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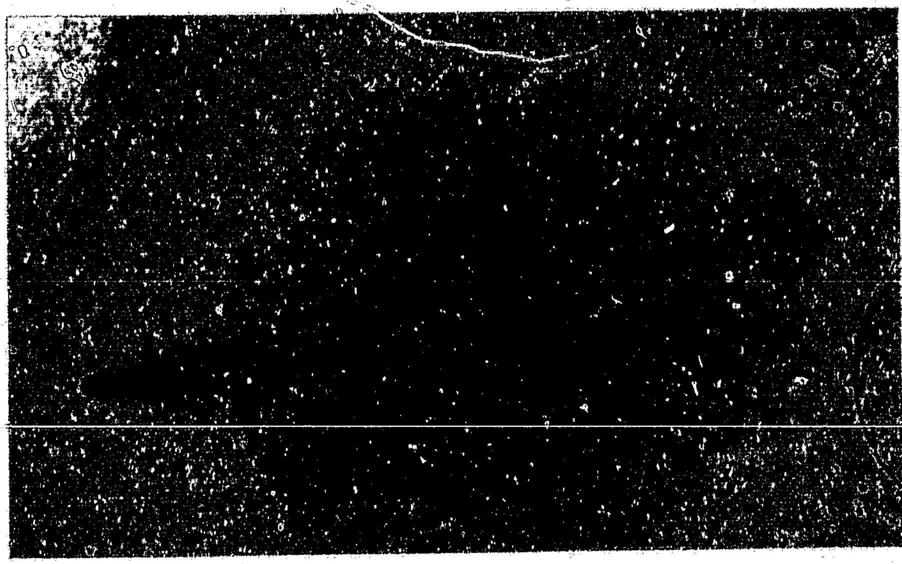
# NASA Technical Memorandum 82386

# COMET SCIENCE WORKING GROUP REPORT ON THE HALLEY INTERCEPT MISSION





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COMET SCIENCE WORKING GROUP REPORT ON

THE HALLEY INTERCEPT MISSION


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## I. SUMMARY AND MAJOR RECOMMENDATIONS

During the past two years, the Comet Science Working Group (CSWG) has developed a comprehensive program for the initial exploration of comets (Report of the Comet Science Working Group, 1979, NASA TM 80543) which consists of two major elements:

(1) A rendezvous with the nucleus of a short-period comet.

(2) A direct investigation of a bright active comet which displays the full complement of cometary phenomena.

The CSWG has emphasized that Halley's return in 1986 will provide our only opportunity to carry out the second of these two key elements until Halley's subsequent return in 2061.

The CSWG once again calls attention to the uniqueness of the Halley 1986 opportunity, and concludes that of various realizable proposals to study Halley in 1986, only the Halley Intercept Mission detailed in this report will adequately address those science objectives of the NASA comet program dealing with active comets. Therefore the CSWG urges NASA to concentrate its efforts on implementing the Halley Intercept Mission.

In view of the scientific benefits that will accrue from coordinating all observations of Halley in 1986 — space probe, Earth-orbit, and telescope — the CSWG strongly endorses the International Halley Watch Program.

With the implementation of the Halley Intercept Mission, one of the two major elements of the NASA comet exploration program will have been addressed. To address the other key element — the rendezvous with the nucleus of a short-period comet — will require the development of the Solar Electric Propulsion System (SEPS). We urge NASA to expedite the development of this urgently needed propulsion system and to continue supporting the development of essential instruments for a rendezvous mission to a comet.

## II. INTRODUCTION

Comets are not all alike; they represent a diverse population, ranging from spectacular, pristine objects on their first passage through the inner solar system to old, volatile-depleted remnants approaching the end of their active lives. The comet exploration objectives developed by past advisory groups have mandated that an effort be made to sample the diversity of the population of comets. At the low activity end of the spectrum, there are a number of short-period comets that are relatively accessible for either flyby or rendezvous missions, but among the bright active comets only one — Comet Halley — provides a suitable mission target in this century.

In 1979, NASA's Comet Science Working Group recommended that NASA's comet exploration program should consist of two essential elements: (1) a rendezvous with the nucleus of a short-period comet, and (2) a flyby of an active comet which displays the full range of cometary phenomena. The CSWG and other advisory bodies (including the Space Science Board) strongly endorsed the Halley Flyby/ Tempel 2 Rendezvous Mission, a single mission which would have addressed both essential elements of the comet exploration program. The implementation of this mission required more resources for the development of the Solar Electric Propulsion System than are likely to be appropriated in FY 81. Consequently, the two elements of the comet exploration program will now have to be carried out in two separate missions. As far as the rendezvous part of the program is concerned, we have to await the development of SEPS. Once that indispensable system is available, we can effect a rendezvous with the nucleus of a short-period comet within almost any chosen five-year interval. Fortunately, there are several possible targets and all the periods involved are short.

As far as the second key element of the comet exploration program is concerned, the situation is very different. If we are to study the unique atmospheric and tail phenomena of a bright active comet, we must go to Halley, and we must go in 1985-1986.

## III. THE UNIQUENESS OF HALLEY

Halley is the only large, active comet whose orbit is predictable enough to be investigated by spacecraft (Report of the Comet Halley Science Working Group, 1977, NASA TM-78420). Its youth argues for a relatively pristine composition, representative of the material from which the solar system formed. Its level of production of gas and dust is orders of magnitude greater than for the faint short-period comets that offer alternative mission possibilities. As a result of its high rate of outgassing, Halley displays the large coma and long, active tails that are the characteristics of fresh comets. Among all of the comets with well-determined orbits, only Halley looks and acts like the pristine long-period comets that are, unfortunately, beyond the range of spacecraft investigation. Therefore, the 1985-1986 apparition of Halley provides us the one opportunity of our lifetimes to carry out direct studies of an important class of solar system objects. Comet Halley offers the only chance to obtain the data on highly active comets that will be needed for a later comparison with results from rendezvous missions to more evolved short-period comets.

