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STUDY OF 1980 COMET ENCKE-ASTEROID MISSIONS USING A SPIN-STABILIZED SPACECRAFT

Volume I

SUMMARY REPORT

October 1973

Prepared Under Contract No. NAS2-7564

by

MARTIN MARIETTA CORPORATION
Denver, Colorado 80201

for

AMES RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Approved: G. R. Hook
G. R. Hook
Program Manager

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FOREWORD

This report has been prepared in accordance with the requirements of Contract NAS2-7564 and under the direction of the NASA Contract Monitor, Edward L. Tindle. The data and conclusions presented are the result of a three-month technical effort conducted for the Ames Research Center by the Martin Marietta Aerospace, Denver Division. The report is divided into the following volumes:

Volume I	Summary
Volume II	Technical Report

Volume I provides a concise overview of the study, and Volume II contains the detailed data and analyses which support the conclusions reached in the study. Volume II, in addition, provides a compilation of previous work accomplished under Martin Marietta sponsorship on several 1980 Encke mission modes which were not included in the study scope of the present contract.

ACKNOWLEDGEMENTS

The participation of the following individuals in this study is acknowledged. Their able efforts, though often limited in duration, contributed significantly to the study and are greatly appreciated.

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TABLE OF CONTENTS

I. INTRODUCTION

The basis of current high interest in the exploration of comets and asteroids was stated recently by Arrhenius, Alfvén, and Fitzgerald (ref. I-1) as follows:

> Although possibilities for further significant observation from Earth have not been exhausted, it is clear that the real breakthrough in understanding formation of matter around the Sun and the early stages of aggregation of solid bodies must come from spaceflight missions to asteroids and comets, first penetrating close to and then directly sampling these bodies. From a scientific point of view, this direct sampling would be the most rewarding, hence the arrival at this stage should be accelerated in all possible ways. However, from the points of view of expediency, technological development, and most efficient planning for this ultimate stage, the logical progression would be to first carry out fast-flyby and rendezvous missions before docking, local investigations, and sample return missions are attempted.

A. BACKGROUND

Considerable effort has been devoted in recent years to the assessment of slow flyby, rendezvous, docking, and sample return missions to the Comet Encke which has been identified as a desirable target for initial spaceflight missions. These mission classes, however, involve long ballistic flight times (of the order of the 3.3-year comet period) and large inflight propulsion maneuvers. Shorter flight times of approximately 1.5 to 1.7 years would be possible if an operational solar electric propulsion system were developed. Less attention has been directed toward the analysis and evaluation of the much shorter ($\sim$ 3 months) and lower-cost ballistic fast-flyby mode.

As a contribution to improved understanding of early comet exploration options, independent studies were undertaken by the Martin Marietta Corporation, Denver Division which resulted in the identification of a number of fast flyby mission options for the 1980 apparition of Encke. The primary impetus for this approach was the prospect of utilizing existing launch vehicles and conventional spacecraft technology. In addition, timely experience and scientific data gained through an early fast flyby could prove valuable in implementing more ambitious succeeding missions, including a flyby of Comet Halley in 1986.

Another desirable consideration in planning for initial exploration of small bodies of the solar system is that of economic combinations of auxiliary objectives with the primary target on a single mission. Such a mission would then generate data to provide a better basis for more extensive future investigations. Consequently Martin Marietta's study was extended to identify asteroids that could be secondary targets for flyby after encountering Encke. It was determined that Geographos and Toro can be such targets.

It was also determined in these studies that a pre-perihelion encounter of Encke was the most desirable since: (1) it provided a mission to the comet while it was still "active", (2) a single spacecraft could pass through both the coma and the tail, spending a considerable number of hours in the tail, and (3) this was the only encounter found where subsequent flybys of asteroids could be accomplished on the same mission.

B. PURPOSE AND SCOPE OF PRESENT STUDY

The present study was undertaken to determine the feasibility and desirability of using a low-cost, light-weight spinning spacecraft for ballistic fast-flyby missions to the comet Encke during the 1980 apparition. The scope was limited to Encke pre-perihelion encounter options and included consideration of subsequent encounters with the asteroids Geographos and Toro. A further objective of the study was to assess the utilization of comet coma probes for science enhancement. The technical effort included tasks in the areas of science analysis, mission analysis, and preliminary definition of both spacecraft and probe designs. The Atlas/Centaur/TE364-4 launch vehicle was specified for the study, and existing spacecraft and probe technology was to be used to the maximum extent possible. Critical design areas requiring additional development were to be identified.

This report volume summarizes the work accomplished in the three task areas as well as the resulting conclusions. Detailed supporting data is included in Volume II. An appendix in Volume II documents prior Martin Marietta study results on mission modes not included in the scope of the present study. These included, for example, an Earth-return mission after the comet flyby.

II. SCIENCE OBJECTIVES AND INSTRUMENTATION

A. COMET SCIENCE

In order to establish scientific objectives, observables, and preferred instrumentation for the exploration of Comet Encke, a model of its physical characteristics was developed. The data shown in Table I are a summary derived from comprehensive review of current literature.

TABLE I COMET ENCKE PHYSICAL PROPERTIES SUMMARY

COMET FEATURE	VALUE USED
Nucleus	Starlike
Dimensions (radius)	1.6 km
Mass	2×10^{16} g
Albedo	0.1
Phase Curve	Lambert
Coma	Nebulous
Dimensions (radius)	2×10^{4} km
Max. Gas Density (H_2O Products)	
Near Nucleus	10^{13} molecules/cm^3
Near 5000 km	10^{5} molecules/cm^3
Max. Vel. of Particulate Matter	300 m/sec
Particulate Emission Rate	6×10^{4} g/sec (per active 100 days)
Tail	
Length	10^{6} km, Ion Tail Only
Width	4×10^{4} km

As shown, there are three structural elements of a comet: nucleus, coma, and tail. Encke's nucleus is presumed to be a solid body containing complex molecules such as H_2O, NH_3, CH_4, and CO_2. These sublimate, dissociate, and provide "daughter" molecules seen in comet spectra. Also interspersed in the nucleus ices are meteoric material. The coma is a near-spherical volume of neutral molecules and meteoric dust centered about the nucleus. The solar wind interacts with the coma to produce a tail downstream and other interaction phenomena upstream. Observations have shown that Encke exhibits a Type I tail of ionized plasma but no Type II dust tail. This is consistent with its aging and earlier mass losses. Upstream of the coma, the solar wind is decelerated, either gradually or suddenly, to a transition region, and it then flows around the coma. Some type of contact surface exists which separates the solar wind and the cometary plasma, but the processes which form and maintain this surface are not clearly known.

In accordance with the wide range of observables and energy processes possible at the comet, considerable breadth in instrumentation has been established (Tables II and III) as the basis for providing data to help answer the scientific questions about Encke. In order to enhance the scientific investigation in the areas of complex molecule detection and particulate matter flux, a coma probe is recommended to (1) extend scientific measurements to regions closer to the nucleus than could be accomplished by the parent spacecraft and (2) to provide limited spatial correlations between probe and spacecraft measurements. The selection of a 5000-km flyby radius (relative to the nucleus) resulted from a careful trade between desire for parent-molecule detection and possible particulate damage to the spacecraft. By means of the probe it is possible to maximize the molecule detection without jeopardizing spacecraft survivability. The goals set for the probe and the instrumentation to achieve them are shown in Table IV.

