelab, Space Telescope, small astronomical satellites, and experiments carried on sounding rockets. A brief summary of some of the most noteworthy functions for each system follows:

- <u>Ground-Based Observatories</u>. This will be the primary source of cometary observations over extended periods of time. Coordination of observing schedules at a large number of observatories throughout the world will be necessary to obtain adequate coverage of the different cometary features. Ground-based observatories will also be responsible for astrometric measurements. A number of redundant sites should be available for this critical supporting function to prevent the occurrence of lengthy data gaps.

• Spacelab. The Spacelab system will provide an instrument platform that can take advantage of the extended wavelength coverage, superior image quality, and darkness of the night sky above the Earth's atmosphere. A possible instrument complement for cometary observations is depicted in Figure 3. One of the principal instruments shown here is the one-meter UV-optical telescope which will provide high angular-resolution (~0.3 arc seconds) imagery over a 0.5° field of view. Large cometary features can be monitored by the Schmidt cameras which have a field of view of ~11° with a 20 arc-second resolution. Although the Spacelab system is an extremely powerful tool for cometary observations, its period of operation will be limited to about two weeks per Shuttle flight.

• Space Telescope. The Space Telescope is able to produce images with a resolution of ~0.1 arc seconds (~75 km at 1 AU), but its field of view is only 3 arc minutes (~130,000 km at 1 AU). This instrument will be very useful for observing time variations in the inner coma region, especially when coverage from the Spacelab one-meter telescope is not available. However, the total viewing time alloted for cometary observations may be rather small due to other observing priorities.

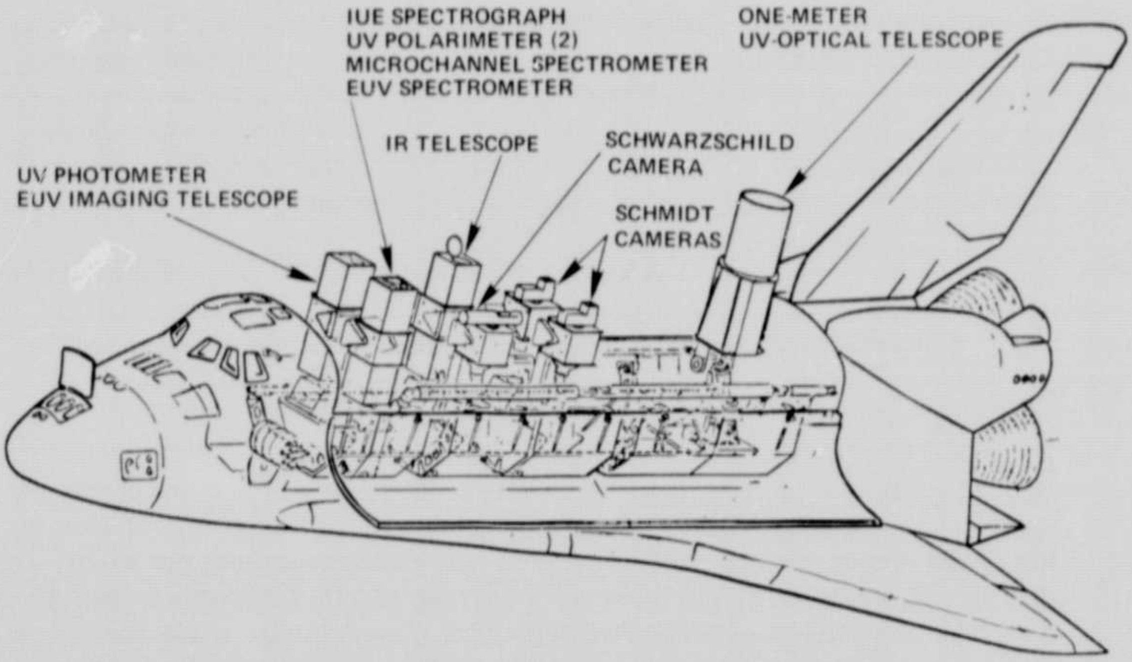

Figure 3. Spacelab Cometary Observatory

• Small Astronomical Satellites (e.g., Solar Observatories, IUE, IRAS) and Sounding Rockets. These systems might be able to fill in some gaps in the coverage provided by the instruments mentioned above. Again however, the total time available for cometary observations will probably not be very great.

MISSION DESCRIPTIONS

Details of the mission profiles for the Halley fast flyby and the Encke rendezvous are described in this section. It has been assumed that the multi-comet trajectory option will be used for the Halley mission. Two alternative plans are offered for the Encke rendezvous mission.