## IV. THE VALUE OF A MISSION TO HALLEY

Recently, the Comet Science Working Group held two meetings at which the science objectives of a mission to Halley and the best way of achieving these objectives were discussed. The group concluded that a scientifically productive mission to Halley which addresses those goals of the NASA comet program dealing with active comets is technically feasible. It was also noted that during a dedicated mission to Halley a more comprehensive investigation of the comet is possible than was the case for the Halley phase of the previously recommended Halley Flyby/Tempel 2 Rendezvous (HFB/T2R) Mission; in that latter mission some of the elements of the study of Halley were sacrificed to optimize the rendezvous at Tempel 2. Among the obvious advantages of a dedicated mission is the flexibility of arrival time at Halley. Rather than being constrained to the HFB/T2R's 1.53 AU preperihelion flyby, the encounter can now occur either preperihelion or postperihelion near 1 AU when the comet is much more active. Second, a better science payload than that proposed for the original Halley probe is possible — with more payload mass, power, data rate and sophistication.

The CSWG reaffirms its view that a valuable scientific investigation of Halley during a flyby is possible.

## V. MISSION CONCEPTS: GENERAL CONSIDERATIONS

Any mission to Halley should be designed to maximize the science return in terms of the objectives of the comet exploration program set down by the CSWG and the Space Science Board (Report of the Comet Science Working Group, NASA TM 80543, 1979; Strategy for the Exploration of Primitive Solar System Bodies — Asteroids, Comets, and Meteoroids: 1980-1990, Committee on Planetary and Lunar Exploration, Space Science Board, Washington, DC, 1980). In order of priority these objectives are:

(1) To determine the chemical nature and physical structure of comet nuclei, and to characterize the changes that occur as functions of time and orbital position.

(2) To characterize the chemical and physical nature of the atmospheres and ionospheres of comets as well as the processes that occur in them, and to characterize the development of the atmospheres and ionospheres as functions of time and orbital position.

(3) To determine the nature of comet tails and of the processes by which they are formed, and to characterize the interaction of comets with the solar wind.

In the particular context of a flythrough of Halley, these can be recast as follows:

(1) Determine the appearance of the nucleus of Comet Halley to infer:

 (a) Size and shape

 (b) Structure

 (c) Heterogeneity

(2) Determine the chemical composition and physical state of both the volatile and nonvolatile material emitted by Comet Halley.

(3) Characterize the processes which occur in bright, active comets (Halley and new comets), including:

(a) Chemical, physical, and plasma processes in the atmosphere and ionosphere

(b) Dynamics of dust and ice grains

(c) Interaction between the solar wind and the coma

(d) Structure and dynamics of the tails

These aims lead us to emphasize a number of practical requirements on any mission to Halley:

(1) Accurate targeting of the spacecraft to a preselected point within the zone of parent molecules next to the nucleus

(2) Good imaging of the nucleus

(3) An "observatory phase" during which imaging of the tail and coma at progressively increasing spatial resolutions will be obtained

(4) Sufficiently long observation time for *in situ* measurements to cover the full $10^7$ km scale of phenomena at Halley

Some of these requirements are self-explanatory. The first is imposed by the objectives of at least three essential instruments: mass spectrometer, dust analyzer, and imaging.

The observatory phase is crucial if we are to tie our past telescopic knowledge of comets to the new revelations concerning the inner coma and nucleus that this mission will produce. The observatory phase will also provide new major information concerning coma and tail phenomena. The imaging experiment should provide mankind's first visual exploration of what an active comet is like.

Of the technically realizable mission concepts that have been proposed for the investigation of Halley, the outstanding one is the Halley Intercept Mission. For reasons outlined in the following sections, the CSWG has concluded that the Halley Intercept Mission concept represents the only adequate science response to the Halley opportunity. Therefore, the CSWG recommends that NASA concentrate its efforts on making sure that the Halley Intercept Mission becomes a reality.

This recommendation is made in full cognizance of other announced efforts to study Halley at its 1985-1986 return. In early July 1980, the European Space Agency (ESA) announced its intention to carry out a spacecraft exploration of Halley. This mission, called Giotto, will involve a spinning spacecraft and approximately 60 kg of scientific instruments. There are also reports that Halley will be studied from space by Japanese and Soviet/French spacecraft. It is known that the Japanese probe will not intercept the comet directly. It is possible that the two Soviet/French probes will not enter the inner coma since the spacecraft apparently will not have dust shields. Thus, it appears that only ESA's Giotto and the NASA Halley Intercept Mission can explore the inner coma and the nucleus, and only the Halley Intercept Mission meets the four essential requirements listed above.

## VI. THE HALLEY INTERCEPT MISSION

The Halley Intercept Mission is based on a 3-axis-stabilized spacecraft. This allows significantly better imaging than can be achieved with most spinning spacecraft. A framing camera on a fixed-attitude spacecraft is the best means of achieving an observatory phase during which sequences of pictures are taken of the comet's tails and extended coma. Furthermore, with a framing camera, onboard optical navigation can deliver the spacecraft to the selected point in the target plane with an accuracy of ±90 km (1 $\sigma$); the most optimistic estimate of delivery accuracy without onboard navigation is ±500 km (Giotto). With optical navigation, it is thus possible to make sure the spacecraft passes through the zone of parent molecules which extends $\sim 10^3$ km from the nucleus, on the sunlit side, at a great enough distance to avoid smear in the highest resolution pictures.

The Halley Intercept spacecraft (Figure 1) has a total mass of $\sim$1600 kg, of which 300-400 kg will be allotted to the dust shield, and $\sim$125 kg to the science payload. A possible science payload is summarized in Table 1.

