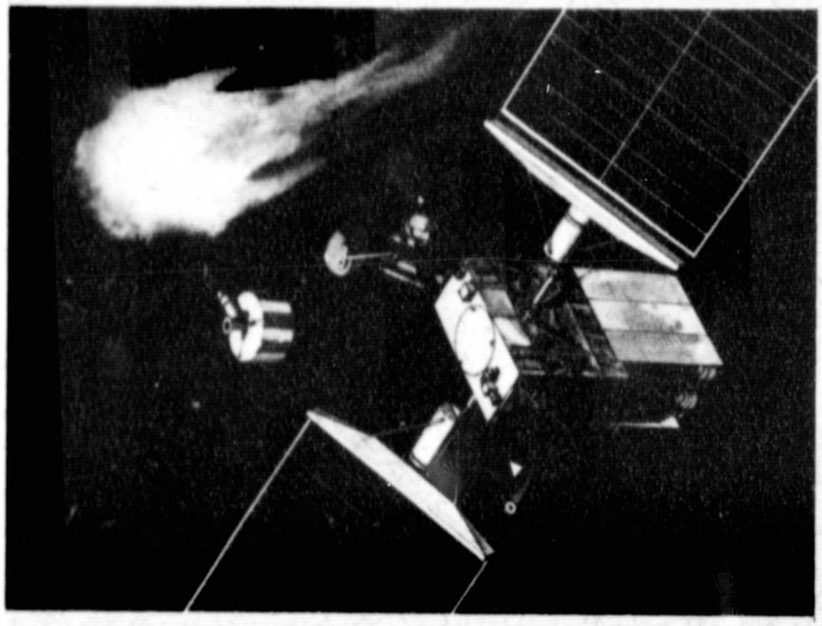
JPL PUBLICATION 79-4

Mission Summary

Halley Flyby/Tempel-2 Rendezvous



January 15, 1979

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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Foreword

This document provides an overview of a unique mid-1985 mission to investigate and compare two different comets during a single flight. The comets include Halley's comet, perhaps one of the most famous of celestial objects because of its spectacular 1910 appearance, and Tempel-2. The planned investigation would couple a high-speed flyby of Halley in 1985 with a long-term rendezvous at Tempel-2 in 1988. The spacecraft would be delivered to the comets by an advanced propulsion stage that would employ sunlight to power ion rocket engines (ion drive). This ion powered stage is being planned by NASA as a part of the Shuttle based transportation system. The dual comet mission is currently receiving significant attention in NASA planning.

Since the study must go through various stages in the planning process, the firmness and validity of the information must be taken in that context. The descriptions reflect our present best estimates of the mission's likely characteristics. The information comes from technical activities sponsored by NASA. Our objective has been to compile in brief form the main technical conclusions in order that these results may interact informationally with the broader questions of scope, pace and priorities in the Planetary Exploration Program as a whole.

Abstract

A unique dual-comet flight opportunity exists in mid-1985 which includes flyby of the large and active comet Halley en route to rendezvous with a second comet, Tempel-2. This mission will utilize ion propulsion at a modest performance level, based on proven technology. The Project is planned for a FY81 start. Launch occurs in July 1985 via the Shuttle/IUS twin stage. Following IUS injection, the ion propulsion stage provides continuous thrust virtually throughout the 3-year flight until the Tempel-2 rendezvous in 1988. En route, a probe is deployed for encounter with Halley about 4 months after launch at a point 73 days before its perihelion. Rendezvous with Tempel-2 occurs about 60 days before the comet's perihelion during the summer of 1988 and continues for about 1 year. Earth will be in favorable relative positions for observing both the flyby and the rendezvous.

