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BALLISTIC MISSIONS TO COMET ENCKE IN 1980
- A NEW PHASE OF SOLAR SYSTEM EXPLORATION -*

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ABSTRACT

A prime mission candidate for initiating exploration of both a comet and asteroids with unmanned spacecraft is available during the 1980 apparition of the short-period Comet Encke. Direct investigation of such bodies is expected to provide the best insight into conditions existing during the early periods of solar system evolution.

A discussion is presented on low-cost ballistic mission options to Comet Encke. Particular emphasis is given to the results of a recently-completed study of ballistically-launched, spin-stabilized spacecraft for 1980 missions to Comet Encke and the asteroids Geographos and Toro. Characteristics and utilization of a small, separable probe to enhance comet science return are also described. In conclusion, it is shown that the Encke ballistic flyby can provide the necessary technical foundation to support the planning of more advanced Encke follow-on missions as well as the challenging flyby of Comet Halley in 1986.

INTRODUCTION

The exploration of Earth's neighboring planets with unmanned spacecraft is systematically building a fund of knowledge on the characteristics of Mars, Venus, Jupiter, and, most recently, Mercury. By the end of the present decade, it is projected that U.S. spacecraft will also be enroute to Saturn and Uranus. The scientific results of the Pioneer and Mariner programs have been impressive and, in some cases, very surprising, but they are still snapshots of bodies as they have evolved since their formation. During their evolution, they have experienced many catastrophic and metamorphic changes as a result of the actions of gravity, volcanism, solar activity, and other dynamic events. As a result of such changes, however, planets offer limited data on solar system origins and formative processes. Potential sources of additional information on the early stages of solar system development are the comets and asteroids which are considered to be very close to the state in which they were formed. The short-period Comet Encke, in particular, is currently the primary NASA candidate for initiating small-body exploration.

Space-flight missions to Comet Encke have been the subject of a number of NASA-sponsored studies over the past several years (see Bibliography in reference 1). In these studies, a variety of mission options and spacecraft configurations have been presented and analyzed. The purpose of this paper is to summarize the results of a recent study performed by the Martin Marietta Corporation's Denver Division for the NASA/Ames Research Center(2). This study was undertaken to determine the feasibility and desirability of using current-technology, light-weight, spin-stabilized spacecraft for ballistic flyby missions to Comet Encke during the 1980 apparition.

As a basis for the definition of scientific objectives and measurements, the physical characteristics of Comet Encke will be summarized first, and a typical instrument complement will be described. The spectrum of mission options for Encke encounters in 1980 will be reviewed with emphasis on pre-perihelion, short-flight-time ballistic opportunities. Also included are options for subsequent flyby of the asteroids Geographos and Toro after Encke encounter. The variations of comet encounter conditions affecting scientific accomplishment will be discussed in relation to the selected mission. The design features of a typical Atlas/Centaur-class spacecraft are described, and the utilization of a separable probe to enhance comet science is also discussed. The impacts of combined Encke/asteroid encounters on spacecraft design and mission are then evaluated. In conclusion, key technical issues are discussed to show the direct relationship of the 1980 Encke flyby mission to the successful accomplishment of follow-on exploration of Encke and to flyby of comet Halley in 1986.

COMET ENCKE CHARACTERISTICS

In 1819, Johann Franz Encke, then at the observatory at Seeburg, Switzerland, proved that the apparently different comets observed in 1786, 1795, and 1818 were actually the same comet that now bears his name. Based on Encke's calculated ephemeris, the comet was successfully acquired at its apparition in 1822. Since 1818, Comet Encke has been observed at each apparition with the exception of 1944. At its brightest, Encke's comet

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* Based on a research report prepared for the Ames Research Center, NASA under Contract NAS2-7564.

is ordinarily slightly fainter than the naked-eye limit. The 3.3-year orbital period of this well observed comet still remains the shortest known for any comet. This frequent accessibility offers the opportunity for an orderly program of progressive exploration.