Table 1. Halley Intercept Mission

Typical Payload

| Instrument | Mass, kg | Power, W | Data, kbps |
|---|---|---|---|
| Neutral Mass Spectrometer | 6 | 5 | 2 |
| Ion Mass/Velocity Spectrometer | 7 | 11 | 3 |
| Electron Analyzer | 4 | 3 | 2 |
| Magnetometer | 3 | 5 | 1 |
| Plasma Wave Analyzer | 4 | 7 | 1 |
| Dust Composition Analyzer | 11 | 12 | 3 |
| Dust Counter | 3 | 3 | 1 |
| Remote Sensor | 12 | 8 | 2 |
| Subtotal | 50 | 54 | 15 |
| Imaging | 76 | 38 | 90 |
| Total | 126 | 92 | 105 |

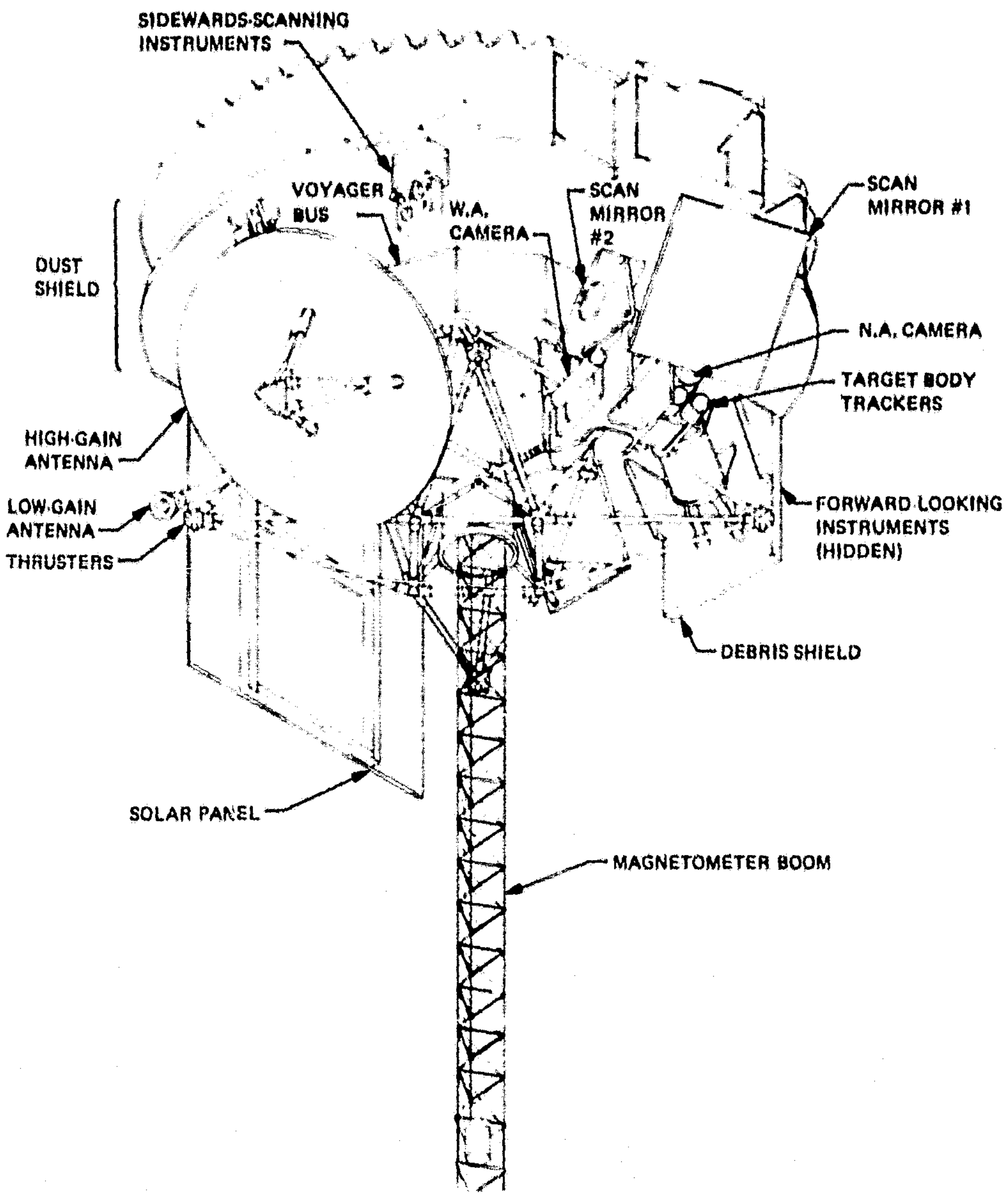


Figure 1. The Halley Intercept Mission Spacecraft.

Halley goes through perihelion (0.6 AU) on February 9, 1986. A major advantage of the Halley Intercept Mission is that it can intercept the comet either before or after perihelion. Several trajectory options are summarized in Table 2 and in Figures 2 and 3. While the CSWG did discuss the relative merits of pre- and postperihelion encounters, the conclusion was that the flexibility of adopting either option should be kept open at the present time. A final decision should be made only after the science payload selection is made, and in full cognizance of other efforts to explore Halley in 1985-1986.

As an example of a typical encounter, we can consider one associated with a launch (using the Shuttle/Twin Stage IUS combination) in July 1985 and an intercept occurring in March 1986, about one month after perihelion. At that time the comet would be 1.1 AU from the Sun, and 0.65 AU from Earth. The relative encounter velocity would be about 60 km/s. Imaging of the comet would begin about two months before encounter (one month before Halley perihelion), and would continue for about one month after closest approach. Optical navigation would be used to guide the spacecraft to within $10^3$ km of the nucleus. The last trajectory correction would occur about one day before closest approach.