B. ASTEROID SCIENCE

The asteroids present a less complex set of observables for investigation when compared to the comet. Nevertheless, close-up studies of asteroids will help in the understanding of processes involved in the origin and evolution of the solar system. Specific questions to be answered during the flyby of the asteroids and the related instrumentation are shown in Table V. The addition of one instrument, an IR Spectrometer, complements the comet payload for asteroid investigations. Imaging and IR instruments are shown in Table V to predominate in the accomplishment of asteroid objectives. This is another way of stating that asteroid science is oriented toward surface morphology rather than toward 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. For quality measurement of the surface morphology, a maximum distance of $\sim$500 km is recommended. Distances greater than 1000 km would degrade image resolution and IR science objectives.

TABLE II MAJOR COMET SCIENCE OBJECTIVES

LEGEND: ● Prime Investigations
o Secondary Investigations

QUESTIONS	IMAGING	UV SPECTROMETER	VISUAL SPECTROMETER	ION MASS SPECTROMETER	NEUTRAL MASS SPECTROMETER	DUST ANALYZER	LANGMUIR PROBE	PLASMA WAVE	MAGNETOMETER	PLASMA PROBE	IR SPECTROMETER
	SCIENTIFIC INSTRUMENTS										
1. Is there a "Rocky" nucleus?	●										o
2. How does gas flow from nucleus?	o	o		●	●						
3. How do particles flow from nucleus?	o					●					o
4. What are parent molecules?		o			●						o
5. What is gas molecule radial distribution?	o	●	o	●	o						
6. What is ionized gas distribution?	o		o	●			o	o	o	o	
7. How is contact surface maintained?	o			o			●	o	o	●	
8. What is extent/concentration of neutral species halos?	o	●									
9. Is there a deceleration shock?							o	●	●	o	
10. What is density of solar wind around comet?								●		o	
11. What is magnetic field?									●		
12. Does comet have energetic particle production mechanism?									o	o	
13. What is ion concentration in tail?				●			o		o		
14. What is dust concentration in tail?						●					o
15. Does density of solar wind influence comet ionization processes?								o	o	●	

TABLE III - COMET SCIENCE INSTRUMENT CHARACTERISTICS

INSTRUMENT	MASS - KG (LBS)	SOURCE
TV IMAGING SYSTEM	23.4 (51.6)	MM-71
Narrow and Wide Angle Cameras Plus Electronics		
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 IV PROBE SCIENCE AND GOALS

PAYLOAD/(SOURCE)	MASS KG (LBS)	GOALS
COSMIC DUST DETECTOR (Mariner 2,4)	2.0 (4.4)	EXTEND MEASUREMENTS TOWARD NUCLEUS. FIND ANISTROPIES 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 (MANY)	1.0 (2.2)	MEASURE ELECTRON DENSITY IN COMA. MEASURE ELECTRON DENSITY IN TAIL.
TOTAL	11.0 (24.2)	

TABLE V MAJOR ASTEROID SCIENCE OBJECTIVES

LEGEND: ● = Prime Investigation
o = Secondary Investigation

MAJOR SCIENTIFIC QUESTIONS FOR ASTEROIDS	IMAGING	UV SPECTROMETER	VIS. SPECTROMETER	ION MASS SPECT.	NEUTRAL MASS SPECT.	DUST ANALYZER	LANGMUIR PROBE	PLASMA WAVE	MAGNETOMETER	PLASMA PROBE	IR RADIOMETER	POLARIMETER
1. Is the asteroid body a decayed comet nucleus?	●										o	
2. Are surface features of comet nucleus & asteroid similar?	●											o
3. Is particulate matter of comet similar to asteroid regolith surface?						●						
4. What is size, shape of asteroid?	●											o
5. What is polarization in curve of asteroid?	o										o	●
6. What is mineralogy composition (surface material) asteroid?	o										●	o
7. Does asteroid have any residual heat?	o										●	
8. Does asteroid have any magnetic field?									●			
9. Does asteroid have accompanying space debris?	o					●						
10. How long has asteroid been in present orbit?	●					o					o	
11. What is density (mass) of asteroid?	●											o
12. Orientation of axis and rotation rate?	●											o
13. Surface reflectivity, albedo curves?	o										o	●
14. Surface roughness of asteroid?	o										●	o
15. Number of craters?	●										o	o

III. MISSION OPPORTUNITY CHARACTERISTICS

Because of the interest in combining the Encke '80 mission with later asteroid encounters and also because of scientific interest in obtaining in-situ measurements while the comet was still active, effort in this study was directed toward pre-perihelion encounters where these conditions exist.

A. COMET-DEDICATED MISSION

A reference mission (Figure 1) was chosen early in the study, and the rationale for selection was primarily scientific. By launching when the Earth is near the comet plane's ascending node (8-28-1980) and arriving at the comet on 11-20-1980 (16 days prior to its perihelion passage on 12-6-1980), the spacecraft has the unique opportunity to fly nearly directly down the comet's tail (Figure 2) and thus obtains in-situ measurements for the longest period. The reference injected weight for this mission is 335 kg (739 lb) with a flyby velocity of 18.3 km/sec. Higher weights can be launched by the Atlas/Centaur/TE364-4 (reduced launch energy, C_3). The primary effects of launching larger spacecraft are (1) higher encounter velocity, and (2) non-zero approach angle. Both of these factors combine to shorten tail-passage time.

Probe deployment mode comparisons were made in the study and are summarized in Figure 3. The bus propulsion mode, which utilizes the spacecraft RCS propulsion, was selected to maintain simplicity of the probe. The bus is initially targeted for the nucleus, the probe is released, and the bus is deflected to the 5000-km flyby radius.

B. ENCKE/ASTEROID MISSIONS

The basic Encke flyby mission requires less than 1/2 of a revolution of the spacecraft about the Sun, with a duration of less than 1/3 of a year. Because of timing relationships between the comet and asteroids, the combined missions require more than one revolution about the Sun. (From 1 3/4 revolutions for Geographos encounter to 2 1/4 revolutions for an encounter with Toro). These combined mission durations vary from about 1 1/3 to 1 2/3 years.

The four missions considered in this study are:

1) Encke/Geographos 1 (Encounter with Geographos occurs near its perihelion)