Whipple(3), in a recent periodical article, gives an excellent summary of comet characteristics and discusses the uncertainties as well as the facts that have evolved over the many years of comet observations. For the purposes of this paper, only a brief discussion of comet physics will be given to establish the basis for defining science instrument and mission-design requirements. In the following discussion, the three basic structural parts of a comet (nucleus, coma, and tail) will be described, and the quantitative parameters for Encke will be summarized.

In general, the existance of a cometary nucleus is based on circumstantial evidence. More direct evidence, however, was obtained by Dr. Elizabeth Roemer in photographs of Comet Encke near aphelion in 1972(4). In these observations, Encke appeared as a "stellar object" with a magnitude of about 20.5. In accord with Whipple's model of an icy-conglomerate (or "dirty snowball") nucleus, it is inferred that such a central body exists to provide the source for gases and dust found in the coma and tail. The nucleus contains complex parent molecules such as H_2O, NH_3, CH_4, and CO_2 in the form of complex ices. As the comet approaches the Sun, these ices sublimate at temperatures of a few hundred degrees Kelvin and provide "daughter" molecules which are seen in comet spectrum measurements. Also interspersed in the nucleus ices is meteoric material which is the source of dust in the comet. It is estimated that Encke's nucleus is about 3.2 km in diameter.

The coma is the "atmosphere" of the comet and is a near-spherical region around the nucleus in which ionization, photo-dissociation, and other processes occur in the material emanating from the nucleus. The coma diameter varies with the solar distance of the comet. At 1 AU, Encke's mean diameter is about 10^5 km and decreases to about 40,000 km at 0.5 AU. In the simple model of an expanding cometary coma, the neutral gas (mainly H_2O products), leaves the nucleus at the speed of sound, or about 300-700 m/sec at a surface temperature of 250-750°K. The flow speed stabilizes at ~ 1 km/sec. The number densities of H_2O and other molecules depend on the amounts in the nucleus, but they decrease as the inverse square of the distance away from the nucleus to $\sim 10^4$ km, where photo-dissociation effects reduce the densities to near-zero values. Near the nucleus, water-product gas densities are of the order of 10^{13} molecules/cm^3 and reduce to about 10^5 molecules/cm^3 at about 5000 km.

The "daughter" products are eventually removed by photo-dissociation, photo-ionization, or collisions with solar wind particles. To conserve momentum, lighter products, like atomic hydrogen, would be heated by any excess energy above that required for dissociation. They should expand at higher speeds and reach greater distances than other species. Recent observations of comets in ultraviolet by the Orbiting Astronomical Observatory (OAO) spacecraft show a half intensity Lyman-alpha halo out to about one million kilometers.

The solar wind interacts with the coma to produce a tail downstream and the upstream phenomena shown in Figure 1. The solar wind is decelerated, either gradually or suddenly, a turbulent transition region follows, and then there is a flow around the coma. A type of contact surface exists and separates the solar wind and cometary plasma, but its maintenance and processes are not clearly known. The solar wind may, in addition, contribute to dissociation and ionization of neutral parent molecules. Ionized constituents of the coma are swept into the tail. Observations have shown that Encke exhibits a Type I tail of ionized plasma but has no significant Type II dust tail. This is consistent with its aging and earlier depletion by mass losses. The maintenance of the tail and its observed fine structure may involve electrodynamic processes not clearly understood.

Table I is a summary of the primary physical properties of Comet Encke. A more detailed discussion of these properties, their derivation, and associated references may be found in reference 2.

COMET SCIENCE OBJECTIVES AND INSTRUMENTATION

In spite of the long history of comet observations, many of the basic physical properties and processes can only be inferred from ground-based studies. Direct measurements in the comet environment will be required to understand more completely their origin and evolution. In accordance with the wide range of observables and energy processes possible at the comet, considerable breadth in scientific objectives is required on initial flyby missions in preparation for later, more ambitious flights. Since the first flyby of a comet is in every sense an exploratory venture, there is no strong rationale that special emphasis be given to only one scientific discipline. The science objectives, therefore, break into three major areas corresponding to the comet's structural parts:

- Identify and measure the nucleus and near-nucleus vicinity,

- Identify the constituents and processes in the coma,

- Investigate the interaction of the interplanetary environment with the comet.