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I. Executive Summary

A. Target Descriptions

1. Flyby/Probe:

Comet Halley

Perihelion date:	9 February 1986
Perihelion distance:	0.59 AU
Period:	76 yr
Inclination:	162 deg to ecliptic plane

2. Rendezvous:

Comet Tempel-2

Perihelion date:	17 September 1988
Perihelion distance:	1.38 AU
Period:	5.3 yr
Inclination:	12 deg to ecliptic plane

B. Key Parameters

Launch Date:	July 1985
Launch Vehicle:	Shuttle/Twin Stage IUS
Halley Flyby:	Nov 1985
Time from perihelion:	73 days before
Solar range:	1.5 AU
Relative encounter speed:	57 km/s
Tempel-2 Rendezvous:	July 1988
Time from perihelion:	60 days before
Solar range:	1.5 AU
End of Nominal Mission:	July 1989
Time from perihelion:	10 months after
Time from launch:	4 yr

C. Objectives

Mission objectives are to determine the physical and chemical characteristics of cometary nuclei and to study the total of cometary phenomena through comparative studies of comets Halley and Tempel-2. Investigations will emphasize

(a) analyses of solids and gases making up the comets, physical state of the nucleus, (b) attempts to determine the mass of the nucleus, and (c) studies of the interactions with the solar wind.

D. Typical Science Investigations

Imaging.

Neutral and Ion Mass Spectrometry.

Plasma Fields and Particles.

Dust Analysis.

Radiometry and Nucleus Sounding.

Particle Counting.

X-ray or γ-ray Fluorescence.

Optical Spectrometry.

E. Brief Mission Description

Using ion propulsion, the rendezvous spacecraft will pass close to the orbit of comet Halley late in 1985 and dispatch a probe to interact directly with Halley's inner coma. The rendezvous spacecraft will then continue, still under ion propulsion, to achieve its rendezvous with Tempel-2 in 1988, and stay with Tempel-2 making measurements throughout perihelion passage. The Tempel-2 rendezvous trajectory is planned such that the en-route Halley intercept occurs at about 1.5 AU from the sun at a point where Halley's activity is beginning to increase as it nears the sun. An ion propulsion stage is used to achieve the trajectory shown in Figure 1 and it requires a solar power array generating 25 to 30 kW of electric power to operate the 6 to 8 ion rocket engines.

F. Program and Technology Status Overview

Preliminary mission and spacecraft design is in progress. Ion propulsion technology development is continuing with engine