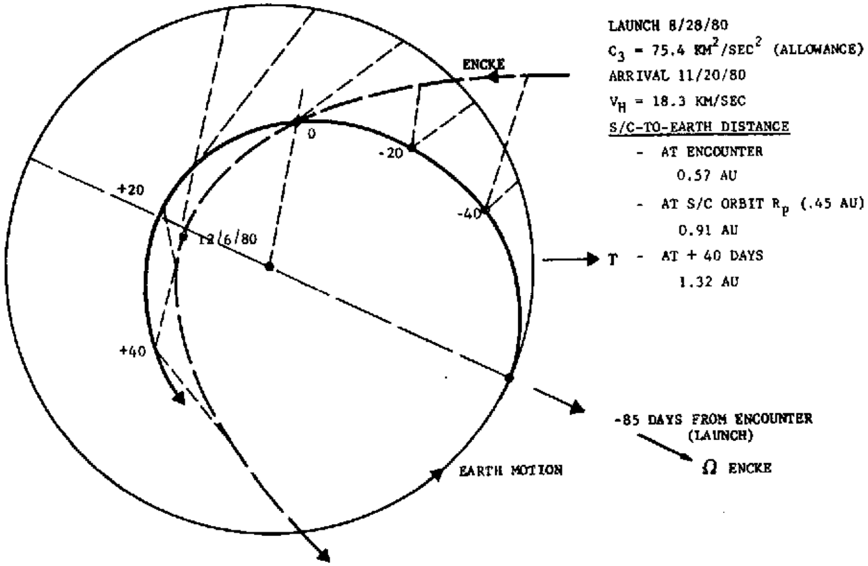


FIGURE 1 COMET REFERENCE MISSION ENCOUNTER TRAJECTORY

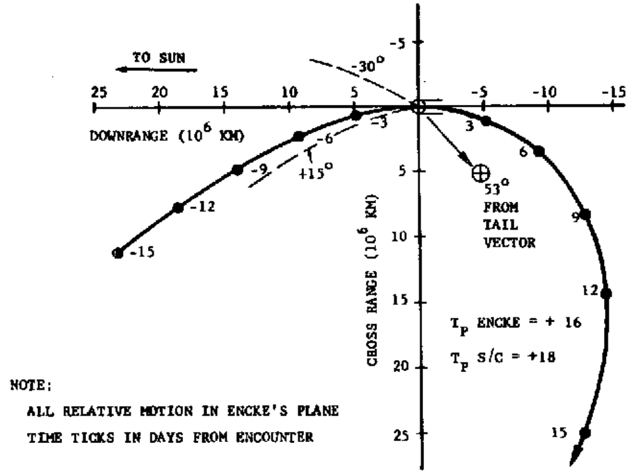
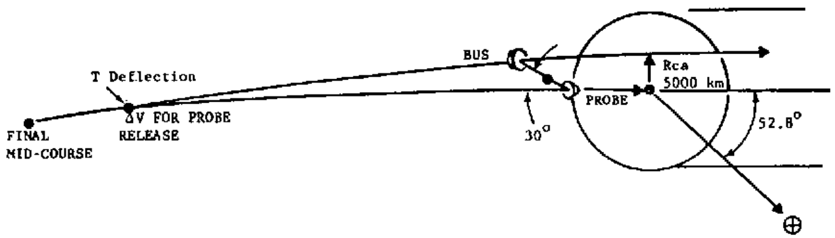


FIGURE 2 SPACECRAFT/COMET RELATIVE MOTION TRAJECTORY



BUS PROPULSION	PROBE PROPULSION	ZERO PROPULSION
ΔV_B = 29 m/s	ΔV_P = 29 m/s	ΔV_P = 6 m/s (60 RPM)
E - 4 Days	E - 4 Days	E - 19 Days
No Probe Propulsion	Probe Propulsion	
No Probe Att. Control	Probe Att. Control	
Uses Existing Bus R.C.S.		

FIGURE 3 PROBE DEPLOYMENT MODE COMPARISON

2) Encke/Geographos 2 (Encounter with Geographos occurs after the asteroid passes perihelion and is near 1 A.U. from the Sun).

3) Encke/Toro (Encounter with Toro occurs near its perihelion)

4) Encke/Geographos/Toro (similar to (1) and (3))

The mission characteristics for these options are listed in Table VI. The impact of the asteroid flyby on the basic comet mission may be summarized as follows:

- Requires additional propulsion system and propellant retargeting ΔV from 130 m/sec (427 ft/sec) to 940 m/sec (3094 ft/sec)
- Increases comet flyby velocity
  from 18 km/sec (59K ft/sec) to 26 km/sec (85K ft/sec)
- Increases total mission duration
  from 3 months to 20 months
- Decreases tail passage time
  from 13 1/2 hrs (maximum) to 1 hr. (minimum)
- Increases injected weight available
  from 335 kg (739 lb) to 560 kg (1235 lb)

For the case of Geographos 2, the communication angle with the Earth (Sun-Geographos-Earth angle) is near zero at encounter. The spacecraft, therefore, probably cannot be tracked from the Earth or communicated with for several weeks before encounter. In addition, there is a dark-side encounter condition (158-deg phase angle). For these reasons, it is recommended that the Geographos 2 mission be dropped from further consideration.

C. NAVIGATION FEASIBILITY

Navigation analyses were conducted for the reference mission (simplest from a navigation standpoint) and for the double, combined mission to Geographos and Toro (most complex). Because of the importance of imaging the nucleus of the comet (and sampling the coma and tail environment) and also imaging the asteroid at close distances, the expected level of ephemeris errors is very important. In the navigation study, it was found that the magnitude of the one-sigma ephemeris error is expected to exceed, typically, 1000 km (at Encke) and to be considerably higher at the asteroids without on-board navigation. Therefore, targeting dispersions due to spacecraft-position knowledge and

TABLE VI COMPARISON OF ASTEROID MISSIONS

	REFERENCE FLYBY MISSION	GEOGRAPHOS 1 MISSION	GEOGRAPHOS 2 MISSION	TORO MISSION	GEOGRAPHOS/TORO MISSION
Required C_3 (km^2/sec^2)* $(ft^2/sec^2 \times 10^{-6})$	75.0 (807)	47.0 (506)	70.0 (754)	68.0 (732)	46.0 (495)
Injected Weight (kg) (lb)	335 (739)	550 (1213)	370 (816)	380 (838)	560 (1235)
ΔV Maneuver/s (m/sec) (ft/sec)	0 (0)	130 (427)	670 (2200)	615 (2018)	200/740 (656/2428)
V_{HP} at Encounters (km/sec) $(ft/sec \times 10^{-3})$	18 (59)	26/13 ** (85/43)	23/14 (75/46)	25/11 (82/36)	26/13/8 (85/43/26)
Mission Duration (days)	85+	485+	538+	608+	622+
Encounter Phase Angles (deg)	0	12/29	9/158	10/114	12/29/78
Sun/Body/Earth Angles (deg)	127	122/16	120/0	121/10	122/16/15
Tail Passage Time (hrs) ***	9-13½	1.2-1.3	1.8-2.3	1.5-1.7	1.1-1.2

*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 (Θ_{AIM}) for a constant flyby radius of 5000 km.

maneuver-exeuction errors can be neglected.

A preliminary assessment was made to determine whether on-board measurements, utilizing the television cameras, could potentially reduce targeting dispersions to the level required to meet science goals. Table VII summarizes the results of this analysis. The major conclusions that can be drawn are:

1) The basic flyby mission without probes can probably be performed without optical sensors, but a concerted effort is needed between now and 1980 (and during the mission) to improve Earth-based ephemeris knowledge of the comet.
2) The basic flyby mission with probe(s) is marginal for probe science return without optical navigation.
3) As long as it is desirable to obtain knowledge on asteroid surface characteristics (and not just overall size or shape) it appears necessary to have on-board optical navigation.

TABLE VII ANTICIPATED DISPERSIONS IN TARGET APPROACH GEOMETRY

	ENCKE MISSION (5000 km Flyby)	AT GEOGRAPHOS 1 (500 km Flyby)	AT TORO (500 km. Flyby)
A. WITHOUT ON-BOARD NAVIGATION			
1. Anticipated 3-Sigma Position Error (km)	3000	4000-8000	8000-12000
2. Possible Effect Upon Mission	Acceptable Imaging Marginal Mass Spec. Marginal Probe Mission With 2-Sigma Errors	Unacceptable Asteroid Imaging	Unacceptable Asteroid Imaging
B. WITH ON-BOARD NAVIGATION*			
1. Anticipated 3-Sigma Position Error (km)	500-1000	Probably Exceeds 1000	Probably Exceeds 1000
2. Possible Effect Upon Mission	Acceptable In All Areas With And Without A Probe	Probably Acceptable -Investigate Further	Questionably. Acceptable - Investigate Further

* Assumes intermediate noise and bias error levels (2-3 pixels); 2 pictures per day; 4 days of tracking.