This latter category includes investigations of tail phenomena, contact interface processes, and upstream activity.

Table II is a listing of a typical science instrument complement for comet flyby missions and is consistent with recommendations of the recent NASA Science Advisory Committee on Comets and Asteroids(1). This list varies, in detail, from those arrived at in other studies of Encke missions

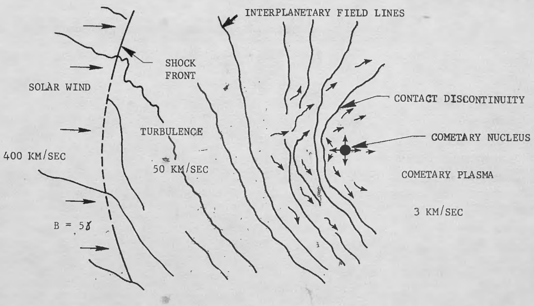


FIGURE 1. MAJOR COMET FEATURES

TABLE I. COMET ENCKE PHYSICAL PROPERTIES SUMMARY

COMET FEATURE	RANGE OF VALUES	NOMINAL VALUE USED
I. NUCLEUS	STARLIKE TO DIFFUSE	STARLIKE
DIMENSIONS (radius)	0.5 to 3.6 km	1.6 km
MASS	$10^{14} - 5 \times 10^{17}$g	2×10^{16}g
ALBEDO	0.02 - 0.7	0.1
PHASE CURVE	LAMBERT & MODIFICATIONS	LAMBERT
MAGNITUDE	$H_N = 16.0 + 5 \log\Delta + 5 \log r + 0.03 (\text{Phase Angle})^\circ$	Δ = S/C-ENCKE DISTANCE IN AU r = HELIOCENTRIC DIST IN AU
II. COMA	NEBULOUS AND DIFFUSE	NEBULOUS
DIMENSIONS (radius)	10^4-10^6 km	2×10^4 km
MAX GAS DENSITY (H_2O PRODUCTS)		
NEAR NUCLEUS	$10^{14} - 10^{12}$ molecules/cm^3	10^{13} molecules/cm^3
NEAR 5000 KM	$10^5 - 10^3$ molecules/cm^3	10^5 molecules/cm^3
MAGNITUDE	$H = 10.93 + 5 \log\Delta + 3.55(r^{1.8}-1)$	Same
MAX. VEL. OF PARTICULATE MATTER	30-300 m/sec	300 m/sec
PARTICULATE EMISSION RATE	6×10^4 to 6×10^3 g/sec	6×10^4 g/sec (per active 100 days)
III. TAIL		
LENGTH	$10^5 - 10^7$ km	10^6 km, ION TAIL ONLY
WIDTH	$10^4 - 10^6$ km	4×10^4 km

but all provide for investigations in five basic disciplines - imaging, optical spectroscopy, dust particle analysis, and plasma and fields analysis. Correlation of instrument categories with comet observable characteristics is shown in Table III.

TABLE II. COMET SCIENCE INSTRUMENT CHARACTERISTICS

INSTRUMENT	MASS - KG (LBS)	SOURCE
TV IMAGING SYSTEM	23.4 (51.6)	MM-71
ULTRAVIOLET SPECTROMETER	3.6 (7.9)	MVM-73
ION MASS SPECTROMETER	2.5 (5.5)	OGO-F
NEUTRAL MASS SPECTROMETER	5.5 (12.1)	OGO-F
PLASMA PROBE (ELECTROSTATIC ANALYZER)	5.0 (11.0)	PIONEER-9
COSMIC DUST ANALYZER (IMPACT IONIZATION)	2.0 (4.4)	PROPOSED BY MAX PLANCK INST.
PLASMA WAVE DETECTOR	5.5 (12.1)	OGO-E
TRIAXIAL FLUXGATE MAGNETOMETER	2.8 (6.2)	APOLLO SUB-SAT.
LANGMUIR PROBE	1.6 (3.5)	OGO-F
VISUAL SPECTROMETER	3.5 (7.7)	OGO-F
TOTAL	55.4 (122.0)	