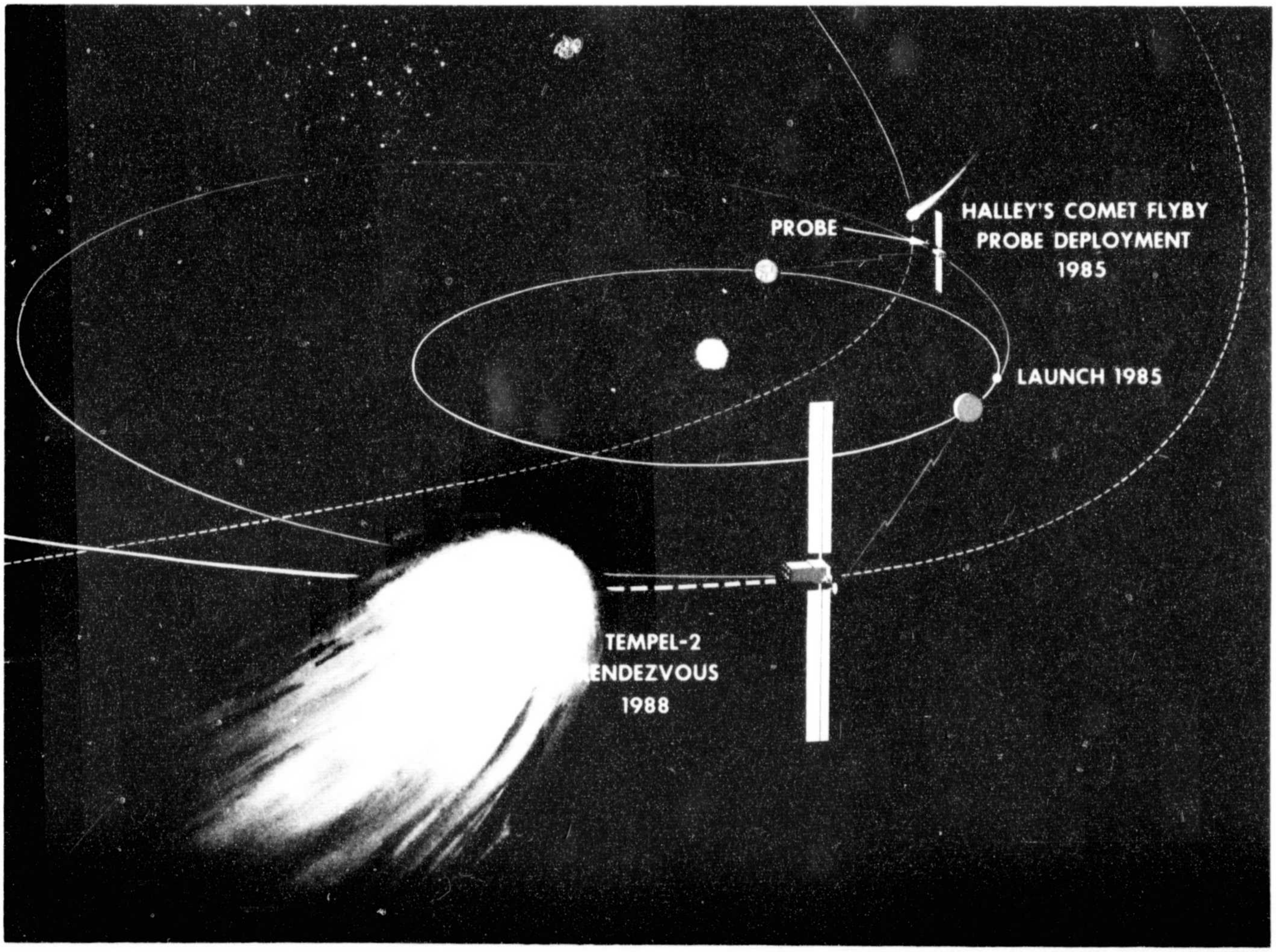

Fig. 1. Tempel-2 Rendezvous with Halley Probe

tests completed in space (SERT II) and over 10,000 hr of continuous operation on ground. A cutaway view of one of the ion rocket engines that will be used for the stage is shown in Figure 2. This engine operates by electrically charging a dense vapor such as mercury or argon and using an electric field to accelerate the vapor to very high exhaust velocities. While the thrust is not high, a few hundredths of a pound compared with thousands of pounds for medium-sized chemical rockets, the ion rocket has the great advantage of going for a long time with little on-board propellant. Rocket engineers term the measure of this fuel efficiency "specific impulse", and for an ion engine it can be ten to a hundred times greater than for a chemical rocket. A further advantage, without which the mission would be impossible, is that the energy for the propellant comes from the Sun, rather than being carried internally as in a combustible fuel.

Each ion engine is about 30 cm in diameter and about 13 cm deep, resembling an oversized coffee can. As depicted in the cutaway, the fuel is vaporized by heating and is fed into the reaction chamber. Electrons are then fired into the vapor from the cathode assembly. The electrons give the fuel atoms a charge, converting them into ions, and the ions are attracted towards two screens at one end of the chamber. One screen is grounded, the other charged up to 1000 volts, and this electric field accelerates the ions to exhaust speeds of 30 km/s. Preliminary propulsion system testing will continue in FY1979 and 1980.

The technology for producing the solar electric power for the ion propulsion stage has also received considerable development effort. Synergism with attempts to alleviate Earth's "energy problem" have produced large lightweight solar array panels capable of generating multi-kilowatts of electric power. Prototype space power arrays using highly efficient solar cells have already been constructed. These arrays fold in accordion fashion for stowage during launch aboard the Shuttle and have deployed dimensions of 4 meters by 35 meters. Two of these "wings" will generate the nearly 30 kW required to operate the ion stage. Currently, a space test of a single wing is planned for 1981 aboard the Shuttle.