IV. SPACECRAFT DESIGN CHARACTERISTICS

The direction taken in the design phase of this study was based on several primary guidelines:

- Utilize light-weight spinning spacecraft;
- Incorporate existing equipment to the maximum extent possible; and
- Base designs on the capability provided by the Atlas/Centaur/TE364-4 launch vehicle.

In the selection of subsystem components and spacecraft configuration details, extensive use was made of the results of studies performed for NASA/ARC by Martin Marietta Corporation and other contractors on advanced planetary missions.

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. Accommodation of the science payload, along with the achievement of balanced subsystem performance, was approached in this study as follows. A basic spaceframe/solar-array concept was selected, and five variations of this basic concept were synthesized to evaluate several alternatives for meeting total system requirements imposed by the Encke reference mission and the selected instrument payload. Then, necessary modifications were made, first to accommodate probes, and finally to accomplish the combined comet-asteroid missions.

Five spacecraft-configuration concepts developed in the study are shown in Figures 4 through 8 and, for ease of reference, are identified by number. With the exception of Concept 5, each incorporates the payload shown in Table III. In Concept 5, the two television cameras are replaced by a single spin-scan camera. All concepts evolved from an effort to maintain a high level of scientific accomplishment within reasonable limits of subsystem performance. A major consideration in each case was to minimize the effects of high target-approach velocity and spacecraft spin on the quality of imaging data. The major configuration differences are shown in Table VIII.