HALLEY FAST FLYBY WITH MULTI-COMET OPTION

The orbital geometry for Halley during its 1985-86 apparition is shown in Figure 4. Notice that Halley will be favorably located for telescopic observations before and after its perihelion passage. However, the geometry is slightly better after perihelion, and Halley is expected to be much brighter during this period.

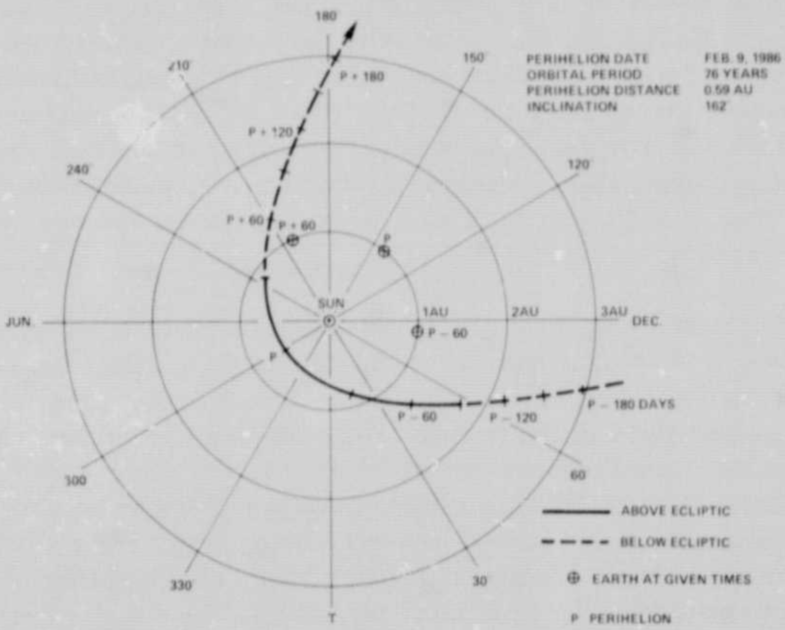

Figure 4. Orbit of Halley's Comet

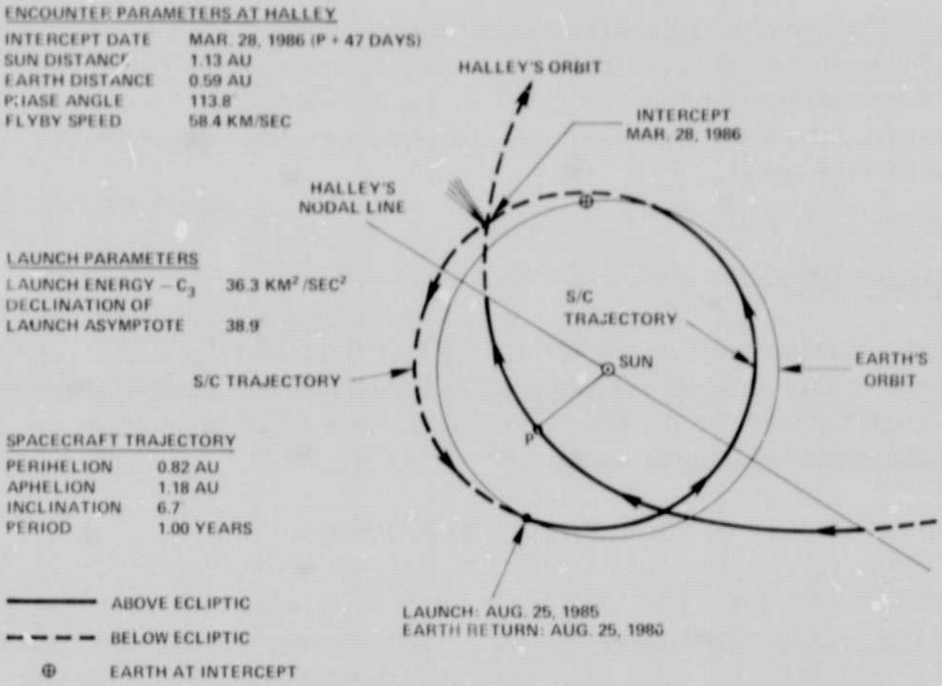

Figure 5. Halley Intercept with Earth Return

Halley's post-perihelion location is also advantageous from a trajectory standpoint. As shown in Figure 5, it is possible to place a spacecraft into a trajectory that first intercepts Halley and then returns to the Earth's vicinity one year after launch. This "boomerang" trajectory concept makes it possible to retarget the spacecraft to another comet after the Halley flyby. By using a series of Earth-swingby maneuvers, the original spacecraft trajectory can be reshaped to effect the second cometary encounter. Alternative maneuver sequences involving a variety of additional cometary targets have been discovered and are described in detail in Reference 6.