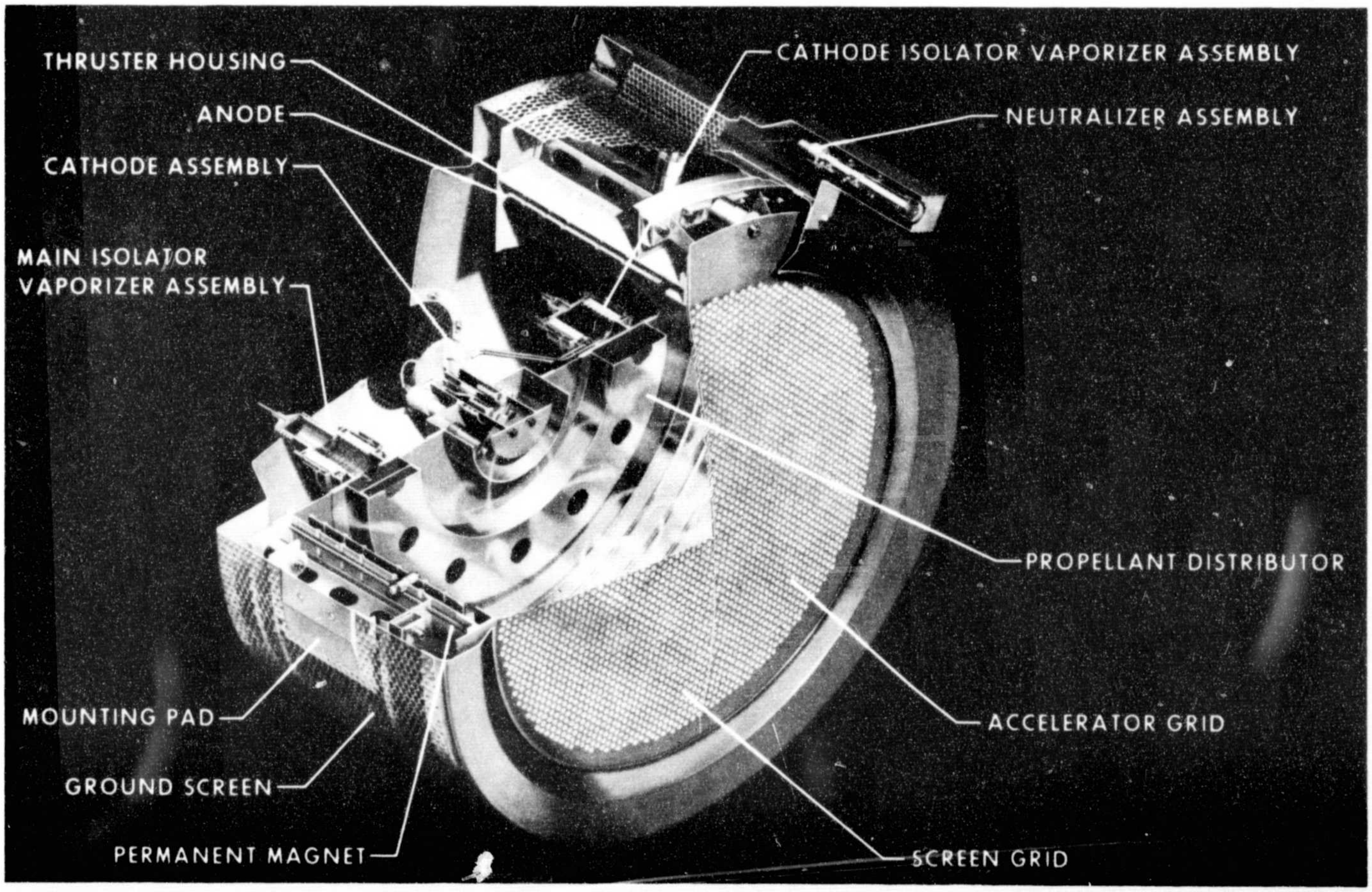

Fig. 2. Cutaway View of Ion Drive Rocket Engine

In addition to these technology developments, a consolidated plan has been prepared to advance the science instrument technology for the planned investigations of the comets. Research programs in gas and dust collection and analysis and high-speed mass spectrometry are receiving increased emphasis. Improvements in all instrument areas that may be needed in the comet investigations are being brought into focus.