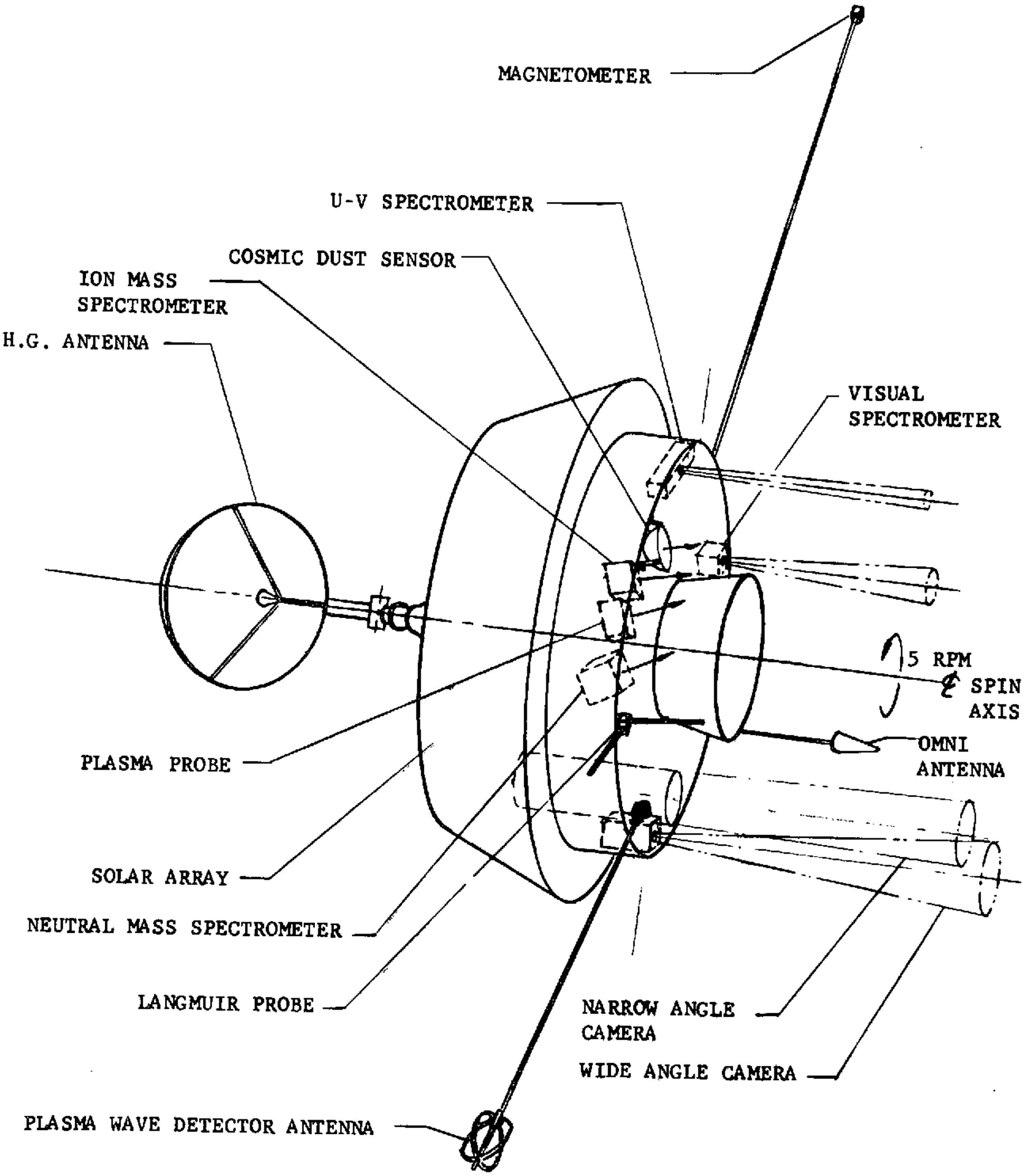


FIGURE 4 SPIN AXIS POINTS TO ENCKE: CONCEPT NO. 1

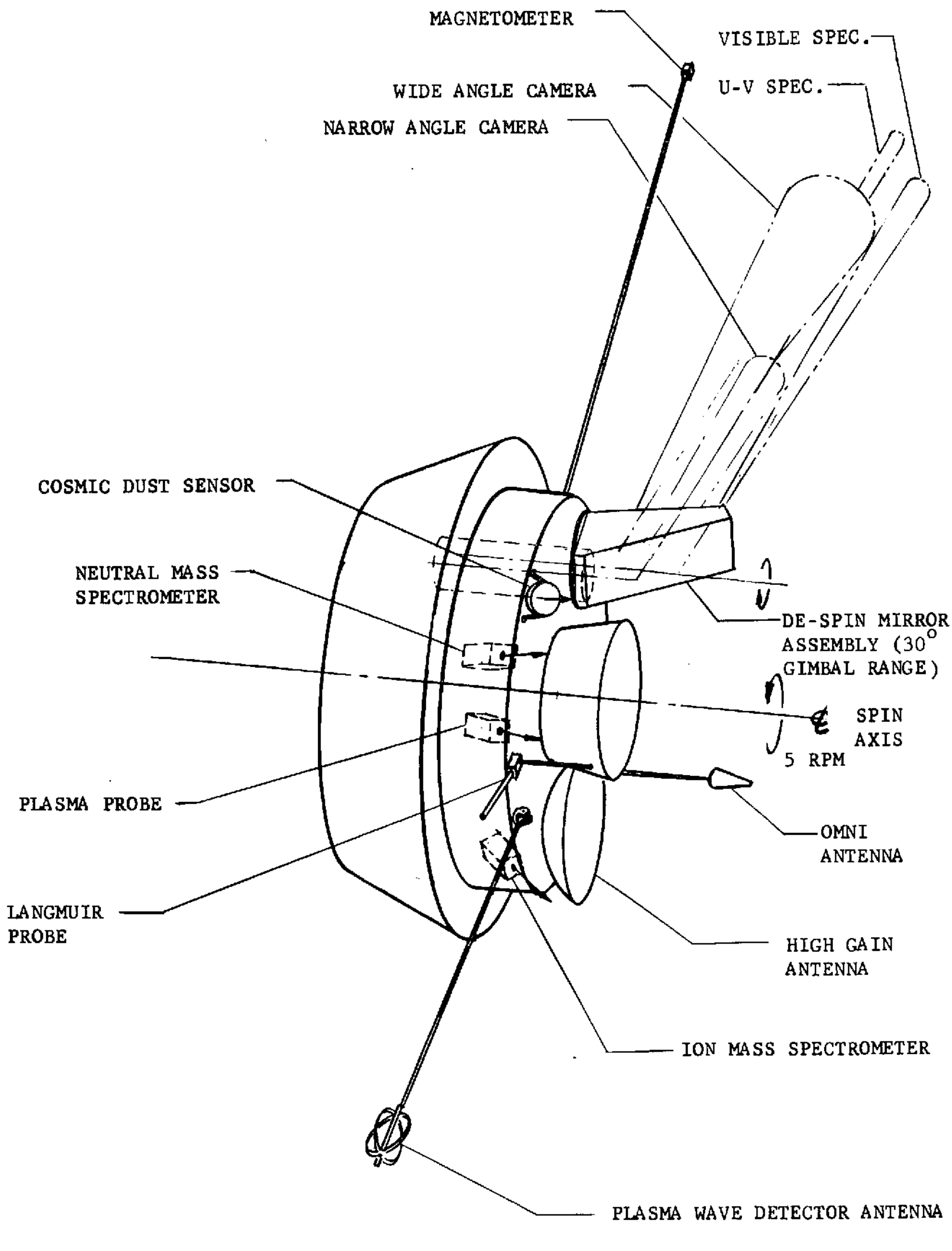
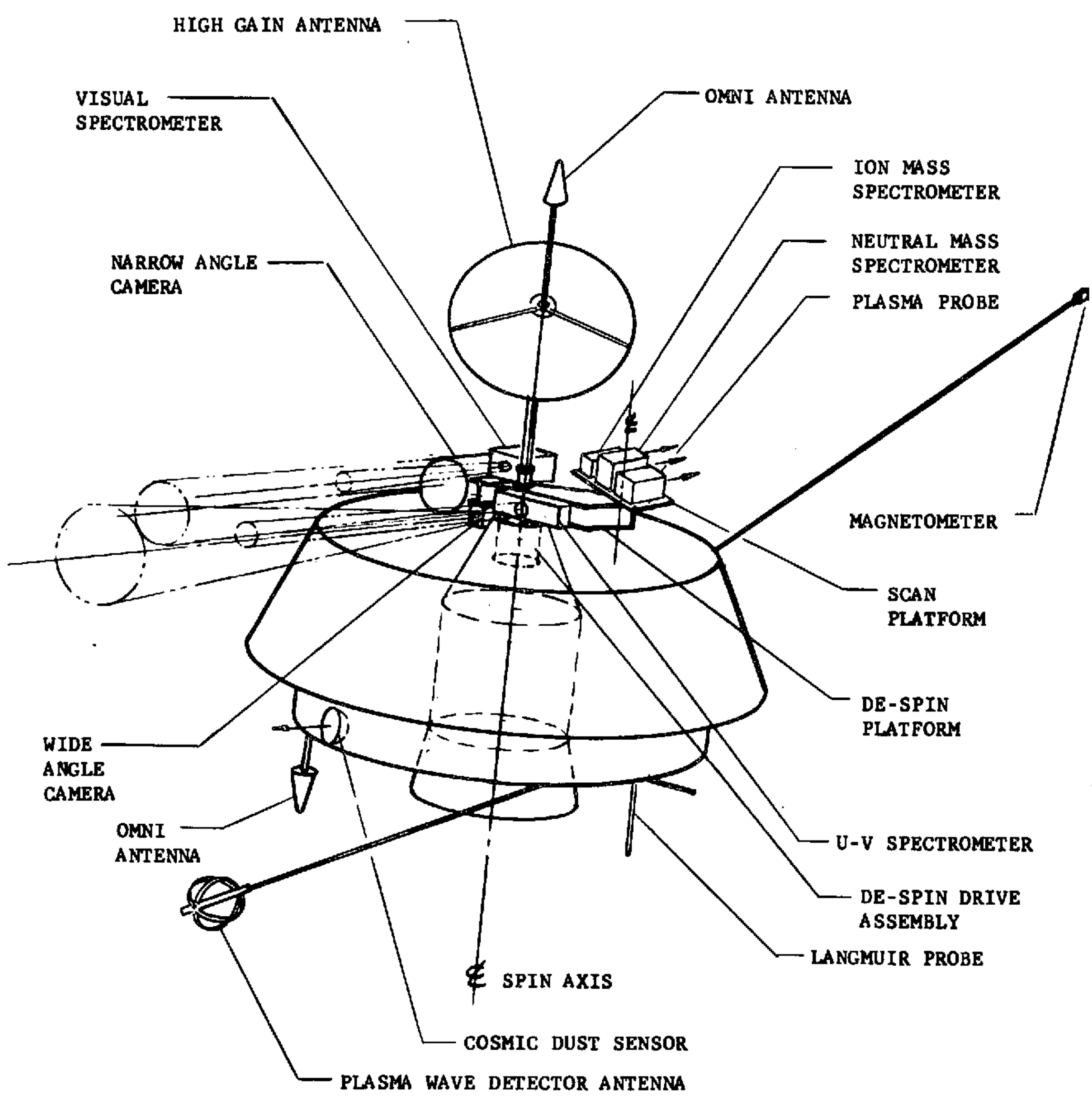
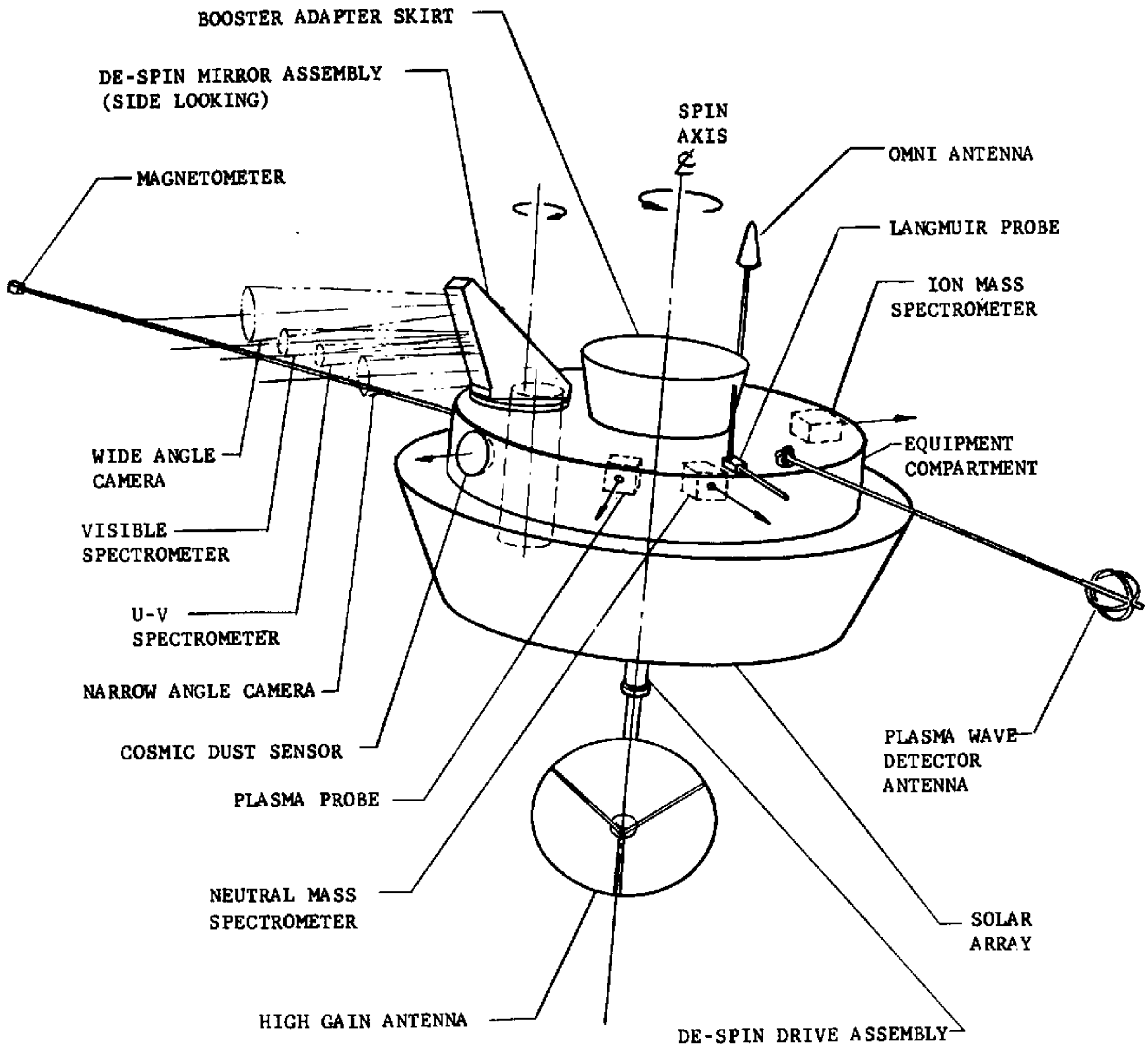