The recommended mission scenario is summarized in Table 2. This plan calls for a single launch of two spacecraft (of identical design to minimize costs) towards a post-perihelion encounter with Halley in March 1986. One spacecraft is targeted for a close flyby of the nucleus while the other traverses the tail region (see Figure 6). Simultaneous measurements in the coma and tail regions will provide valuable data on the large-scale features of Halley's comet. Following the Halley encounter, it is planned to use Earth-swingby maneuvers to retarget one spacecraft to comet Borrelly in January 1988, and the other to comet Tempel-2 in September 1988. The orbital parameters for comets Borrelly and Tempel-2 are given in Figure 7. Notice that viewing conditions from Earth are quite good for both comets during these apparitions.

Table 2

Dual-Spacecraft Multi-Comet Mission Summary*

Launch Date: August 25, 1985 Launch Vehicle: Shuttle with Interim Upper Stage Simultaneous Launch of Two Spacecraft Spacecraft #1: Targeted for Encounters with Comets Halley and Borrelly Spacecraft #2: Targeted for Encounters with Comets Halley and Tempel-2			
Encounter Date	Sun Distance (AU)	Earth Distance (AU)	Flyby Speed (km/sec)
Comet Halley March 28, 1986	1.13	0.59	58.4
Comet Borrelly January 16, 1988	1.40	0.70	17.7
Comet Tempel-2 September 22, 1988	1.39	0.99	13.2

*Parameters are shown for nominal launch date. Launch-window variations are given in Reference 6.

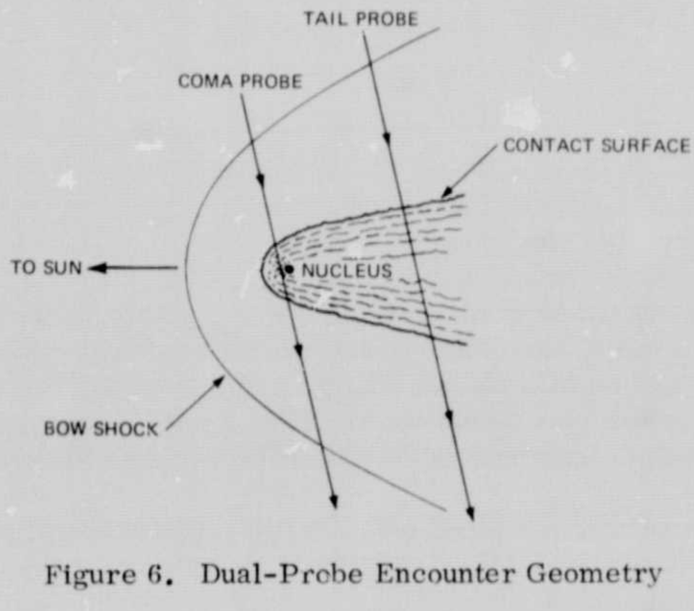

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Figure 6. Dual-Probe Encounter Geometry