II. Expanded Description

A. Science Rationale

Missions to the comets in the solar system will contribute to the understanding of their role in the formation and evolution of the solar system and of the general laws of fragmentation and accretion. Comets, while offering a chance to study what is possibly primordial matter in a relatively undisturbed state, may provide the only way to learn of the early stages of the formation of larger celestial bodies in the solar system. Our ignorance of the accuracy of the various theories of cometary origin, composition, and behavior will remain until automated spacecraft encounter and explore such a body.

Typical of the questions pertaining to cometary phenomena are:

What is the origin of comets? Are they captured interstellar matter or relatively unmodified samples of the primitive solar nebula?

What is their makeup or nature? Do they have a coherent, solid nucleus? What are the physical and chemical characteristics of the solid matter? Is the icy conglomerate model correct?

Are comets all very similar or are there fundamental variations from comet to comet? What is the comparative relationship between them?

What are the parent volatiles in the nucleus? By what process are they dissociated and ionized in the cometary "atmosphere"?

What is the nature of the comet/solar-wind interaction? Is there a bow shock and/or contact surface? Do magnetic fields control the configuration of filaments or streamers within the ion tail? How are the ions created? How are they accelerated?

What are the composition, size, and velocity distribution of emitted solid particles? Are the solid particles charged? Do electromagnetic forces play any role in the behavior of dust tails?

What are the variations of the significant phenomena with heliocentric distance and as a comet evolves?

What becomes of "burned out" comets? Are they completely disrupted into the debris we know as meteor streams, or is there a significant nuclear remnant, perhaps what we see as Apollo and Amor asteroids?

B. The Opportunity

A unique dual-comet flight opportunity exists in mid-1985 to permit the pursuit of these questions concerning cometary phenomena. A virtual once-in-a-lifetime appearance of the famous comet named for Sir Edmund Halley will occur in December 1985 through February of 1986. Halley's comet last appeared in 1910. It attracted a significant amount of attention then. Even though its 1985 appearance will not be as spectacular as its 1910 appearance, Halley's 76-year period gives it a once-in-a-lifetime connotation for most persons now alive. After the 1985 appearance, Halley's comet will not return again until 2061.

Because of its high level of activity as it nears the Sun along with its large size and relatively young age, Halley's comet holds an important position as a target for scientific investigation. All of the science working groups that have been empanelled by NASA to examine the possibility of comet exploration have agreed that Halley's comet displays the widest range of phenomena of interest. The ideal mission would be to investigate it from a spacecraft in a rendezvous mode for extended periods of time. However, because of national fiscal priorities in FY78-79, a flight program that would have achieved a rendezvous with Halley's comet during the 1985-86 appearance was not possible. This leaves the option of a very fast (57 km/s) probe intercept and flyby (Fig. 3) as the only remaining alternative to get any sort of investigation of Halley's comet. And to achieve this goal, a program leading to a launch in July 1985 is required.

Fortunately, a trajectory capability exists (through the use of ion propulsion) to combine the rather brief Halley encounter (or flyby) opportunity with a longer term rendezvous investigation of a second, less well-known comet, Tempel-2 (Fig. 1). Tempel-2 is a smaller, less-active comet, not quite as young as Halley's comet, that returns every 5.3 years. Its return in 1988 places it in a favorable geometric position for an ion-propelled vehicle to pass close to Halley, close enough to drop a small probe into it while en route to Tempel-2 where a full-fledged rendezvous can be effected.

