3.10 MARINER MISSION TO ENCKE 1980

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I. INTRODUCTION

A. Why Study Comets?

The planetary program has always been conducted with the hope that the results would reveal great insight into the early period of solar system history and perhaps into the actual formation processes themselves. However, little knowledge has been gained of this very early stage for several reasons: The intense surface bombardment of all larger bodies, particularly in the inner solar system during that period; the subsequent differentiation of large bodies; and atmospheric effects and continued bombardment of the surface. The most promising approach to acquisition of knowledge pertaining to the early state of the solar system, its origin and evolution, therefore seems to be in the study of small bodies, e.g., comets and asteroids.

B. Do we need a space probe?

Ground based comet observations have yielded relatively little information regarding their composition and behavior, and this section will point out the need for a close-up look at comets.

There is little hope of verifying the existence of a nucleus without close-up viewing with ~100 meter resolution cameras, in fact no one has seen a cometary nucleus as anything more than a point of light its approximate size implied from apparent brightness. Also, the nucleus size, shape and albedo (all important for thermal balance calculations) cannot be determined without a space probe.

Even though within the last two years 3 probable parent species (H_2O, HCN, and CH_3CN) have been detected by ground based radio observations, the source of most observed radicals and ions is not known. Furthermore, other "parent" species must be present as well as other molecular species which arise as a result of molecular interactions and photo-processes. The whole question of molecular abundances must remain open without in situ study by a mass spectrometer.

A cometary flyby mission should enable the determination of the gas to dust ratio (necessary for thermal balance calculations) as well as the composition of solids. The composition will be compared to cosmic abundances which may provide an idea of the region of comet formation, whether from the outer regions of the solar nebulae or from interstellar material. If the nuclear bodies represent the primitive material of the solar nebula, it represents the oldest and least modified of any material we are ever likely to study.

In spite of efforts to understand the formation of ion tails and energization processes therein, the whole question of solar wind interaction remains open. Several interaction modes are possible: ionospheric, atmospheric, unipolar induction, and possibly a vestigial cometary field. These questions will remain unanswered until fields and particles measurements are made which will verify the existence (or nonexistence) and location of bow shock and contact surface caused by the comet as it acts as an obstacle to the solar wind flow. Quite possibly one could also observe changes in the comet tail structure and behavior in response to traveling interplanetary phenomena such as blast waves and other discontinuities in the solar wind.

The mission described in this paper is based upon the use of the spare Mariner 10 Spacecraft with as little science and hardware changes as possible (1, 2).

C. Why Encke?

Three general criteria largely determine the quality of a cometary flyby: the activity of the comet, the relative velocity of the encounter, and the approach distance. All long period comets are excluded from consideration since their positions are never well enough known in advance to maneuver a spacecraft sufficiently near to them. Encke's perihelion distance is less than any other short period comet, and its intrinsic activity is quite high so that its activity as determined by its visual brightness is larger than any other suitable comet except P/Halley.

Flyby velocity relative to P/Encke at perihelion can be as low as ~7 km $\sec^{-1}$ while relative velocities of other short period comets with perihelia near 1 AU are typically ~15 km $\sec^{-1}$. The ballistic intercept of P/Halley has a relative velocity of 55 km $\sec^{-1}$.

Because P/Encke is brighter at encounter than other available comets, it can be found earlier so that terminal guidance techniques can be used, which can result in an approach distance of a few hundred km.

II. EXAMPLE EXPERIMENTS AND HOW GOOD ARE THEY FOR P/ENCKE?

A. Volatile Analysis

One of the critical areas mentioned was that of volatile analysis. It is important to measure number densities down to say 10^{-4} that of H_2O which for P/Encke at ~0.4 AU means that number densities as small as 10^2 cm^{-3} must be measurable. This can be accomplished with a double-focusing, magnetic sector mass spectrometer having a unit duty cycle detector (measuring all masses simultaneously).

To obtain unit duty cycle performance, one can use a microchannel array at the focal plane of the spectrometer and the electrons produced are accelerated to a phosphor coated surface, the photons produced here can be directed to a photodiode array by fiber optics. The overall gain is $\sim 10^6$ with mass range of 1-100 amu being read out simultaneously. The ionizing efficiency may be improved over present mass spectrometers by using higher ionizing beam currents. One ion per 10^2 neutrals cm^{-3} instead of one per 10^3 cm^{-3} is probably realizable. The spectrometer can be operated with a retarding potential to create a barrier against molecular fragments and products from spacecraft contamination.