FIGURE 5 SPIN AXIS POINTS TO EARTH : CONCEPT NO. 2



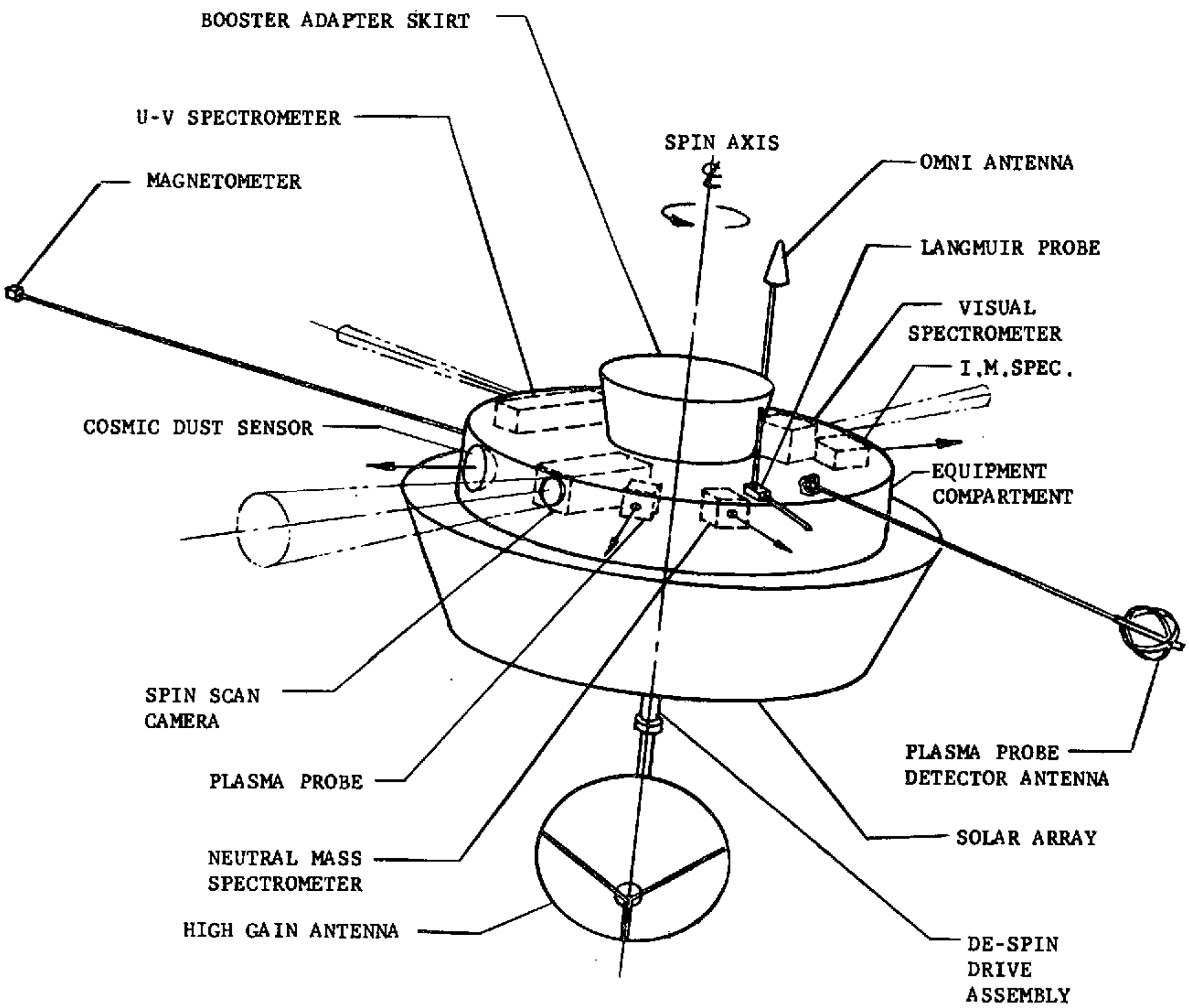
SPIN AXIS PERPENDICULAR TO EARTH/ENCKE/SPACECRAFT PLANE
(DE-SPUN PLATFORM) : CONCEPT No. 3

FIGURE 6



SPIN AXIS PERPENDICULAR TO EARTH/ENCKE/SPACECRAFT PLANE (DE-SPUN MIRROR): CONCEPT NO. 4

FIGURE 7



SPIN AXIS PERPENDICULAR TO EARTH/ENCKE/SPACECRAFT PLANE (SPIN SCAN CAMERA): CONCEPT NO. 5

FIGURE 8

TABLE VIII SUMMARY OF CONCEPT CHARACTERISTICS

CHARACTERISTICS	SPACECRAFT CONCEPT 1	2	3	4	5
SPIN-AXIS DIRECTION	To Target	To Earth	*	*	*
ANTENNA	Despun	Fixed	Despun	Despun	Despun
OPTICAL INSTRUMENTS	Fixed	Fixed	Despun Platform	Fixed	Spin Scan
	Point S/C	Despun Mirror		Despun Mirror	
RAM INSTRUMENTS	Fixed	Fixed/ Canted	Despun Platform	Fixed	Fixed

* (Perpendicular to Earth-Spacecraft-Encke Plane)

The coma probe design developed in this study (Figure 9) is quite simple compared to probes designed to penetrate dense planetary atmospheres. It was concluded in the study that a single probe was an appropriate complement for the Encke spacecraft. Figure 10 shows the location of the installed probe which would be separated from the spacecraft with explosive nuts and springs to impart the necessary separation velocity. For spacecraft concepts 1 and 3, the probe will be located in the aft end of the booster adapter cone. For the Encke-Geographos-Toro asteroid mission, this adapter location is occupied by a required additional propulsion system (Figure 11). The probe then will be installed on the aft end of the vehicle, offset enough from the center to clear the booster adapter structure. This location may require a balancing mass to be installed and jettisoned with the probe. For Concept 2, the probe could be installed above the central cylinder for all missions. The additional high gain antenna required on the forward end for the asteroid missions would be offset from the center and would rotate aside to provide enough clearance for probe separation. For Concepts 4 and 5, the probe is installed above the central cylinder for all missions. The despun high-gain antenna must be positioned off-center to provide clearance for probe separation.