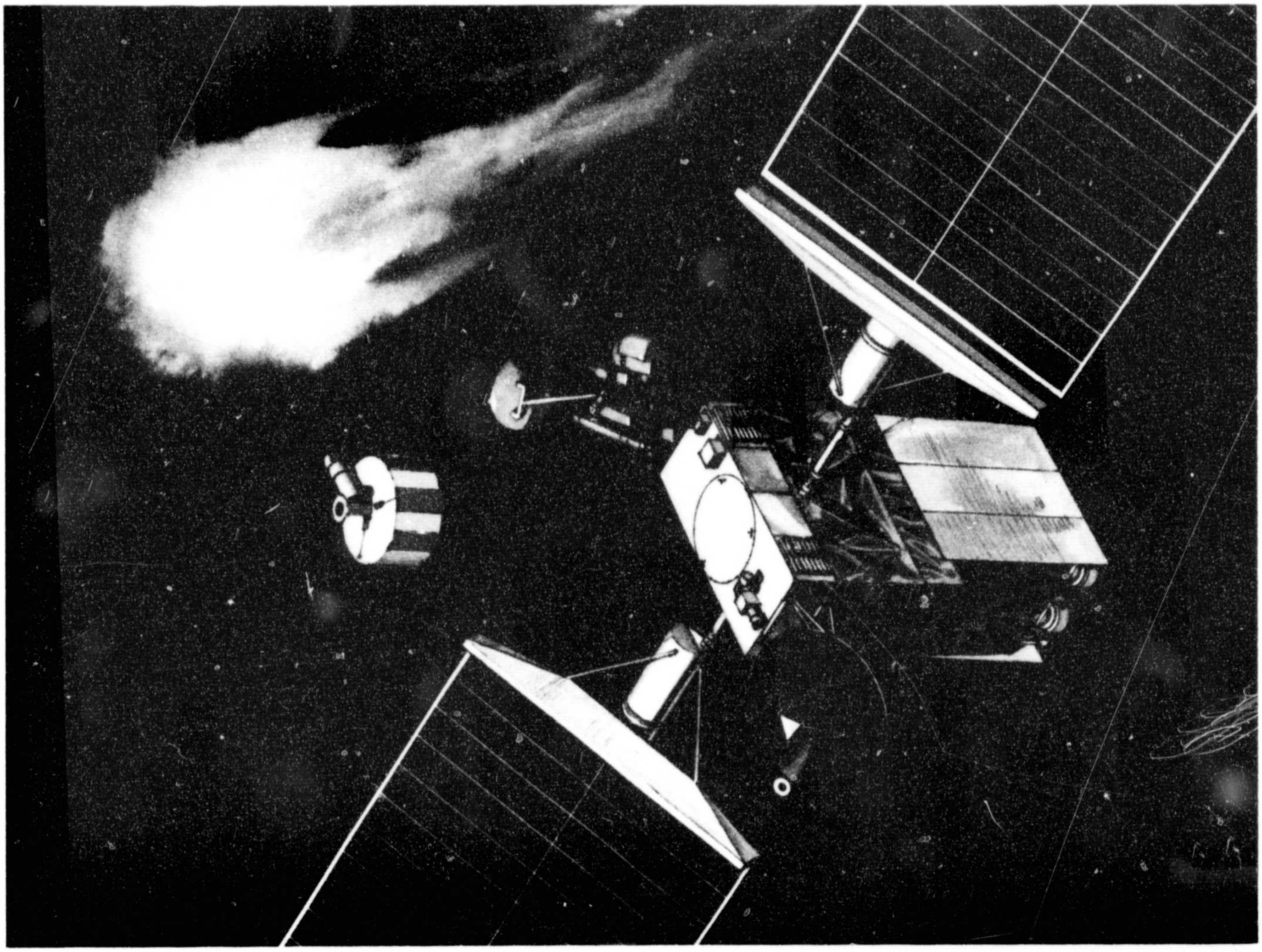

Fig. 3. Probe Deployment at Halley's Comet

The result is a unique opportunity to investigate and compare two distinctly different comets from a single launch. And Halley's comet can still be included as one of the targets. The goals lost by the inability to gain approval for a rendezvous with Halley's comet can be largely recovered with this two-for-one opportunity that retains a significant subset of the originally planned Halley investigation and adds the rendezvous at Tempel-2. This two-for-one opportunity is certain to maximize the science return for dollars expended.

C. Example Payloads

The flyby portion at Halley's comet would be devoted to a study of cometary/solar-wind interactions and to a quantitative assessment of the basic environment, including such factors as the size and general character of the nucleus, the density and size distribution of emitted solids, and the composition and distribution of coma gases.

The rendezvous portion at Tempel-2 will be devoted to a detailed study of the nucleus. The objectives of the detailed study of the nucleus and its near environment are:

(1) To provide visual and thermal mapping of the nucleus.

(2) To analyze gases and solids flowing from the nucleus.

(3) To identify dominant ionization processes occurring near the nucleus.