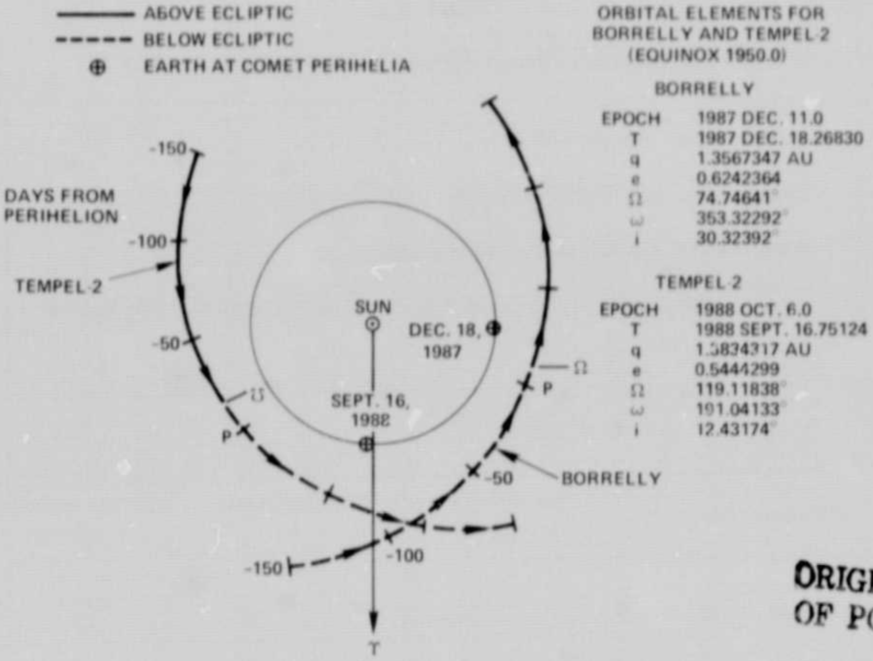

Figure 7. Orbits of Comets Borrelly and Tempel-2

A modification of this plan has been proposed by Biermann and Michel (Reference 7). Instead of launching both spacecraft on the Shuttle, they have suggested an independent launch with the Ariane rocket for the second spacecraft. In their proposal, the second spacecraft would be built by the European Space Agency (ESA). They envision a joint NASA/ESA Halley mission with NASA contributing the coma probe while ESA furnishes the tail probe.

ENCKE RENDEZVOUS

Existing spacecraft delivery systems do not possess the propulsive capability that is required for the Encke rendezvous mission. However, there are at least two ways to correct this shortcoming. One possibility would be to develop the long-awaited low-thrust propulsion system (solar-electric propulsion or "ion drive"). This system would have a large payload capacity, but its high development cost has continually postponed its anticipated readiness date. Another promising solution would be to assemble a large multiple-stage booster rocket in low Earth orbit. In this plan a dual Shuttle flight would be required to transport the booster components and the rendezvous spacecraft into the assembly orbit.

At this time, it is not obvious which one of these schemes might be used to carry out the Encke rendezvous mission. Therefore, mission profiles for both proposals are described.

Low-Thrust Propulsion Technique

Rendezvous missions to Encke's comet using low-thrust propulsion technology have been studied in great detail. A good account of a possible Encke mission is presented in Reference 8. For the purposes of this report, a brief summary of the mission schedule will suffice.

With the program constraint that at least two years should elapse after the Halley flyby before launching the rendezvous spacecraft, the earliest permissible launch date would not occur until March 1988. This is rather fortuitous however, because March 1988 happens to be the optimum launch period for a low-thrust trajectory that would rendezvous with Encke about 100 days before its 1990 perihelion passage. A plot of this trajectory is shown in Figure 8. The rendezvous will occur just about the time that significant cometary activity is beginning. As activity increases, it might be wise to keep a safe distance between the spacecraft and Encke's nuclear region until possible environmental hazards can be assessed. A more adventuresome exploration strategy could be employed during the next perihelion passage in 1994.

New design concepts for low-thrust propulsion systems utilize concentrating solar arrays to obtain greater propulsive energy (Reference 9). The concentrating solar array is just a flat array that has been surrounded by reflecting mirrors to increase the amount of solar radiation striking the cell blanket (see Figure 9). With this system, payload weights in excess of 1000 kg could be carried to Encke.