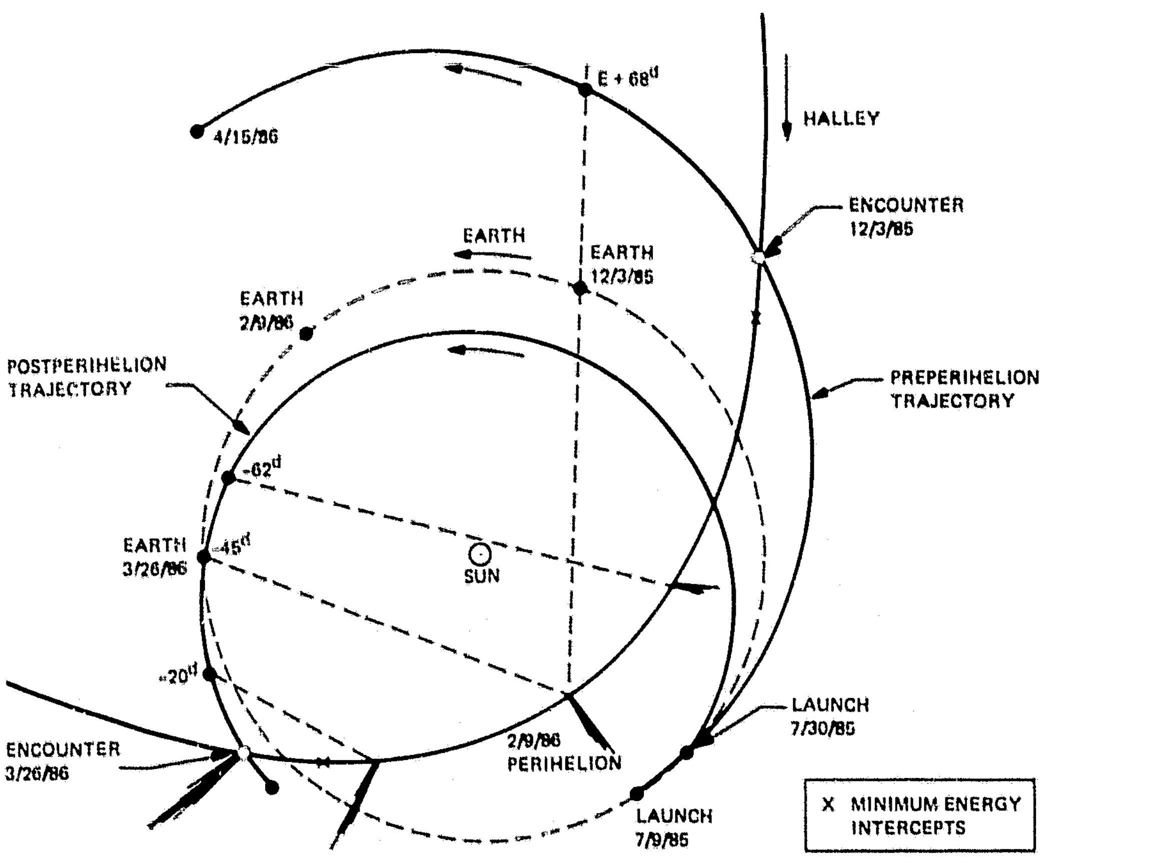


Figure 2. Ecliptic Projection of Two Possible Trajectories for the Halley Intercept Mission, One Arriving Preperihelion, the Other Postperihelion.

Table 2. Halley Intercept Mission Trajectory Options

| | SEPS | Ballistic preperihelion | | Ballistic postperihelion | |
|---|---|---|---|---|---|
| | HFB/T2R reference | Minimum energy | Reference | Minimum energy | Reference |
| Launch[a] | | | | | |
| Date | 7/23/85 | 6/26/85 | 7/9/85 | 7/13/85 | 7/30/85 |
| Launch energy, $km^2/s^2$ | 23 | 15 | 21 | 6 | 24 |
| Geo declination (VHL) | 23° | 39° | 36° | 12° | 46° |
| Injection capability, kg[b] | 3700 | 3750 | 3420 | 5330 | 2880 |
| Flight time to Halley, days | 128 | 165 | 146 | 211 | 239 |
| Halley encounter | | | | | |
| Date | 11/28/85 | 12/9/85 | 12/3/85 | 3/15/86 | 3/26/86 |
| Days from perihelion | -73 | -62 | -63 | +34 | +45 |
| Flyby speed, km/s | 57 | 55 | 56 | 68 | 60 |
| Approach phase angle | 49° | 58° | 53° | 109° | 114° |
| Earth range, AU | 0.62 | 0.72 | 0.65 | 0.92 | 0.65 |
| Solar range, AU | 1.53 | 1.36 | 1.45 | 0.92 | 1.09 |
| Geo declination | 17° | 7° | 12° | -23° | -32° |

[a]Launch assumed to be first day of 30-day launch period (excepting 10-day period for SEPS).

[b]Injection capability assumes Shuttle/Twin IUS with 60,000-lb Shuttle lift.

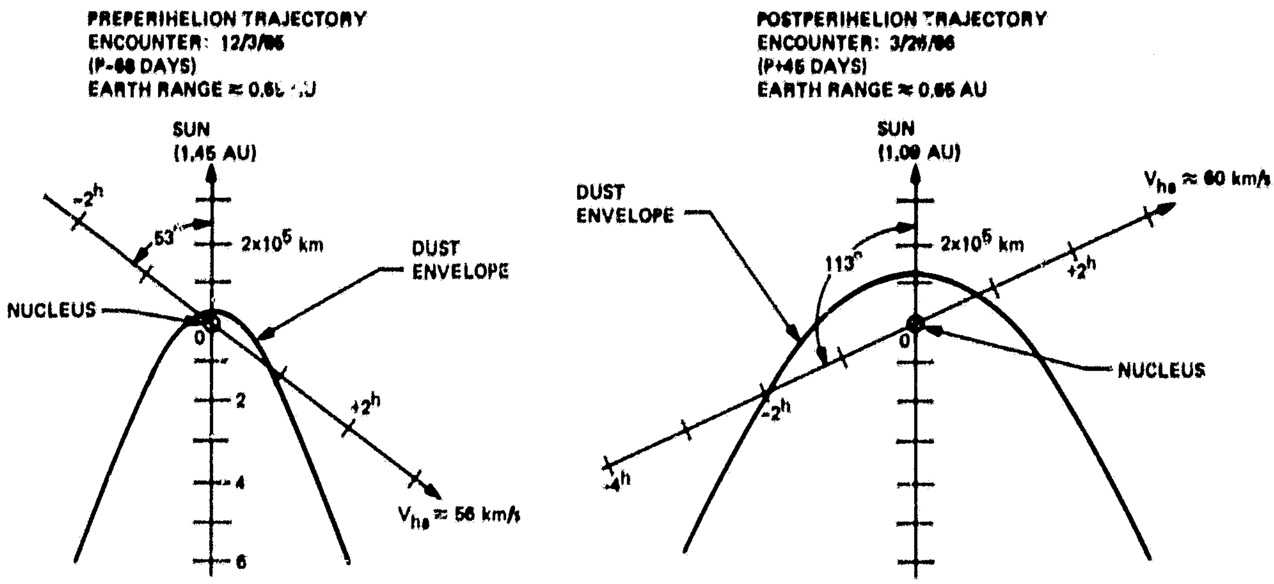


Figure 3. Encounter Geometry for Pre-and Postperihelion Halley Intercept Trajectories.