The P/Encke H_2O source strength was measured at 0.71 AU (assuming that all of the atomic hydrogen results from dissociation of H_2O). Scaling this measurement to 0.4 AU and using typical values of the lifetime and initial velocity of H_2O we obtain the H_2O density as a function of nuclear distance.

Table 1 gives the number density of H_2O and of other species with various lifetimes having mixing ratios of 10^{-2} to 10^{-4} that of H_2O at three distances from the nucleus. Also given are the integration times required to give a SNR of three for the spectrometer described above. Clearly, the desired sensitivity with short integration times is easily achieved with such an instrument.

B. Non-Volatile Analysis

Chemical Analysis of the non-volatile components is one of the most important objectives and one of the most difficult to achieve. Typical dust detectors use a target of gold or tungsten which upon impact volatilizes and partially ionizes the incident particle, after which the ions are analyzed by some form of mass spectrometry for example time of flight. This type of instrument would have a mass range of 10^{-10} to 10^{-15} grams and hopefully a mass resolution ($\Delta m/m$) of 60 from perhaps 12 to 70 amu.

The dust model assumes a distribution derived from observations of Arend-Roland (3) and Bennett (4). The model was scaled to Encke by assuming a total mass of dust equal to the total mass of volatiles, which is probably near the upper limit of solids. Table 2 shows the fluence and density for various size particles. The peak of the distribution is a density of 25×10^{-6} cm^{-3} at a 200 km miss distance so that a 100 cm^2 target area would result in counting rates of 10^3 per second so that saturation would not be a problem. Particles of mass 10^{-10} grams (4×10^{-4} cm diameter) and smaller can be detected with this analyzer but for larger particles an additional particle detector is required, e.g., optical, microphone, cell penetration or capacitor discharge detectors. An instrument designed with a mass range of 10^{-3} to 10^{-6} grams and a detector area of 10^4 cm^2 would result (for a trajectory 200 km from the nucleus) in count rates of 10^{-1} to 10^2 sec^{-1}. These dust and particle detectors would complement each other and leave a gap in particle size of only one order of magnitude between 10^{-3} and 10^{-4} cm.

C. Imaging

The primary scientific goal of the imaging system is to furnish high resolution pictures of the nucleus. The cameras used in this study consist of dual cameras one of which is the Mariner 10 150 cm f/8.43 system and one is the Mariner 9 50 cm f/2.35 system. For design purposes we assume Encke has a nuclear diameter of 3 km and ρr^2 = 0.24 where ρ is the geometric albedo an r is the nuclear radius. Taking into consideration the image smear due to spacecraft attitude drift and the relative velocity of the comet and spacecraft, and assuming a lunar phase function we calculate the nucleus resolution as a function of distance (Figure 1). Also shown is the time to encounter, the exposure time, and image size. The camera system takes a picture every 42 seconds with alternate cameras (a picture every 84 seconds per camera),

Table I

Mass Spectrometer Operation in P/ENCKE at 0.4 AU
(Molecular density and integration time to give SNR = 3)

Number Density Lifetime	Distance		
	200 km	500 km	1000 km
H_2O 7.272×10^4 s	6.8×10^6 cm^{-3} 1.3×10^{-4} s	1.1×10^6 cm^{-3} 8.2×10^{-4} s	2.6×10^5 cm^{-3} 3.5×10^{-3} s
10^{-2} H_2O $\tau \geq 5 \times 10^5$ s	9.3×10^4 cm^{-3} 9.7×10^{-3} s	1.5×10^4 cm^{-3} 6.0×10^{-2} s	3.7×10^3 cm^{-3} 2.4×10^{-1} s
10^{-3} H_2O $\tau \geq 5 \times 10^5$ s	9.3×10^3 cm^{-3} 9.7×10^{-2} s	1.5×10^3 cm^{-3} 6.1×10^{-1} s	3.7×10^2 cm^{-3} 2.6 s
10^{-4} H_2O $\tau \geq 5 \times 10^5$ s	9.3×10^2 cm^{-3} 9.9×10^{-1} s	1.5×10^2 cm^{-3} 6.8 s	3.7×10^1 cm^{-3} 37 s
10^{-2} H_2O $\tau = 1.476 \times 10^4$ s	6.5×10^4 cm^{-3} 1.4×10^{-2} s	9.4×10^3 cm^{-3} 9.6×10^{-2} s	2.0×10^3 cm^{-3} 4.5×10^{-1} s
10^{-2} H_2O $\tau = 2.52 \times 10^3$ s	4.8×10^4cm^{-3} 1.9×10^{-2} s	4.4×10^3 cm^{-3} 2.1×10^{-1} s	4.4×10^2 cm^{-3} 2.1 s