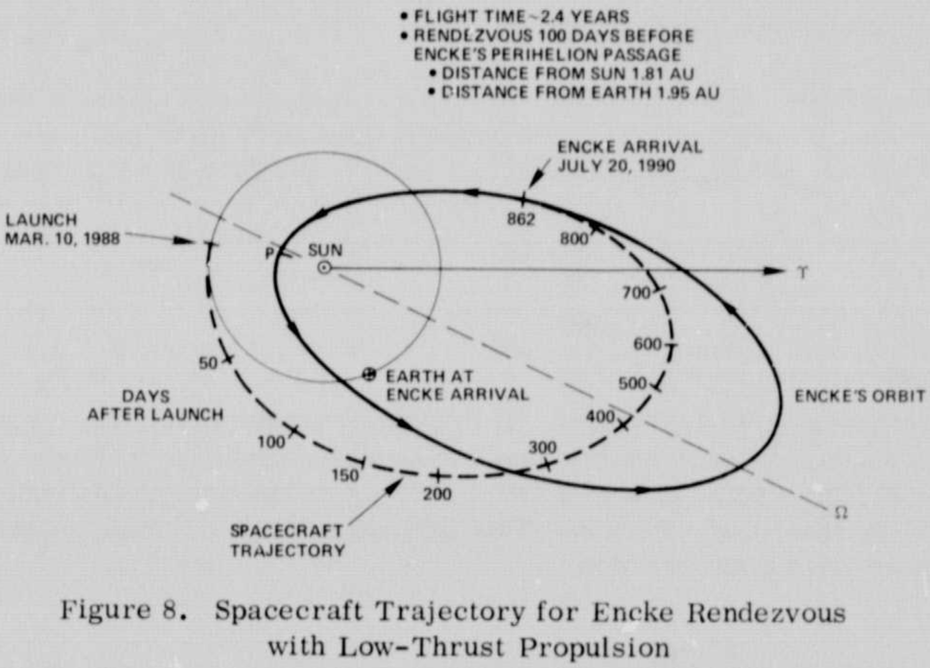

Figure 8. Spacecraft Trajectory for Encke Rendezvous with Low-Thrust Propulsion

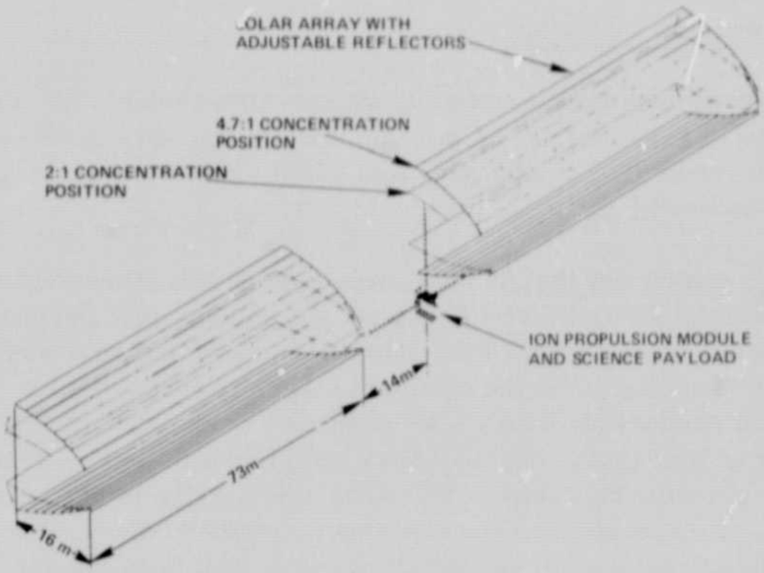

Figure 9. Ion-Drive System with Large Concentrating Solar Array (from Reference 9)

Ballistic Mission Mode with Dual Shuttle Launch

Encke rendezvous trajectories using a multi-impulse ballistic flight mode have been investigated by Hollenbeck and Van Pelt (Reference 10). They have found that the ballistic mode is particularly effective for aphelion-class missions. Energy requirements are about the same as perihelion-class missions, but flight times are reduced by more than a year.

The mission profile for the 1992 aphelion-class rendezvous is shown in Figure 10. Notice that Earth-based coverage of the rendezvous will be facilitated by Encke's near-opposition location. The heliocentric distance of ~4 AU will also be beneficial. Encke will be in a dormant state at this time, and it should be possible to examine the nucleus at close range without undue risk.

The ΔV requirement for the ballistic Encke rendezvous is quite high. The two primary spacecraft maneuvers will require a velocity increment of 4.3 km/sec. Adding 300 m/sec for midcourse corrections and trim maneuvers results in a total ΔV requirement of 4.6 km/sec. It is planned to accomplish these maneuvers with a two-stage propulsion module that uses space-storable propellants (References 11 and 12). Figure 11 shows that a 2900-kg propulsion module could deliver a 600-kg spacecraft to Encke. This payload capability should be adequate for the Encke rendezvous mission.