## VII. IMAGING ON THE HALLEY INTERCEPT MISSION

The Halley Intercept flyby spacecraft is distinct from all other current Halley initiatives in that it includes complex systems for supporting a high-quality imaging experiment. These systems are essential to the performance of the mission as well as to the attainment of key scientific objectives.

Included on the spacecraft are two cameras (one wide angle and one narrow), a versatile and automatic pointing system that will ensure a high degree of instrument stability during all phases of the mission, and a sophisticated data management and telemetry system that can provide rapid and efficient handling and transmission of imaging data. These systems are essential to the Halley Intercept Mission, for they make possible:

(1) Accurate navigation and delivery to the vicinity of the nucleus in a predictable way.

(2) The previously unavailable capability for unsmeared imaging under conditions of long (∿15-min) exposures during cruise and observatory phases of the mission.

(3) A substantial capability (∿10 frames) for rapid, unsmeared, accurately pointed imaging of the nucleus at the brief time of Halley encounter when there will be large *a priori* uncertainties in its direction relative to the spacecraft.

Table 3 lists design parameters for the two cameras planned for the Halley Intercept Mission. The scientific return that can be expected from this system covers a broad range of cometary science and will substantially address many of

Table 3. Halley Intercept Mission Imaging System Characteristics

| Camera | Narrow angle | Wide angle |
|---|---|---|
| Focal length, mm | 1500 | 100 |
| Aperture, mm | 175 | 50 |
| Focal ratio | f/8.5 | f/2 |
| Resolution, μrad/pixel | 10 | 150 |
| Field of view, deg | 0.46 | 6.9 |
| Spectral range, μm | 0.4-1.1 | 0.2-1.1 |
| Number of filter positions | 8 | 8 |
| Detector | 800 x 800 CCD | 800 x 800 CCD |
| Exposure range | 5 msec to 15 min | 5 msec to 15 min |

the prime scientific objectives proposed by earlier Comet Science Working Groups and also by the Space Science Board. The narrow-angle camera is a copy of the camera to be flown on the Galileo mission, while the wide-angle camera is a new design optimized for imaging the very faint coma and tails. For a postperihelion encounter mission, picture taking would start 64 days before encounter when the spacecraft is 250 million km from the comet and continue until about 2 days after encounter. Thus the spacecraft would obtain coverage of the comet as it passes through perihelion and cannot be observed well from Earth. It is planned to obtain 2800-8700 pictures with resolution better than the 100-1000 km (depending on observing conditions) which can be obtained from the ground. The Halley Intercept Mission will take some 1000 pictures with better resolution than can be obtained with Space Telescope (30-40 km per line pair). Pictures can be taken and stored, with compressed data also transmitted in real-time, at a rate of one image every 8.7 seconds. At a distance of 1000 km, the nucleus would be ∿500 pixels in diameter (assuming a diameter of 5 km) and the resolution would be 20 m/lp. We can expect to obtain three pictures with resolution better than 33 m/lp and 15 better than 100 m/lp. All told, the planned resolution, rate and quantity of pictures, sensitivity range, and filter options are adequate to achieve the scientific objectives listed below:

(1) Nucleus

(a) Determine the bulk characteristics of the nucleus, including size, shape and possibly rotation.

(b) Characterize the chemical and physical diversity of the nucleus through measurements of color, albedo, roughness and texture.

(c) Characterize the state of activity of the nucleus at the time of encounter.

(d) Relate the activity on the nucleus to its surface characteristics.

(2) Atmosphere

(a) Characterize the geometric structure and dynamic behavior of the atmosphere.

(b) Determine the relationship of the coma structure to activity on the nucleus and in the tail.

(3) Tail phenomena

(a) Characterize geometric structures and dynamic phenomena in Halley's tails, and the response of the ion tail to solar-wind conditions.

In addition, the imaging data that will be returned from the Halley Intercept Mission can, in concert with other international Halley initiatives and future NASA programs, substantially address objectives related to the evolution of cometary nuclei, the physical differences that may exist between the nuclei of different comets, and also the relationship of cometary nuclei to other solar system objects, particularly the meteorites. The rationale for this assertion is as follows: First, the images of Halley's nucleus will be unique (at least for a period of 76 years), for they will be the only high-resolution images of a relatively fresh and highly active nucleus that we have the technical ability to obtain. These data, when compared with similar high-resolution pictures of the highly evolved nuclei of shorter period comets that are technically attainable on future missions in NASA's comet program, will provide us with clear insights into both the long-term evolution of these objects and the kinds of intrinsic differences in physical structure that they exhibit. Secondly, since the Halley Intercept Mission could encounter Halley before its perihelion passage, a comparison of its images with those of Giotto could give direct and unique knowledge of how the nucleus of a relatively fresh, active comet evolves in response to the massive activity stimulated by the Sun as the comet passes through its perihelion.

# VIII. IN-SITU EXPERIMENTS

The Halley Intercept Mission will not merely fly by a comet; it will fly through it, obtaining new data along the way which cannot be obtained by any other means. The scientific objectives of the in-situ measurements on the Halley Intercept Mission are to:

(1) Determine the elemental composition and physical state of the volatiles and solids in the cometary atmosphere.

(2) Understand the physical and chemical processes which occur there (e.g., jets, activity bursts, large-scale solar-wind interaction, ionization, acceleration, small-scale plasma structures).

(3) Understand the variations in composition and processes which occur with time and distance from the Sun and from one comet to the next.

The last objective, the study of variations in a single comet and of the variations among comets, cannot be fulfilled during a single encounter with a given comet. Valuable information would result from two separate encounters with Halley at two different times, for example, by the Halley Intercept Mission and by Giotto. The comparison with other comets will have to await a future rendezvous mission or an extended mission encounter with a second comet during a possible extended Halley Intercept Mission phase (Section X).

In the rest of this section and in Section IX, we discuss the different types of measurements which can and should be performed on the Halley Intercept Mission. The CSWG emphasizes that a multi-instrument payload such as that listed in Table 1 is necessary to accomplish the stated objectives. A reduced complement of instruments would lead to ambiguities in the results obtained.