(4) To identify global and surface properties of the nucleus.

(5) To investigate temporal and solar-distance variations of cometary processes.

Example payloads for the Halley probe and Tempel-2 encounter include the following:

1. Halley probe payload

(1) Neutral mass spectrometer.

(2) Ion mass spectrometer.

(3) Proton/electron energy analyzer.

(4) Magnetometer.

(5) Plasma wave analyzer.

(6) Dust impact counter and analyzer.

(7) Imaging (under study).

2. Tempel-2 rendezvous payload

(1) Neutral mass spectrometer.

(2) Thermal ion mass spectrometer.

(3) Solar wind/electron analyzer.

(4) Magnetometer.

(5) Imaging.

(6) Collected dust analyzer(s).

(7) Dust counter.

(8) Radiometer.

(9) X-RF (or γR) spectrometer.

(10) Optical spectrometer.

3. Other 'prime' instruments for rendezvous

(1) Radio sounder.

(2) Plasma wave spectrometer.

D. Mission Description

A unique trajectory opportunity exists which includes flyby of the comet Halley en route to rendezvous with Tempel-2. This mission is available only through the utilization of ion propulsion. Selection of Tempel-2 as the rendezvous target results in the shortest mission, the lowest ion drive performance requirements, and the least difficult flight system design requirements. The mission requires launch in the summer of 1985.

The Halley Flyby/Tempel-2 rendezvous trajectory is illustrated in Figure 1. Launch occurs in July 1985 via the Shuttle/IUS twin stage. Figure 4 presents a series of scenes that depict deployment of the ion drive spacecraft from the Shuttle as follows:

(1) Shuttle drops off ion-rocket stowed atop chemical rocket booster.

(2) "Solid" rocket booster blasts ion spacecraft out of low Earth orbit and escapes Earth.

(3) Ion rocket separates from burned out final stage of solid rocket.

(4) Ion rocket deploys solar array wings to begin producing electricity.

(5) Ion engines ignite to begin rendezvous trajectory.

The ion propulsion stage provides continuous thrust virtually throughout the 3-yr flight from IUS injection until rendezvous.

About 4 months after launch, Halley is encountered as it approaches perihelion. The relative encounter speed between spacecraft and comet is 57 km/s. As shown in Figure 1, the Earth is in favorable position at the time of Halley encounter.

Rendezvous with Tempel-2 takes place during the summer of 1988. At the time of rendezvous, Tempel-2 is about 60 days prior to perihelion and the solar range is about 1.5 AU. The Earth is also in good relative position at the time of rendezvous. A summary of mission trajectory data is provided in Table 1. The nominal mission is assumed to extend about 1 year after rendezvous to allow scientific exploration during the comet's most active period around perihelion.

E. Halley/Tempel-2 Flight System Description

The Flight System shown in Figure 3 is composed of a rendezvous spacecraft, an ion propulsion stage, and a Halley atmosphere probe. The flight system is three-axis stabilized and carries science instruments, needed to achieve the science and mission objectives. The ion propulsion stage is composed of a thrust assembly and the solar array which, in addition to supplying power to the spacecraft and probe, also provides power for low thrust propulsion. The atmosphere probe is designed to transport a complement of science instruments into the atmosphere near the nucleus of Halley's comet and transmit acquired data to the parent spacecraft in real time for relay playback to Earth.

The Flight System mass summary is given in Table 2.

Table 1. Mission/Trajectory Characteristics Summary

Launch	
Date	8/1/85
C_3, km^2/s^2	35 max
Halley Flyby	
Date	11/28/85
Mission Time	120 d
Time from Perihelion	-73 d
Solar Range	1.5 AU
Tempel-2 Rendezvous	
Date	7/18/88
Mission Time	1080 d
Time from Perihelion	-60 d
Solar Range	1.5 AU
End of Nominal Mission	
Date	7/14/89
Mission Time	1400 d
Time from Perihelion	+300 d
Solar Range	3.0 AU
System Solar Range Required	
Transit Min/Max	1.0/3.1 AU
Comet Perihelion	1.4 AU