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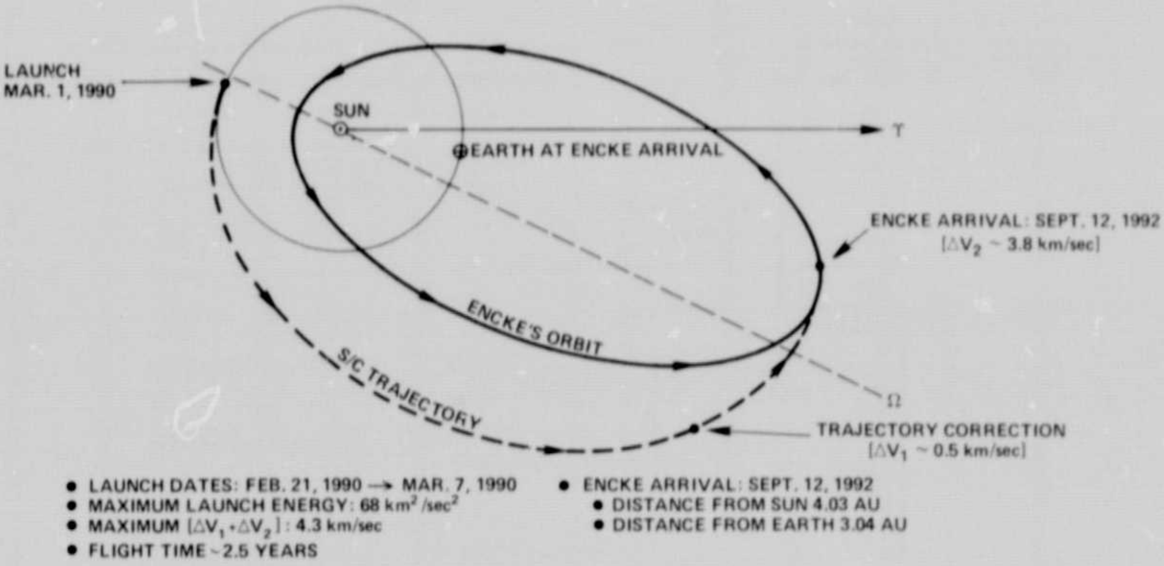

Figure 10. Mission Profile for Encke Rendezvous Using Multi-Impulse Ballistic Flight Mode (ΔV Requirements Taken from Reference 10)