Table II

Dust Concentration and Fluence, Nominal Model

Diameter, cm	Velocity, ms^{-1}	Concentration, m^{-3} at 10 km*	Fluence, m^{-2} at 10 km†
0.925×10^{-4}	277	3.62×10^2	1.14×10^7
0.975×10^{-4}	272	8.46×10^2	2.66×10^7
1.125×10^{-4}	248	6.80×10^3	2.14×10^8
1.5×10^{-4}	212	1.01×10^4	3.17×10^8
2.175×10^{-4}	177	6.83×10^3	2.15×10^8
3.3×10^{-4}	141	2.94×10^3	9.24×10^7
5×10^{-4}	114	9.84×10^2	3.09×10^7
9.5×10^{-4}	82	5.92×10^2	1.86×10^7
1.975×10^{-3}	56	1.22×10^2	3.84×10^6
3.325×10^{-3}	43	1.98×10^1	6.22×10^5
6×10^{-3}	32	5.00	1.57×10^5
1×10^{-2}	24	5.17×10^{-1}	1.62×10^4
2×10^{-2}	16	9.75×10^{-2}	3.06×10^3
5×10^{-2}	8.6	5.10×10^{-3}	1.60×10^2
1.2×10^{-1}	4.6	2.61×10^{-4}	8.21
3.34×10^{-1}	1.9	1.31×10^{-5}	0.41

*Concentration $\propto R^{-2}$
†Fluence $\propto R^{-1}$

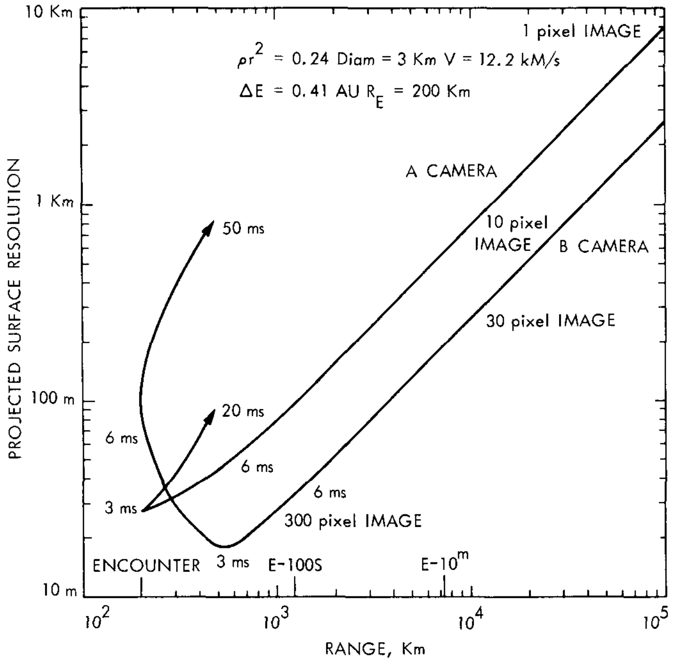

Figure 1. Nucleus Resolution

so we can estimate the total number of pictures obtainable as a function of resolution. For example we obtain 4 pictures with better than 100 meter resolution and about 70 pictures with better than 1 km resolution.

D. Ultraviolet Spectrometer

The ultraviolet spectrometer can obtain two dimensional maps of the coma and corona from which we can obtain production rates, and observe the coma structure and tail symmetry relative to the sun comet vector. It can also hopefully resolve mass ambiguities in the mass spectrometer measurements, e.g., CH_4, NH_2 and O all at mass 16; NH_3 and OH at mass 17; and CO and N_2 at mass 28.

By slight modifications to an existing instrument designed for the MJS Mission (5) an instrument suitable for comet missions can be obtained. An example calculations shows that for the NO bands 1909-2260 Å with a production rate Q of 10^{-3} that of H_2O a SNR of 3 is obtained with an integration time of ~4 minutes.

E. Magnetic Fields and Plasma Experiments

The fluxgate Magnetometers and electrostatic analyzers already on the Mariner 10 Spacecraft are capable of detecting a bow shock and contact surface if they exist. They would measure changes in the magnetic field strength and direction as well as fluctuations up to 10 Hz, and the energy, flow direction, and density of the electrons and ions. Also energization processes in the tail could perhaps be identified.