TABLE III. SUMMARY OF COMET INSTRUMENTS AND OBSERVABLES

INSTRUMENT CATEGORIES	COMET OBSERVABLES
IMAGING	GROUNDBASED COMPARISONS NUCLEUS IMAGING INNER COMA DETAILS TAIL FINE STRUCTURE
SPECTROSCOPY ULTRAVIOLET AND VISUAL	UV EMISSIONS IN COMA AND TAIL IDENTITY AND ABUNDANCE OF RADICALS HIGH SPATIAL RESOLUTION OF SPECTRA
SOLID PARTICLES	PARTICLE MATERIAL FROM NUCLEUS DUST IN TAIL
PLASMA PROPERTIES	SOLAR WIND MATERIAL UPSTREAM CONTACT SURFACE MAINTENANCE TAIL EXTRUSION AND DYNAMICS
PARTICLES AND FIELDS	MAGNETIC FIELDS IN TAIL ELECTROMAGNETIC WAVES IN TRANSITION REGION AND TAIL
MASS SPECTROMETRY ION AND NEUTRALS	IDENTITY AND ABUNDANCE OF CONSTITUENTS IN COMA AND TAIL

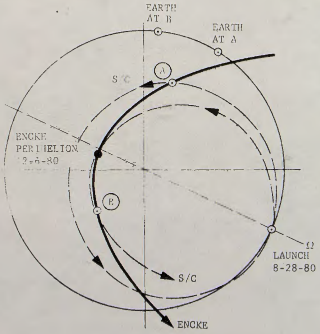
1980 ENCKE MISSION OPTIONS

Considerable effort has been devoted to the assessment of slow flyby (< 5 km/sec), rendezvous, docking, and sample return missions to Comet Encke. This class of missions is characterized by launch from the comet-orbit descending node and involves long ballistic flight times (of the order of the 3.3 year comet period) and large inflight propulsion maneuvers. Shorter flight times would be possible with the availability of an operational solar electric propulsion system. The work reported herein was directed to the much shorter (~ 3 months) and lower cost ballistic flyby missions launched from the comet-orbit ascending node. The primary impetus for this approach was the prospect of utilizing existing launch vehicles and spacecraft technology as an option for consideration by program planners. In addition, timely experience with this flyby mode could prove valuable to implementation of follow-on Encke missions and to a practical Halley mission during its 1986 apparition.

Another desirable consideration in planning for initial exploration of small bodies in the solar system is that of economically combining auxiliary objectives with the primary target on a single mission. In earlier Martin Marietta Corporation studies, it was determined that the orbits of the asteroids Geographos and Toro provided opportunities for encounters of either or both asteroids on some of the 1980 Comet Encke missions.

A variety of short-flight-time mission options are available for planning the exploration of comet Encke. However, mission characteristics and encounter conditions vary considerably with the spacecraft arrival date at the comet. Heliocentric flight profiles are typified in Figure 2 for encounters before (comet-dedicated reference mission) and after Encke's perihelion passage. The tabulated data summarize major differences in encounter conditions and show the increased launch energy required for the post-perihelion mission as illustrated by the reduced spacecraft weight that can be launched by the Atlas/Centaur/TE364-4.

The pre-perihelion missions offer the advantage of observing Comet Encke at a near-maximum activity level$^{(2,5)}$ and are compatible with several options to enhance science return. For example, launching when the Earth is near the comet plane's ascending node (8/28/80) and arriving at the comet on 11/20/80, 16 days before its perihelion passage on 12/6/80, the spacecraft has the unique opportunity to fly nearly directly down the comet's tail and thus obtain <u>in-situ</u> measurements for as long as 13½ hours. The Atlas/Centaur/TE364-4 launch vehicle provides a 335 kg injected weight capability for this specific comet-dedicated mission, and flyby of the comet is at a relative velocity of 18.3 km/sec. (Weights up to 560 kg are available for other encounter conditions as will be discussed later.) Further, flyby of the asteroids mentioned previously is limited to the pre-perihelion Encke encounters. The high activity of the comet also leads to consideration of separable probes for investigations deep in the coma.