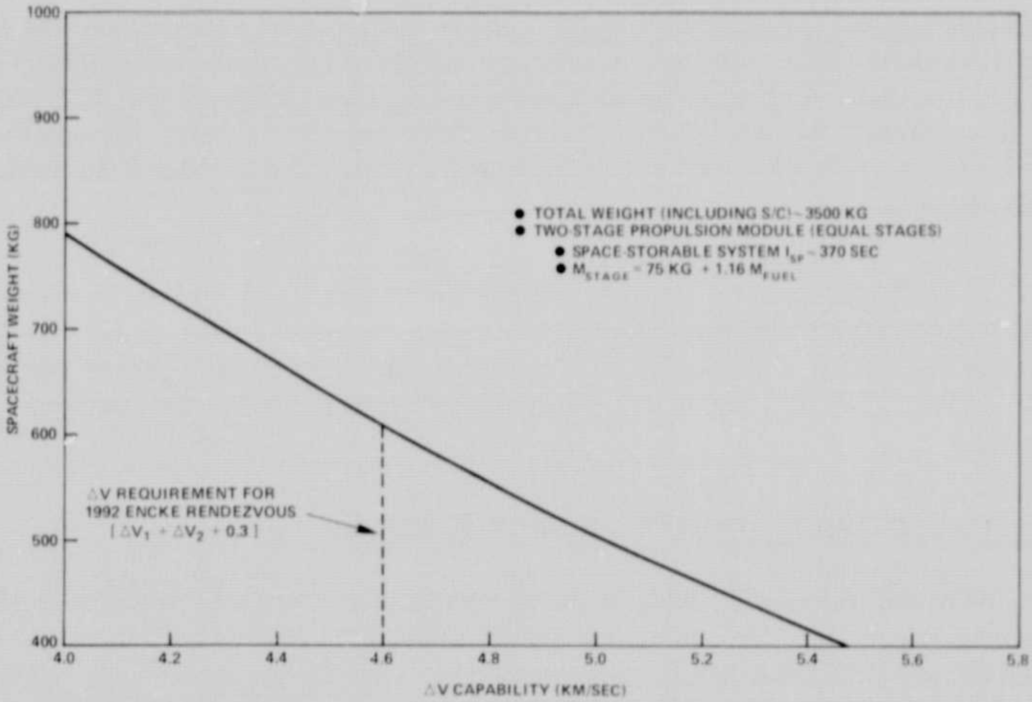

Figure 11. Performance for Spacecraft Propulsion Module

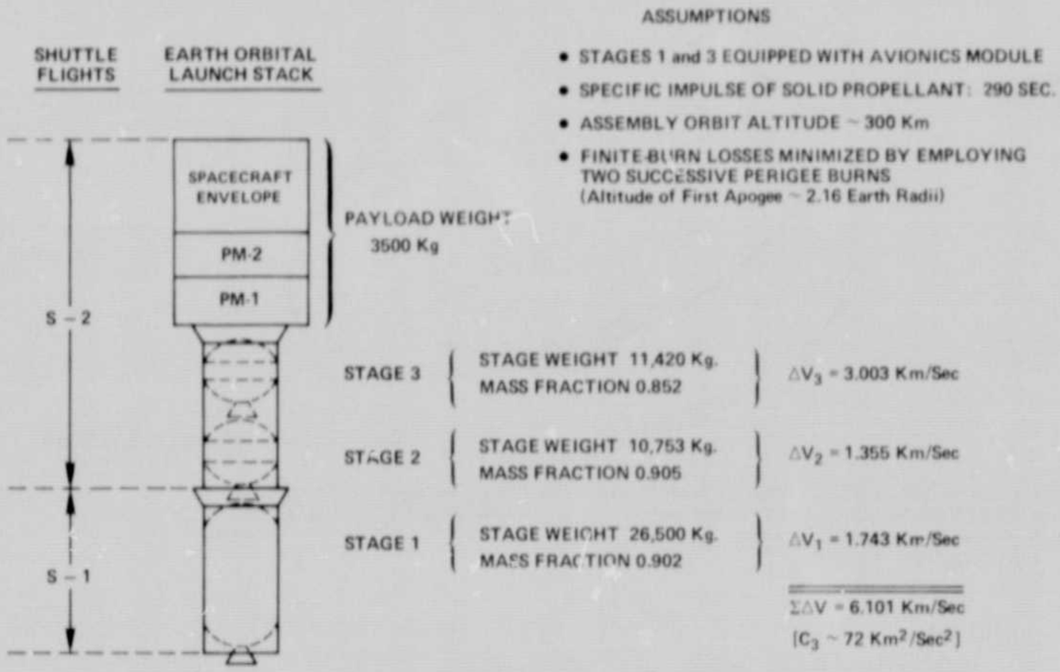

Figure 12. Performance Summary for Dual Shuttle Launch

The 3500-kg load (propulsion module + spacecraft) can be injected into the heliocentric transfer orbit with the three-stage solid-rocket combination that is depicted in Figure 12. The upper twin-stage configuration (stages 2 and 3) is identical to one version of the Interim Upper Stage (IUS) that will be ready for use in 1980. Stage 1 is just a larger solid motor incorporated with the standard IUS modular stage segments.

Two Shuttle flights will be needed to carry the launch stack into an Earth parking orbit where stage 1 will be mated to the larger component (twin-stage + payload). Appropriate weight allowances for IUS support frames, SC/IUS power supply, RTG coolant kits, etc. have been used in computing the Shuttle payload capacity.

FLIGHT SCHEDULE AND CONCLUDING REMARKS

The preferred mission strategy for a progressive and orderly study of comets is shown in Figure 13. This program should provide an understanding of comets and their physical behavior that is comparable to planetary knowledge. Some of the most noteworthy features of the recommended program are the following:

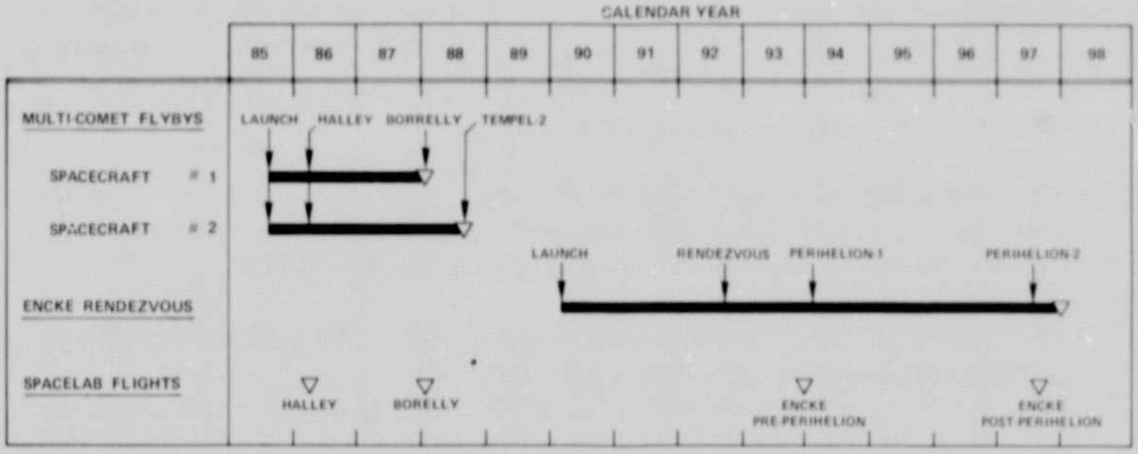

Figure 13. Flight Schedule for Cometary Exploration Program

- The Halley mission will give the cometary program an auspicious beginning. The dual-flyby plan will increase the science return from this mission and will also furnish some desirable redundancy.