F. Other experiments have been considered some of which are perhaps desirable and others which are probably not useful for a comet mission. Those which are not useful include infrared spectrometry for lack of instrument sensitivity, mass determination by use of radio tracking, and radio measurements of electron densities. Those instruments which should be considered further are an infrared radiometer, a plasma wave detector, and a plasma ion spectrometer.

III. MISSION DESIGN

Due to the unique relationship between the Earth and Encke orbit geometries during the 1980 apparition, there is an opportunity for a short flight time-low flyby velocity mission. This situation will not occur again for 33 years. Due to spacecraft thermal control constraints, the encounter was chosen to occur at a solar distance of 0.4 AU.

A. Mission Profile

A single spacecraft is launched in early September 1980 by a Titan launch vehicle. The spacecraft encounters Encke in late November within a few hundred kilometers of the nucleus. The encounter sequence begins with periodic imaging a few days before closest approach. Analysis of the gaseous and solid material in coma continues as the spacecraft passes to the anti-sun side of the nucleus and enters the tail. Imaging ceases shortly after closest approach.

B. Trajectory and Targeting

Figure 2 shows a typical trajectory as seen from the north ecliptic pole. The spacecraft orbit is nearly in the plane of Encke's orbit which is inclined about 12° to the ecliptic plane. The comet approaches the slower moving spacecraft from the outside, i.e., at small phase angles, overtakes it and continues inward towards perihelion. The spacecraft aimpoint was selected to be along the anti-sun line as close as possible to the nucleus such that the 3σ error eclipse just touches the nucleus (Figure 3).