Ⓐ TYPICAL PRE-PERIHELION ENCOUNTER
ENCKE ENCOUNTER DATE: 11/20/80
* SPACECRAFT WT = 335 kg (739 lb)
RELATIVE VELOCITY = 18.3 km/sec
HELIOCENTRIC RADIUS AT ENCOUNTER = 0.53 AU
SPACECRAFT PERIHELION = 0.45 AU

Ⓑ TYPICAL POST-PERIHELION ENCOUNTER
ENCKE ENCOUNTER DATE: 12/16/80
* SPACECRAFT WT = 225 kg (496 lb)
RELATIVE VELOCITY = 9.7 km/sec
HELIOCENTRIC RADIUS AT ENCOUNTER = 0.43 AU
SPACECRAFT PERIHELION = 0.35 AU

* ATLAS/CENTAUR/TE364-4 LAUNCH VEHICLE

FIGURE 2. TYPICAL ENCKE BALLISTIC FLYBY MISSIONS

From a spacecraft design standpoint, some additional advantages accrue to the pre-perihelion mission. Communication distances are shorter, and encounter occurs when Encke is 0.5 to 0.6 AU. In contrast, the trajectories for the post-perihelion encounter approach the Sun about as close as does the comet (0.35 AU), thus producing a more severe thermal environment for the spacecraft. In general, the reduced activity of the comet, coupled with high launch energy and thermal requirements, make the post-perihelion missions less attractive for initial comet exploration.

Encounters near Encke perihelion can produce relative velocities as low as 7 km/sec (Figure 3). This seemingly attractive situation, however, is complicated by complex interactions with launch-energy requirements (Figure 4) and restricted Earth-launch periods. In addition to requireing a larger launch vehicle, missions in this class are subject to the limitations discussed for post-perihelion missions. The remaining discussion, therefore, is concerned with pre-perihelion encounter missions to Encke.

COMA PROBE UTILIZATION

A 5000-km flyby distance at the comet was selected on the basis of a balance between two competing factors. From a scientific standpoint, it is desirable to fly deep into the comet's coma to determine the types and quantities of parent molecules emanating from the nucleus. However, particulate matter close to the nucleus is a hazard to the spacecraft at high flyby velocities. It was determined that a small (45 kg), simple probe was feasible for coma penetrations to within approximately 200 km of the nucleus. The instrument payload and goals for probe operation are shown in Table IV. In addition to detection of parent-molecules, a probe will permit measurements of possible directional concentrations of dust/ particulate matter emissions by going to the

TABLE IV. PROBE SCIENCE & GOALS

PAYLOAD/SOURCE	MASS KG (LBS)	GOALS
COSMIC DUST DETECTOR (Mariner-2,4)	2.0 (4.4)	EXTEND MEASUREMENTS TOWARD NUCLEUS FIND ANISOTROPIES IN DIRECTION, RAYS
ION MASS SPECTROMETER (OGO-F)	2.5 (5.5)	DETECT IONS NEAR NUCLEUS LEARN OF ENERGY PROCESSES
NEUTRAL MASS SPECTROMETER (OGO-F)	5.5 (12.1)	IDENTIFY COMPLEX MOLECULES DETERMINE RADIAL DISTRIBUTION
LANGMUIR PROBE (OGO-F)	1.0	MEASURE ELECTRON DENSITY IN COMA MEASURE ELECTRON DENSITY IN TAIL

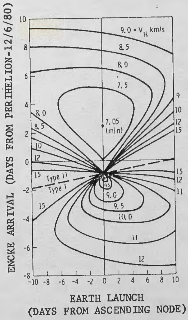


FIGURE 3. SPACECRAFT APPROACH VELOCITIES NEAR ENCOUNTER

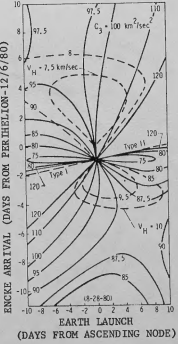


FIGURE 4. SPACECRAFT LAUNCH ENERGIES

regions near the nucleus. Further, spatial distribution is added to measurements in the categories of mass spectroscopy, particulate matter, and electron density.