- A cost-effective multi-comet mission profile is utilized for the flyby missions. With this technique, two spacecraft will be able to carry out four separate cometary intercepts in only three years.

- The mission set contains a good distribution of the various types of short-period comets. Halley and Encke are particularly significant because they represent radically different stages of cometary evolution. The dissimilarity in the physical characteristics of these two comets is quite striking.

- The Encke rendezvous is scheduled for September 1992. This date is well-timed for several reasons.* Because the launch date for the 1992 rendezvous will occur in 1990, there will be plenty of time available to design an optimal science payload for the rendezvous mission based on data obtained from the Halley, Borrelly, and possibly even the Tempel-2 encounters. In addition, extremely favorable viewing geometry will exist for Earth-based observations throughout Encke's 1994 apparition (see Figure 2).

*Non-technical factors should also be considered. The 500th aniversary of Columbus' discovery of the New World will occur in 1992, and an exploration of another "new world" would be a fitting way to commemorate this famous occasion.

- The Encke rendezvous will occur at a heliocentric distance of ~4 AU where Encke's physical activity will be virtually nonexistent. This will permit a close examination of Encke's nucleus for an extended period before the next perihelion passage.

- The 1992 aphelion-class Encke rendezvous mission could be accomplished with either a low-thrust propulsion system or a ballistic technique that exploits the large payload capacity of a dual Shuttle launch.

- An active cometary observational program will be an essential element of the total program. The flight schedule includes four sorties of the Spacelab cometary observatory. It is also anticipated that the cometary missions will stimulate a greater interest in cometary observations by ground-based observatories.

- The sequential mission strategy is fiscally attractive and provides good program continuity. Funding peaks are reduced considerably by the five-year spread between the primary launch dates.

Opportunities for international participation in a program of cometary exploration are numerous. Astronomers throughout the world, both amateur and professional, will be able to make important contributions to a coordinated program of ground-based observations. Multi-national space projects such as Spacelab and the Space Telescope will be major components of the observational program. A cooperative mission to Halley's comet might also be considered. It appears likely that a great many nations would be interested in an opportunity to participate directly in one of the most exciting space missions of this century.

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1. Report No. TM 78033	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Cometary Exploration in The Shuttle Era		5. Report Date January 1978
		6. Performing Organization Code 580
7. Author(s) R. W. Farquhar and W. H. Wooden, II		8. Performing Organization Report No.
9. Performing Organization Name and Address Goddard Space Flight Center Greenbelt, Maryland 20771		10. Work Unit No. 186-68-73
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Admin. Washington, D.C. 20546		13. Type of Report and Period Covered Technical Memorandum
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

A comprehensive program plan for cometary exploration in the 1980-2000 time frame is proposed. The proposal involves an observational program as well as a series of missions to comets. Plans for ground-based observations, a Spacelab cometary observatory, and the Space Telescope are included in the observational program. The cometary mission sequence begins with a dual-spacecraft flyby of Halley's comet. The nominal mission strategy calls for a simultaneous launch of two spacecraft towards an intercept with Halley in March 1986. After the Halley encounter, the spacecraft are retargeted: one to intercept comet Borrelly in January 1988 and the other to intercept comet Tempel-2 in September 1988. The additional cometary intercepts are accomplished by utilizing a novel Earth-swing-by technique. The next mission in the cometary program plan, a rendezvous with Encke's comet, is scheduled for launch in early 1990. It is planned to rendezvous with Encke in September 1992 at a heliocentric distance of ~4 AU. Following this near-aphelion rendezvous, the spacecraft will remain with Encke through the next two perihelion passages in February 1994 and May 1997. The rendezvous mission will be terminated about seven months after the second perihelion passage.

17. Key Words (Selected by Author(s)) Cometary exploration program Cometary science Halley's comet		18. Distribution Statement Unclassified — Unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 25	22. Price*

*For sale by the National Technical Information Service, Springfield, Virginia 22151.

GSFC 25-44 (10/77)