Table 2. Flight System Mass Summary

Rendezvous Spacecraft (including contingency)	575 kg
Halley Probe	200 kg
Solar-electric propulsion stage	1400 kg
Total Flight System Mass (without propellant)	2175 kg

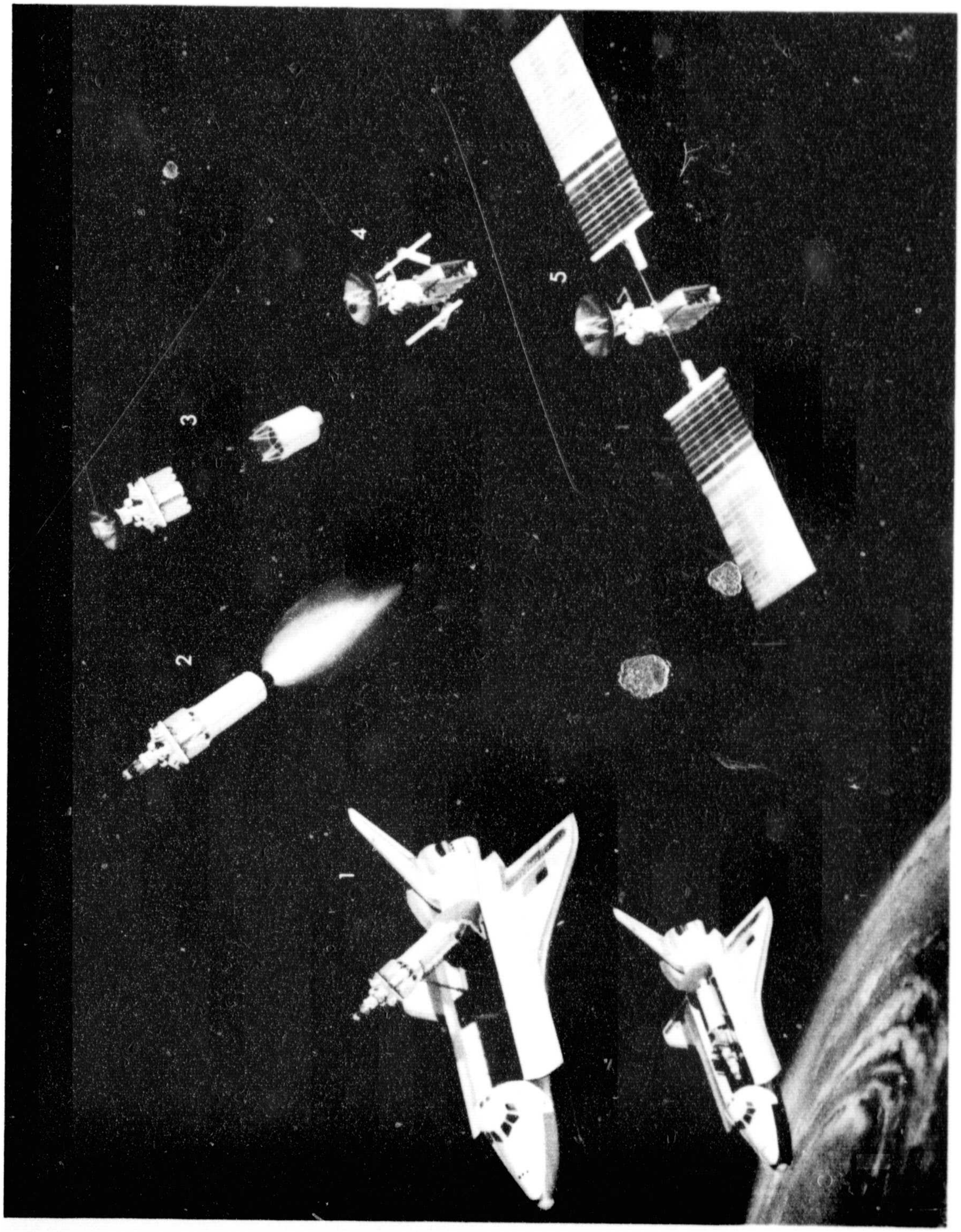

Fig. 4. Deployment Sequence of Ion Drive Spacecraft from Shuttle

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