The coma-probe design (Figure 5) is quite simple compared to probes designed to penetrate dense planetary atmospheres. Analysis of the Encke low-density coma environment(2) has shown that the probe would not require an aerodynamic shape or a heat shield, even at flyby velocities of 18 to 26 km/sec, for penetrations of the coma to within approximately 200 km from the nucleus.

The probe is spin-stabilized and is released from the spacecraft a few days before comet encounter. Probe instruments are turned on approximately one hour before closest approach, and data are transmitted directly to Earth in order to simplify the flyby spacecraft subsystems.

COMBINED COMET/ASTEROID MISSIONS

When compared to the comet, the asteroids present a less complex set of observables for investigation. Nevertheless, close-up studies of asteroids will help in understanding processes involved in the origin and evolution of the solar system. A particular point of interest in comparative study of comets and asteroids is to determine whether they have a common origin and evolution to the point that some asteroids may be "dead" comets.

As in the case of the comet nucleus, the target to be viewed is small. Geographos measures about 1.5 x 6.0 km and Toro is roughly spherical with about a 4.4 km diameter. The addition of one instrument, an infrared spectrometer, complements the comet-science payload for asteroid investigations. The predominance of imaging and IR instruments in accomplishing asteroid objectives (Table V) is indicative of science orientation toward surface morphology. This is in contrast to the gaseous- and particulate-emission investigations necessary on a comet flyby mission. For both the TV and IR instruments, a smaller flyby distance is required at the asteroid than at the comet to obtain quality

TABLE V. ASTEROID SCIENCE AND GOALS

PAYLOAD	GOALS
TV IMAGING	SIZE AND SHAPE ROTATION RATE AND AXIS ORIENTATION SURFACE FEATURES, ALBEDO
*IR SPECTROMETRY	TEMPERATURE AND ALBEDO SURFACE ROUGHNESS AND TEXTURE COMPOSITION AND MINEROLOGY
OTHER INSTRUMENTS	
MAGNETOMETER LANGMUIR PROBE UV SPECTROMETER PARTICULATE DETECTOR	SEARCH FOR "DISCOVERY" OF FIELDS, FINE MATTER, GAS ENVIRONMENT, AND PLASMA FLOW

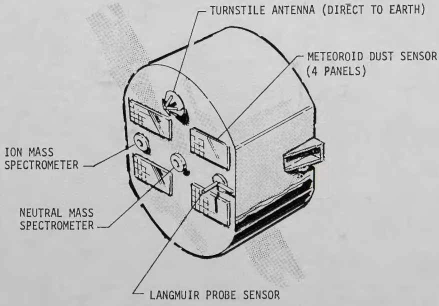


FIGURE 5. TYPICAL PROBE CONFIGURATION

measurement of surface characteristics. A maximum distance of approximately 500 km is necessary and asteroid flyby distances greater than 1000 km would degrade image resolution and IR science accomplishment.

The characteristics of two feasible combined comet/asteroid missions are compared with the reference comet flyby in Table VI. The increased launch weights possible on the combined mission result in increased relative velocities and approach angles at Comet Encke encounter. Although these factors reduce time in the tail environment of the comet (Figure 6), sufficient time is still available to perform significant scientific investigations. The variation of approach angle with spacecraft arrival date provides, in detailed mission planning, for adjusting encounter conditions to accommodate likely comet-tail orientations off of the Sun-comet line.

COMET/ASTEROID SPACECRAFT

The science payload selected for the 1980 Encke mission opportunities is comprehensive in scope and demanding of spacecraft resources and capabilities. Visual imaging of small bodies (comet nucleus and asteroids) at high spacecraft/target relative velocities is, in particular, a difficult task. The conflicting pointing requirements of the optical instruments and the "ram" or relative-velocity-oriented instruments (mass spectrometers and plasma probe), place additional constraints on system design. A typical Encke mission spacecraft, incorporating the 55.4 kg science payload defined earlier, is shown in Figure 7. This spin-stabilized configuration incorporates, to a high degree, existing subsystem equipment from the Pioneer program. Spacecraft diameter at the base of the conical solar array is 262 cm (103 in) and overall height, not counting the despun antenna assembly is 128 cm (50 in). Mass of the configuration shown is 332 kg (731 lbs).