## A. MEASUREMENT OF GASES

The determination of the chemical composition of volatile cometary material is one of the principal objectives of any comet mission. Although there is no direct flight experience with mass spectrometers at a high-velocity intercept of gas and dust, several different types of neutral mass spectrometers are being developed and can be used. They all take advantage of the high flyby speed ($\approx$60 km/s), employing an energy analyzer or combinations of energy and mass analyzers. A typical approach is to electrostatically sweep charged particles out of the collimated beam of cometary atmosphere prior to ionization of the neutral gas. The newly formed ions are deflected electrostatically into a shielded energy analyzer while the unionized gas and the dust continue along their original path, essentially without further interaction with the instrument. Hence, primarily molecules moving at speeds close to 60 km/s are detected and difficulties with background (e.g., $H_2$, $H_2O$, CO, $CO_2$, $CH_4$) encountered in conventional mass spectrometers due to outgassing are much reduced. The width of each mass peak will also yield some information on the kinetic temperature of the gas, which in turn helps to identify both the chemical reactions which produced the species and aeronomical processes. Based on current theories and predictions on cometary comas and typical (predicted) instrument sensitivities of 0.1 to 0.01 counts/sec per molecule/$cm^3$ one expects that some 22 species (10 of them parent molecules) can be identified and their average concentrations along the path of the spacecraft be determined to better than 10%. Possibly 20 additional species (nine of them parent molecules) could be identified with lower accuracy. For comparison, only three parent species have been identified to date.

## B. MEASUREMENTS OF DUST

The CSWG emphasizes that the determination of the composition, as well as mass and space distributions of the dust grains, should be a major objective of the Halley Intercept Mission. This solid material will represent our only means of investigating the nature of a major (perhaps principal) constituent of the nucleus. Furthermore, comparison of such observations with theoretical models will provide a major breakthrough in understanding past and future Earth-based observations of active comets. Most importantly, these observations will provide the basis of extrapolating future, very detailed rendezvous measurements to active, pristine comets.

The dust composition analysis could be performed with an improved version of the sort of instrument flown on the Helios spacecraft. This type of instrument takes advantage of the high flyby speed in that a plasma cloud is rapidly produced when a dust or ice grain impacts a target plate at 60 km/s. These ions are accelerated into a time of flight mass spectrometer. The anticipated results include elemental composition on a particle-by-particle basis from which the major minerals can be identified. The grain size distribution can be determined as a function of position along the spacecraft trajectory. We note, however, that the state of the art of analyzing the composition of high-velocity particles is still at the frontiers of technological innovation, and we urge NASA to continue its vigorous support of these developments.

A dust counter is essential to characterize adequately the total dust production of the nucleus and the mass distribution of the emitted particles. Measurement of the total dust production is required to calculate the important gas-to-dust production ratio. Dust composition analyzers, due to their very small collecting areas, cannot serve as adequate dust counters because they sample only a fraction of the expected mass spectrum, being sensitive to only the most abundant particles (mass range $\simeq 5 \times 10^{-13}$ to $6 \times 10^{-11}$ gm). Thus a separate dust counter is needed. One which incorporates the entire area of the protective dust shield is highly desirable.

## C. PLASMA MEASUREMENTS

The CSWG recommends that the Halley Intercept Mission include an adequate complement of instruments to determine the overall structure, distribution and dynamics of the cometary and solar wind plasmas and magnetic fields. We support the recommendation of COMPLEX that "measurements of the plasma, electromagnetic fields and energetic particles, as well as neutral and ionized particles be made in a volume of space surrounding the nucleus and encompassing the major solar wind interaction areas. These areas include the undisturbed solar wind, the hypothetical shock front, postshock plasma flow, contact discontinuity between the solar wind and cometary plasmas, and the outflowing cometary gas and plasma"

(Strategy for the Exploration of Primitive Solar System Bodies — Asteroids, Comets and Meteoroids: 1980-1990, Committee on Planetary and Lunar Exploration, Space Science Board, Washington, DC, 1980). More specifically, we recommend that this mission carry instrumentation to measure the magnetic fields, the plasma turbulence spectrum, the ion composition, and the energy distributions of both thermal and energetic ions and electrons.

The magnetic field is expected to be the agent which transmits the solar wind pressure to the ionosphere; therefore, measurements with good spatial resolution and sensitivity down to less than 1 γ are desirable. At Venus, plasma waves were found to play an important role in the solar wind/ionosphere coupling processes and were an excellent indicator of various shock and upstream processes. Particles may also be accelerated to relatively high energies by plasma turbulence; thus not only should the plasma waves be measured, but energetic ion and electron fluxes should also be determined. The solar wind plasma characteristics need to be measured across the shock front and throughout the decelerated post-shock region. The COMPLEX report states that "in order to elucidate the physical and chemical processes that control comet atmospheres, it is necessary to determine the nature and spatial and velocity distribution of the important ... ionized constituents." The Halley Intercept spacecraft will pass through the cometary environment with a velocity of about 60 km/s; therefore, even the thermal ionospheric ions will have energies in excess of tens of eV in the instruments' frame of reference. Ion composition measurements with mass identification ($\Delta m$) better than 1 amu in the range up to about 50 amu are desirable; these abundance measurements should be accompanied by the determination of the energy distribution from thermal energies (<0.1 eV) up to many keV's. As mentioned earlier, it has been established that at Venus the barrier to the solar wind flow is the ionosphere; therefore, it is very important that the Halley Intercept Mission measure the ionospheric thermal plasma density and its energy distribution and/or temperature.

Measurements of magnetic fields, plasma waves, and energetic electrons can be made with existing or fairly standard instruments. Special measurement techniques will probably be required to separate cometary thermal electrons from the electrons in the plasma sheath created by collisions of cometary dust and gas with the spacecraft. Two different types of ion spectrometer have been under development recently — electrostatic analyzers combined with either a magnetic analyzer or a time-of-flight analyzer. With either type of device, the ion mass resolution will probably be limited to $m/\Delta m \approx 25$. This resolution is adequate for separating $H_2O^+$ from $H_3O^+$ (which is predicted to be the most abundant ion in the inner coma) but not for distinguishing $CO_2^+$ from $HCO_2^+$, for example. These instruments are capable of measuring three-dimensional velocity distribution functions over the range of speeds anticipated (tens of km/s to twice the local solar wind speed).