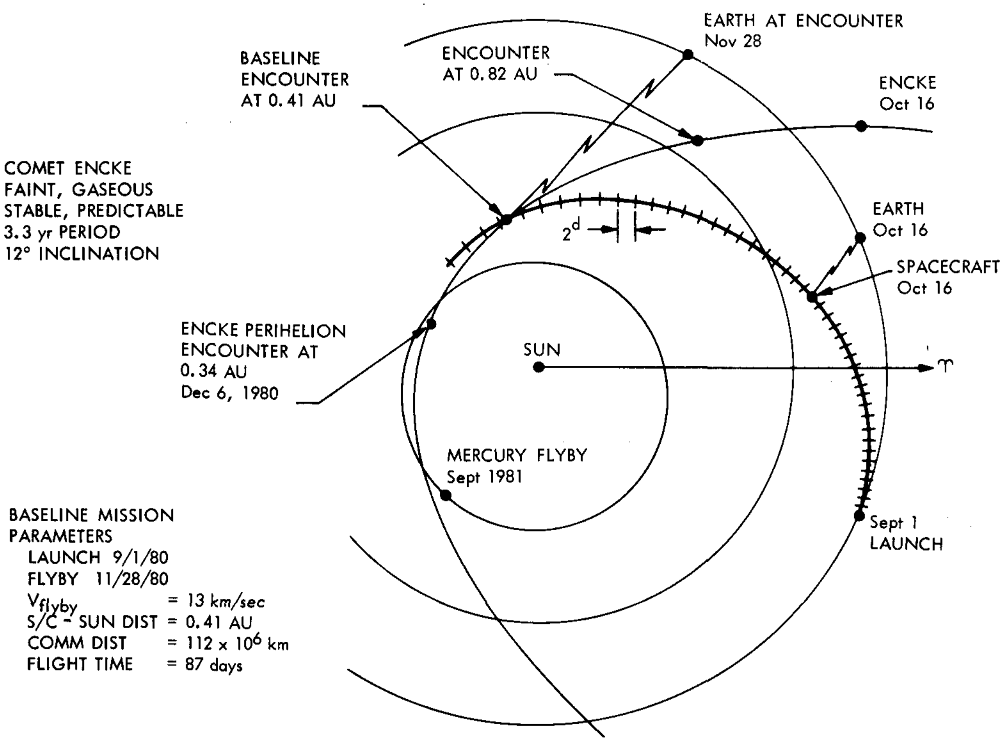

Figure 2. Mariner Encke 1980 - Trajectory Profiles

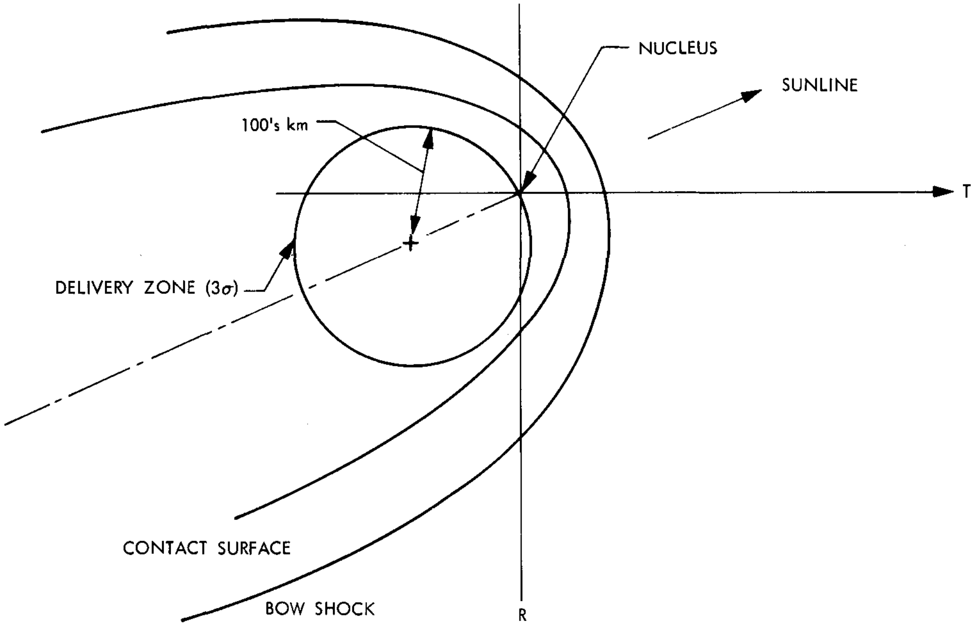

Figure 3. Mariner Encke Targeting Requirements

Analysis shows that nine days before encounter, the onboard TV cameras will acquire the comet and begin the optical navigation phase. The final spacecraft maneuver will occur between E-6^d and E-4^d.

C. Spacecraft

Acceptable solutions were found for all the problems caused by the constraint of retaining the spare Mariner 10 Spacecraft. The two major problems were thermal control of the spacecraft (no more than 6 sun intensity allowed) and approach navigation to within a few hundred kilometers of the nucleus. This spacecraft appears to be capable of supporting a wide variety of science experiments. Figure 4 shows the Mariner 10 Spacecraft.

IV. CONCLUSIONS

The mission presented here represents a reconnaissance type mission which is necessary before more elaborate comet missions are attempted such as a rendezvous or flyby of Halley. The mission design itself is based on limited observations and theory. In spite of these constraints, the available spacecraft and science instruments discussed here will provide a wealth of new information which will result in answers to many of the questions discussed in Section I.

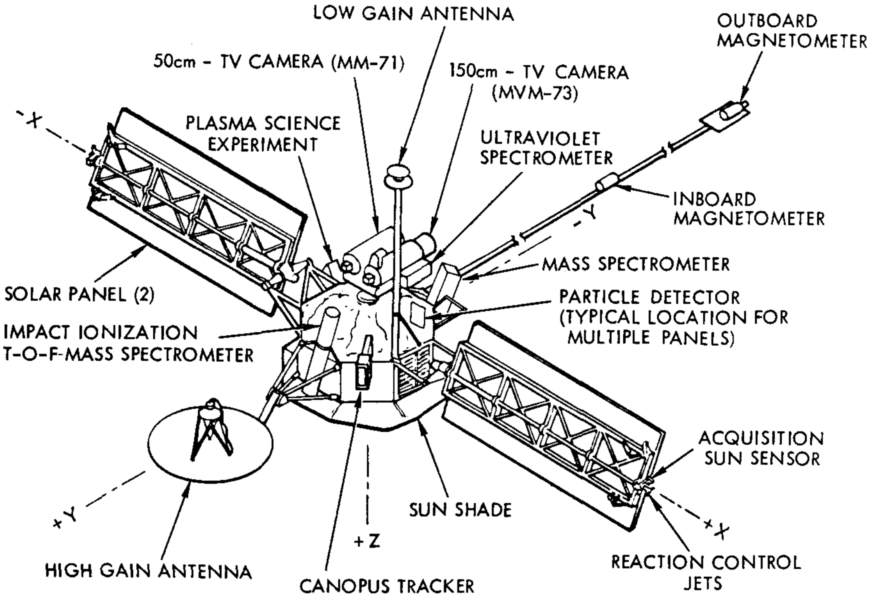

Figure 4. Mariner Encke 1980 Baseline Configuration

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6. The work described in this paper was supported by NASA Contract NAS 7-100.