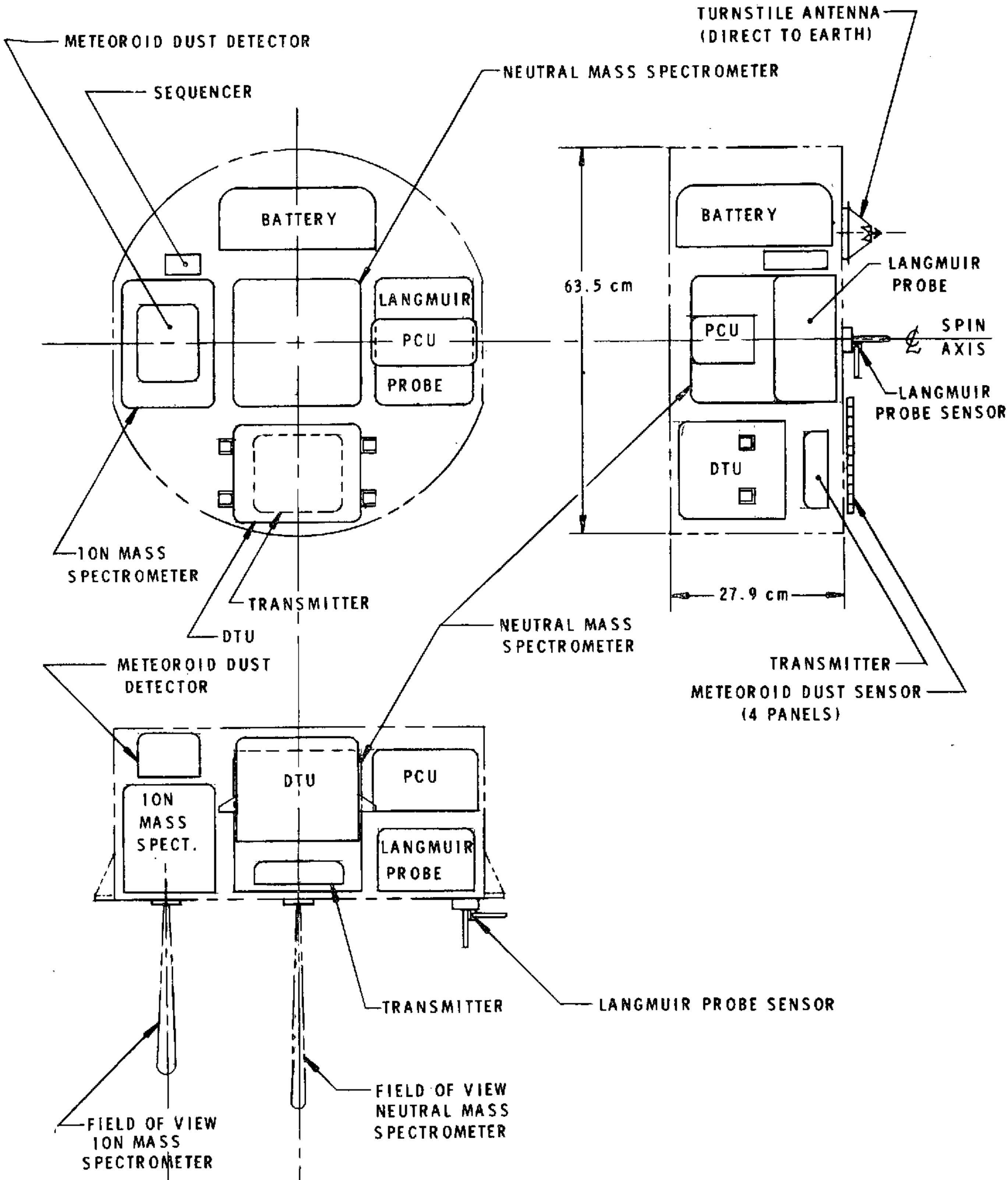
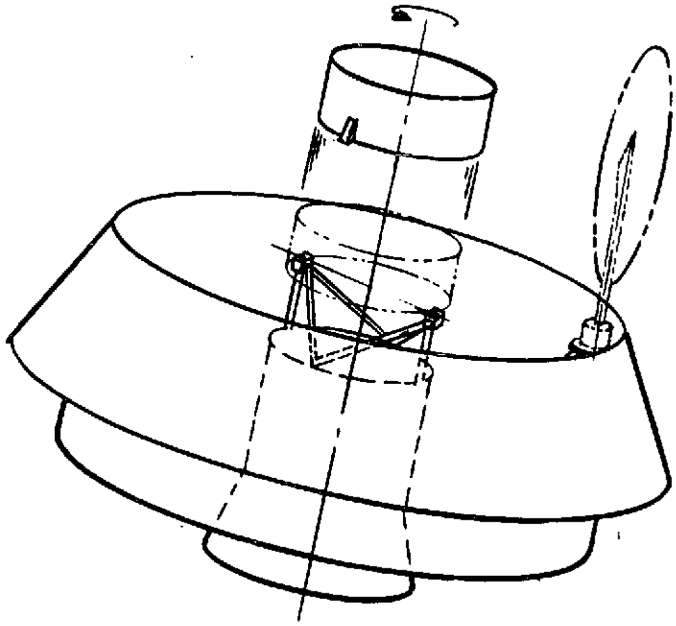
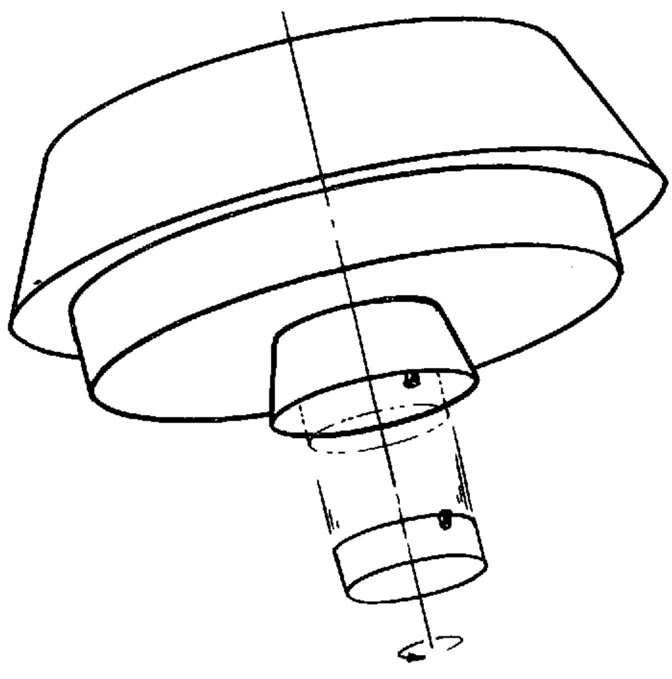