The shunt-regulated solar array power subsystem provides 235 watts at Encke encounter and about 180 watts at encounter of the asteroids. A nickel-cadmium battery is used to augment the solar array in carrying peak loads. A high-gain antenna, coupled with an on-board tape recorder, provides for the required storage and rapid transmission of scientific data at the comet. Thermal control is adequately maintained by passive methods (louvers and insulation) which contribute to spacecraft simplicity. A monopropellant hydrazine system provides for both spacecraft stabilization and the necessary propulsion for mid-course velocity correction maneuvers.

In this particular configuration, an Encke-pointing attitude was maintained, and communication with the Earth was achieved with a high-gain de-spun antenna. The body-mounted science instruments are fixed in the positions shown. Although a de-spun instrument platform was investigated for comparison, it was found to increase spacecraft mass by about 26 kg and to add considerably to design complexity. An attractive alternate imaging system, still in the development stage, was investigated by the Jet Propulsion Laboratory(5) as part of the science package for a Pioneer-class Encke mission. This system is a high-sensitivity frame camera utilizing an array of charge-couple devices (CCD) as the sensor with internal image motion compensation. The key technical issue, common to all of the concepts under consideration, however, is the acquisition and tracking of the small comet nucleus and the asteroids. This issue concerns the interrelationships between imaging system characteristics (e.g., sensitivity and resolution), imaging system installation on the spacecraft, and the collection and processing of data within the attitude control system. Comprehensive study of these interrelationships is required to determine the preferred concept for implementation in detailed spacecraft design.

Some modifications to the basic spacecraft are required to accommodate the coma probe and to perform the combined Encke/asteroid missions. The central cylinder of the spacecraft structure provides the locations for probe installation. Separation is accomplished with explosive nuts and springs to impart the necessary separation velocity. The higher weight of the spacecraft-with-probe configuration results in somewhat different encounter conditions at comet compared to the reference mission discussed earlier. The effect of this added weight at launch is to reduce time in the comet tail to approximately 6 hours for 388-kg spacecraft/probe configuration (Figure 6).

For the missions which include asteroid encounters, additional propulsion capability is required. The Encke-Geographos mission can be performed by merely increasing the hydrazine tankage. However, for the Encke-Geographos-Toro mission, it was determined that a bipropellant main propulsion system would be required to provide the necessary maneuver velocity. Tankage space is available inside the solar array framework and the engine is mounted inside the booster adapter cone.

A considerable launch-performance margin is available in the Encke-Geographos mission, even with a probe installed on the spacecraft. The spacecraft in this configuration has a mass of 429 kg in comparison to the Atlas/Centaur/TE364-4 launch performance of 550 kg. The double-asteroid mission, however, presents a different situation. The spacecraft mass of 560 kg (without probe) just matches launch vehicle capability and, thus, presents an interesting trade-off between the relative scientific value of multiple-asteroid encounters versus deep coma probing at the comet.

ENCKE '80-PREPARATION FOR HALLEY '86

Halley, the largest and most active of the periodic comets, is a target of particular significance in small-body exploration. The next appearance of Halley will be in 1986, but its 76-year period means a once-in-a-lifetime opportunity for observation and study. The retrograde motion of

TABLE VI. COMPARISON OF ASTEROID MISSIONS

	REFERENCE COMET MISSION	GEOGRAPHOS MISSION	GEOGRAPHOS/TORO MISSION
Required C_3 (km^2/sec^2)*	75.0	47.0	46.0
Injected Weight (kg) (lb)	335 (739)	550 (1213)	560 (1235)
ΔV Maneuver/s (m/sec)	0	130	200/740
V_{HP} at Encounters (km/sec)	18	26/13**	26/13/8
Mission Duration (days)	85+	485+	622+
Encounter Phase Angles (deg)	0	12/29	12/29/78
Sun/Body/Earth Angles (deg)	127	122/16	122/16/15
Tail Passage Time (hrs) ***	9-13½	1.2-1.3	1.1-1.2

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* Corresponds to 10-day launch period in all cases.
** Indicates Encke/asteroid values (typical).
*** Assumes that tail passage time is maximized by varying targeting point for a constant flyby radius of 5000 km.