The Halley Intercept Mission must be designed to investigate plasma physics phenomena over a distance of at least $10^7$ km from the nucleus. These distant measurements will provide important new information on solar wind mass loading by atmospheric ions and on cometary plasma processes that lead to charged particle energization.

ISEE-3 measurements clearly demonstrated that magnetospheric electrons and ions can be detected as far as 0.01 AU upstream from Earth (0.01 AU from Halley would be seven hours away, at 60 km/s), and this tells much about magnetospheric energy balance and acceleration processes. Voyager was able to determine that energetic sulphur and oxygen was streaming away from Jupiter many weeks before encounter (distances as great as 800 $R_J \approx 6 \times 10^7$ km).

For the Halley mission, we know that the very weak gravity allows neutrals to escape over a huge distance so that the spacecraft will be immersed in the comet atmosphere long before it reaches the bow shock. Relevant OGO-5 measurements of Comet Bennett are shown in Figure 4. It seems that it will take about a day to traverse the atmosphere of an active comet ($5 \times 10^6$ km) even at a speed of 60 km/s. COMPLEX and the Space Science Board have recommended coverage out to $10^7$ km. We believe that continuous plasma measurements should be made starting at least two days before closest approach to the nucleus.

## IX. NON-IMAGING REMOTE SENSING

While it is true that most of the science emphasis should be placed on imaging and key in-situ measurements, it is highly desirable that some remote sensing measurements be obtained as well. Much of the current physical information concerning comets comes from UV and visible spectroscopy, as well as thermal IR measurements. Of necessity, most comets in the future will be studied remotely from Earth and Earth-orbit by these and future remote sensing techniques. The Halley Intercept Mission provides an important opportunity to calibrate the theoretical techniques that have been used to interpret such measurements, but the calibration can only be exploited fully if remote sensing instruments are included in the spacecraft payload.

In this respect recent history teaches us an important lesson. If UV spectrometers and photometers such as those carried on all early Mars missions had been carried on board the Viking Orbiters, the results of the Viking mission would have been greatly enhanced. Excellent in-situ measurements of the upper atmosphere were obtained by the Viking Landers during descent but there were no simultaneous remote sensing measurements to serve as "ground truth." CSWG urges NASA to avoid a repetition of this undesirable situation in its comet program, and recommends that remote sensing experiments be included on the Halley Intercept Mission and on any future comet rendezvous spacecraft.

## X. POST-MISSION OPTIONS

The CSWG notes that by carefully selecting the launch/arrival strategy of the Halley Intercept Mission, several important extended mission opportunities become available. For example, a Halley encounter on March 26-28 is consistent with a trajectory that returns to Earth one year after launch. Subsequent Earth swingbys can be used to reshape the trajectory to encounter any one of the short-period comets: Encke, Tempel 2, or Borrelly. In each case the second encounter would take place less than 3 years after launch, and each case provides an opportunity to examine a less active, more evolved comet. The encounter circumstances for these three options are summarized in Table 4. The trajectory for the Tempel 2 option can be easily modified to encounter the Apollo asteroid Geographos in September 1987 at 13 km/s. Owing to the lower encounter velocities at the

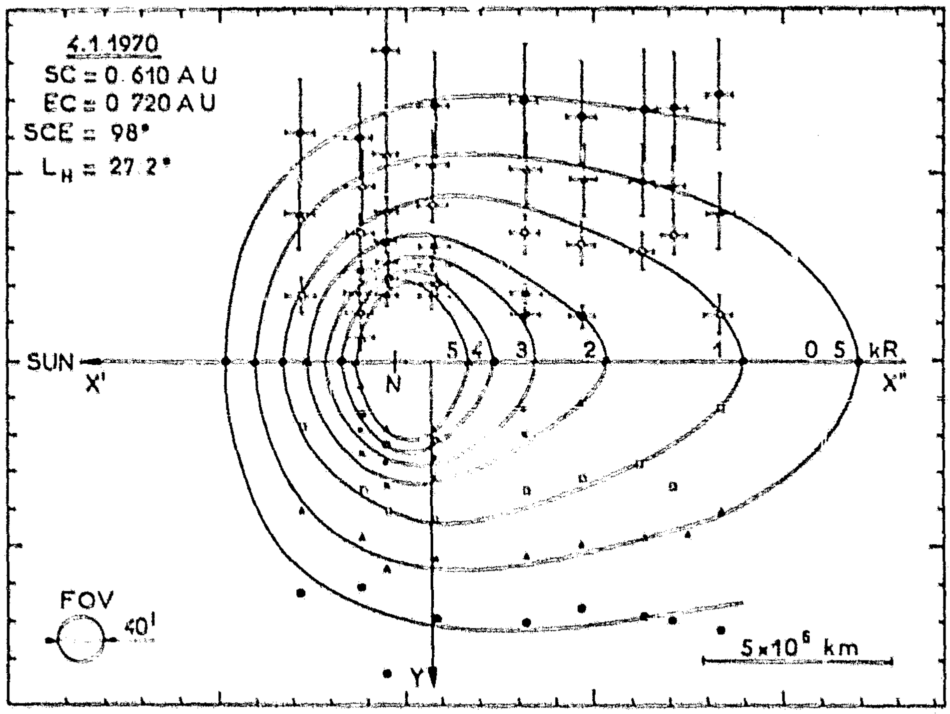


Figure 4(a). Lyman-Alpha Isophotes of Comet Bennett (J. L. Bertaux, J. E. Blamont, and M. Festou, Astronomy and Astrophysics, 25, 415, 1973).