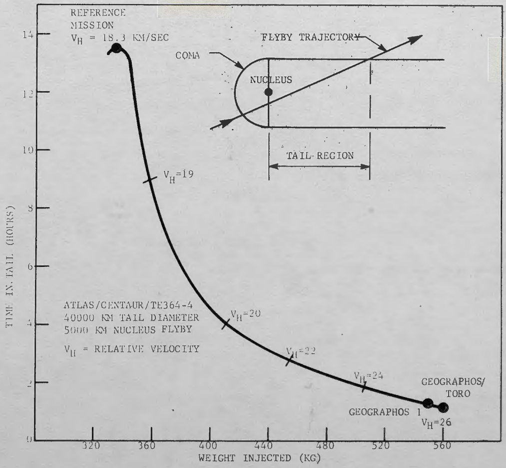

FIGURE 6. EFFECT OF INJECTED SPACECRAFT WEIGHT ON TIME IN COMET TAIL

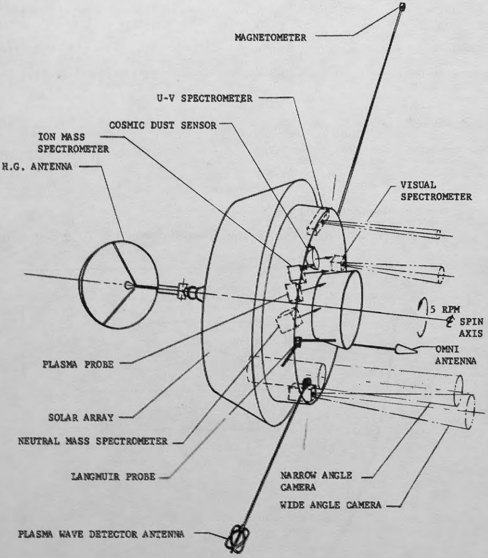

FIGURE 7. TYPICAL SPACECRAFT CONFIGURATION

this comet in its orbit presents a unique problem in the planning and accomplishment of spaceflight missions. Spacecraft encounter velocities will be of the order of 50 km/sec, even with SEP spacecraft. The lessons learned on an Encke '80 mission of the class discussed herein can provide timely scientific and technical input required for the successful implementation of a Halley mission.

High encounter velocity presents a number of problems for scientific instrumentation which could be resolved and tested on the Encke mission. The issue of detecting and tracking the comet nucleus with the imaging system has already been identified. In addition, mass spectrometers, vital to the determination of comet constituents, need to be developed and proven for high-velocity operation. Several mass spectrometers are in development for planetary missions, but techniques for long-time collection of comet-specific species need to be incorporated into instrument design. The flow-through spectrometer concept appears promising for comet applications.

The cosmic dust analyzer is another important instrument that needs further development. In theory, fast flyby velocities aid in ionization of particles, but there are problems with spectral scan rates, with ambiguity of chemical species detected, and with inlet design which assures that ionization does not occur before hitting a detector plate.

Successful operation of these instruments as well as the increase of fundamental comet knowledge obtained in an exploratory Encke mission are required to provide a high degree of confidence in the success of the more difficult Halley flight.

CONCLUDING REMARKS

It has been shown that a number of Encke pre-perihelion, short-flight-time mission options during the 1980 apparition of the Comet Encke are available for consideration by the scientific community and NASA program planners. In addition, ballistically-launched, spin-stabilized spacecraft-within the capability of the Atlas/Centaur/TE364-4-can feasibly support a broad-based instrument complement for the effective accomplishment of scientific goals in the exploration of Comet Encke and the asteroids Geographos and Toro. Furthermore, resolution of key technical questions to support an Encke '80 mission can provide the groundwork necessary for continued small-body exploration including encounter of Comet Halley in 1986.

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