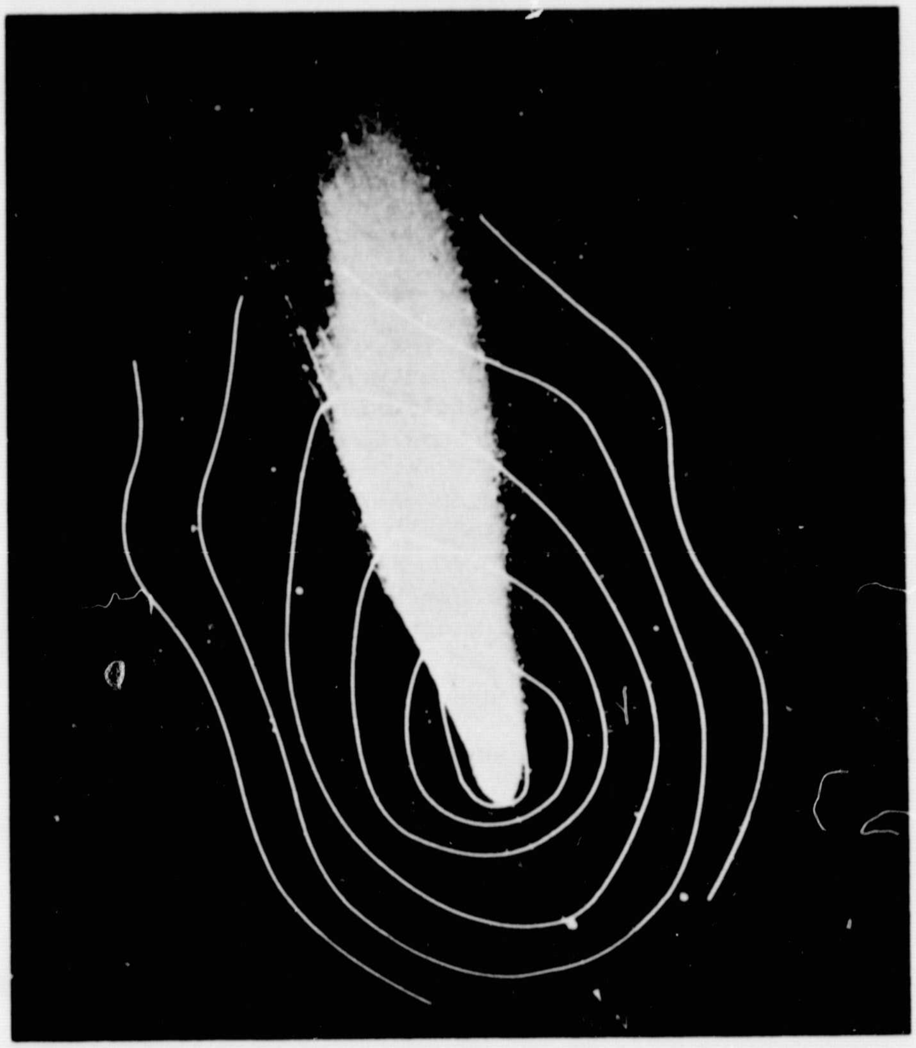

Figure 4(b). Lyman-Alpha Brightness Contours Superimposed on a Photograph of Comet Bennett (After C. Lillie).

Table 4. Sample Post-Halley Options

| Comet | Encounter date | Flyby velocity (km/s) | Encounter distance (AU) | |
|---|---|---|---|---|
| | | | Earth-Comet | Sun-Comet |
| Encke | Sept 87 | 31 | 1.0 | 1.1 |
| Borrelly | Jan 88 | 17 | 0.7 | 1.4 |
| Tempel 2 | Sept 88 | 13 | 1.0 | 1.4 |

second comet, even better imaging of the nucleus than will be possible at Halley can be obtained. These and other data could form an important basis on which to plan a later rendezvous mission to the same comet.

Extended mission opportunities, with somewhat longer flight times, exist for preperihelion Halley flyby trajectories.

The CSWG recommends that a trajectory be selected for the Halley Intercept spacecraft which leaves open the opportunity of effecting an extended mission exploration of another comet.

## XI. CONCLUSIONS

The Comet Science Working Group concludes that a mission to Comet Halley which will substantially address those objectives of the NASA Comet Exploration Program dealing with active comets is technically feasible.

Of the various concepts proposed, the CSWG finds that the Halley Intercept Mission is the only one which is sufficiently sophisticated to address adequately the unique Halley opportunity and the objectives of the United States science community.

Important unique characteristics of the Halley Intercept Mission include:

(1) Optical navigation and resulting accurate delivery of the spacecraft to a desired point near the nucleus. This accuracy of delivery has two important implications:

(a) High probability that the mass spectrometers and other in-situ measurement devices will reach the cometary ionosphere and the zone of parent molecules next to the nucleus.

(b) High probability that sunlit, high-resolution images of Halley's nucleus will be obtained under proper lighting conditions.

(2) An observatory phase during which high-quality images of the tail and coma structure will be obtained at progressively higher spatial resolutions as the spacecraft approaches the comet.

In addition, complete measurements of the comet/solar wind interaction can be made around the time of encounter over the full $10^7$ km scale recommended by the Space Science Board (Section VIII).

While the Comet Science Working Group believes that the scientific return from the 1986 Halley apparition can be enhanced significantly by coordinating all efforts to study this comet, and consequently strongly endorses the International Halley Watch Program, the CSWG has concluded that the Halley Intercept Mission represents the single indispensable element of this world-wide effort. Other space missions to Halley should provide valuable science and contribute significantly to the common effort to study this unique body. However, these other missions, alone or in concert, will not sufficiently meet the objectives set down by the United States science community (Space Science Board, Comet Science Working Group, International Halley Watch Working Group, etc.) for the investigation of Halley. These objectives can be achieved by the proposed Halley Intercept Mission; therefore, the CSWG recommends that NASA concentrate its resources on supporting this outstanding mission.

With the realization of the Halley Intercept Mission the world will see a first-class investigation of a unique celestial object which has figured prominently in its cultural history. The observatory phase of the mission will provide essential science as well as the means of communicating to the world the progress of this exploration as it evolves and the answers to the universal questions, "What is a comet?" and "What does Halley look like?" The entire complement of instruments will address important questions dealing with one of the two major objectives of the NASA Comet Exploration Program and return data which are needed for later comparison with those obtained during a future rendezvous with a short-period comet. Should we miss this unique opportunity, it will be left to our descendants in the next century to fulfill one of the two essential elements in NASA's Comet Exploration Program.