FIGURE 9 PROBE EQUIPMENT ARRANGEMENT CONCEPT



FORWARD PROBE CONCEPT



AFT PROBE CONCEPT

FIGURE 10 PROBE LOCATION CONCEPTS

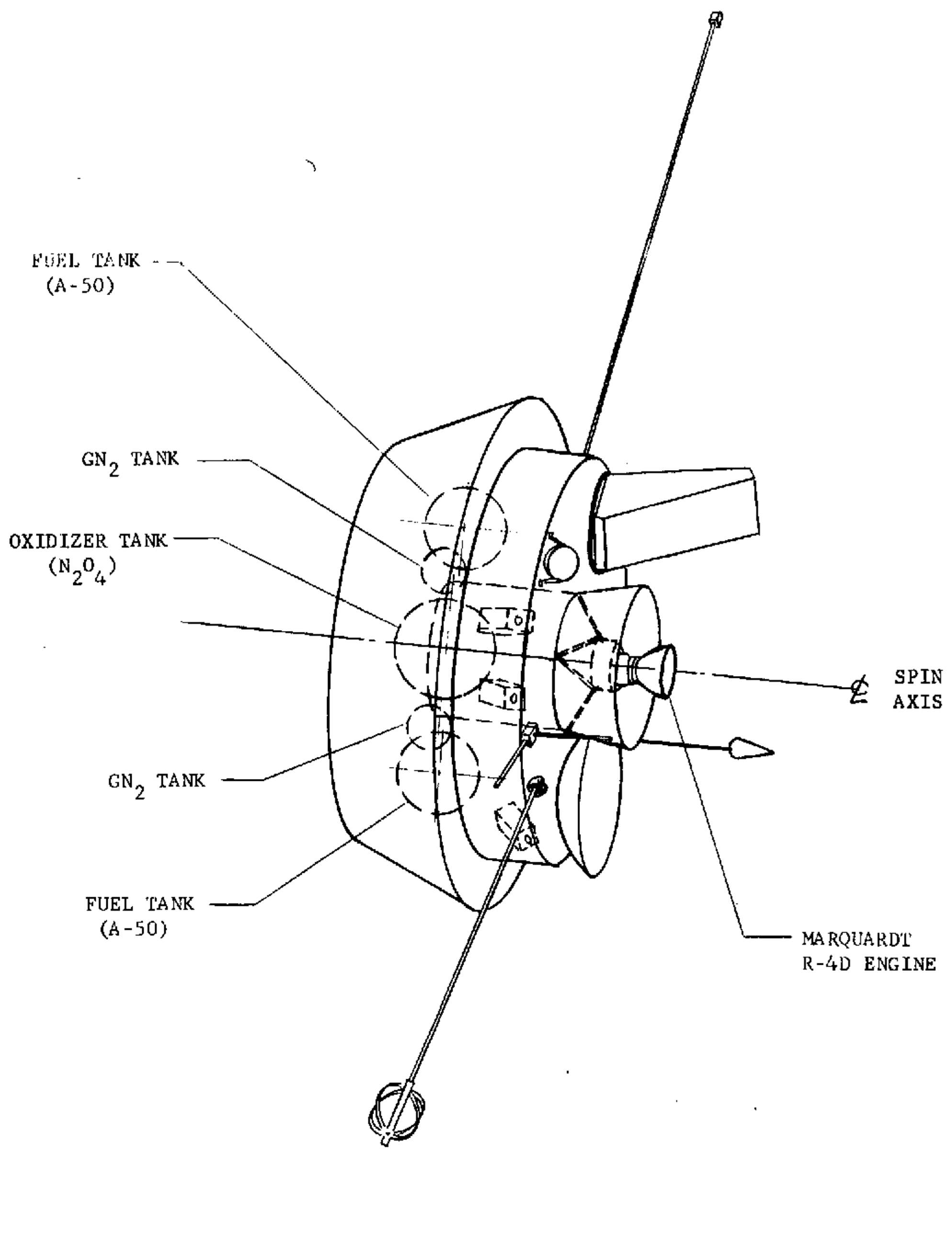


FIGURE 11 ASTEROID MANEUVER PROPULSION INSTALLATION

Table IX is a summary of the mass of each spacecraft concept, with and without probes, on three of the five missions investigated. It was shown in Chapter III that the mission to Encke with a subsequent encounter of Geographos near one AU is not an acceptable mission. The Encke-Toro mission has also been deleted as an acceptable option because the low allowable spacecraft weight (375 kg) is not consistent with the required addition of a main propulsion system to provide a 615 m/sec velocity change. The three missions shown, therefore, represent the preferred options within mission and launch vehicle constraints.

The spacecraft masses shown for the Encke-only mission are, with the exception of Concept 3, within launch vehicle capability of the reference mission, which maximizes the time spent in the comet environment. The higher mass of Concept 3 and of all the concepts in a probe mode can be launched to Encke by the Atlas/Centaur/TE364-4. However, encounter conditions at Encke will be somewhat different with a resulting reduction in tail passage time (fig. 12). It has been concluded that this results in a minimal effect on science accomplishment. A considerable launch-performance margin is available in the Encke-Geographos mission, even with a probe installed on the spacecraft. The double-asteroid mission, however, presents a considerably different situation. When no probes are carried, Concepts 2 and 5 are compatible with the mission-imposed weight constraint on this mission. Concepts 1 and 4 are less than two percent above this constraint, and design refinements or science modifications could yield acceptable weights. For the configurations carrying probes, none of the resulting weights are within launch vehicle capacity when the nitrogen-tetroxide/Aerozine-50 propulsion system is used for the major course-change maneuvers. A brief analysis showed that an advanced space-storable propulsion system would not provide sufficient performance to carry a probe on this mission option, except in the case of Concept 5.

The five spacecraft configurations studied are all spinning spacecraft, but each differs in pointing or despun complexity. The impact on science for each of the configurations is summarized in Table X. All configurations satisfy, to a reasonable extent, the requirements of the science instruments and are optional solutions for resolution during detailed spacecraft design.

TABLE IX SPACECRAFT MASS COMPARISON

CONCEPT	MISSION MODE: ENCKE-ONLY		ENCKE-GEOGRAPHOS		ENCKE-GEOGRAPHOS-TORO
	NO PROBE	PROBE	NO PROBE	PROBE	NO PROBE
1	332 kg (731 lb)	388 (854)	370 (815)	432 (951)	569 (1255)
2	326 (718)	382 (841)	365 (806)	424 (934)	561 (1237)
3	358 (789)	415 (914)	397 (876)	455 (1003)	609 (1342)
4	332 (732)	388 (856)	370 (816)	432 (952)	570 (1257)
5	299 (658)	353 (779)	337 (736)	394 (868)	515 (1136)
L/V Capability	Minimum = 335 (739) (Ref. Mission)		550 (1213)		560 (1235)

NOTE: Spacecraft Mass Estimates Include 10% Design Margin

TABLE X CONFIGURATION IMPACT ON SCIENCE

	SPACECRAFT CONCEPT				
SCIENCE CATEGORY	NO. 1 (ENCKE POINT)	NO. 2 (EARTH POINT)*	NO. 3 (DESPUN)	NO. 4 (PERPENDICULAR)*	NO. 5 (SPIN-SCAN)
Imaging/Optical	Good until near RCA	Good until RCA	No Restrictions	No Restrictions	Limited by camera technology
Mass Spectrometer	Full ram until near RCA, then restricted measurements	Partial ram in spin-scan throughout encounter	Full ram throughout encounter	Partial ram in spin-scan througout encounter	Partial ram in spin-scan throughout encounter
Plasma Probe	Full ram until RCA, Partial thereafter	OK (in spin-scan mode)	Full ram	OK (in spin-scan mode)	OK (in spin-scan mode)
Cosmic Dust	Full ram until RCA, partial thereafter	OK (in spin-scan mode)	OK (in spin-scan mode)	OK (in spin-scan mode)	OK (in spin-scan mode)

* Incorporates Despun Mirror

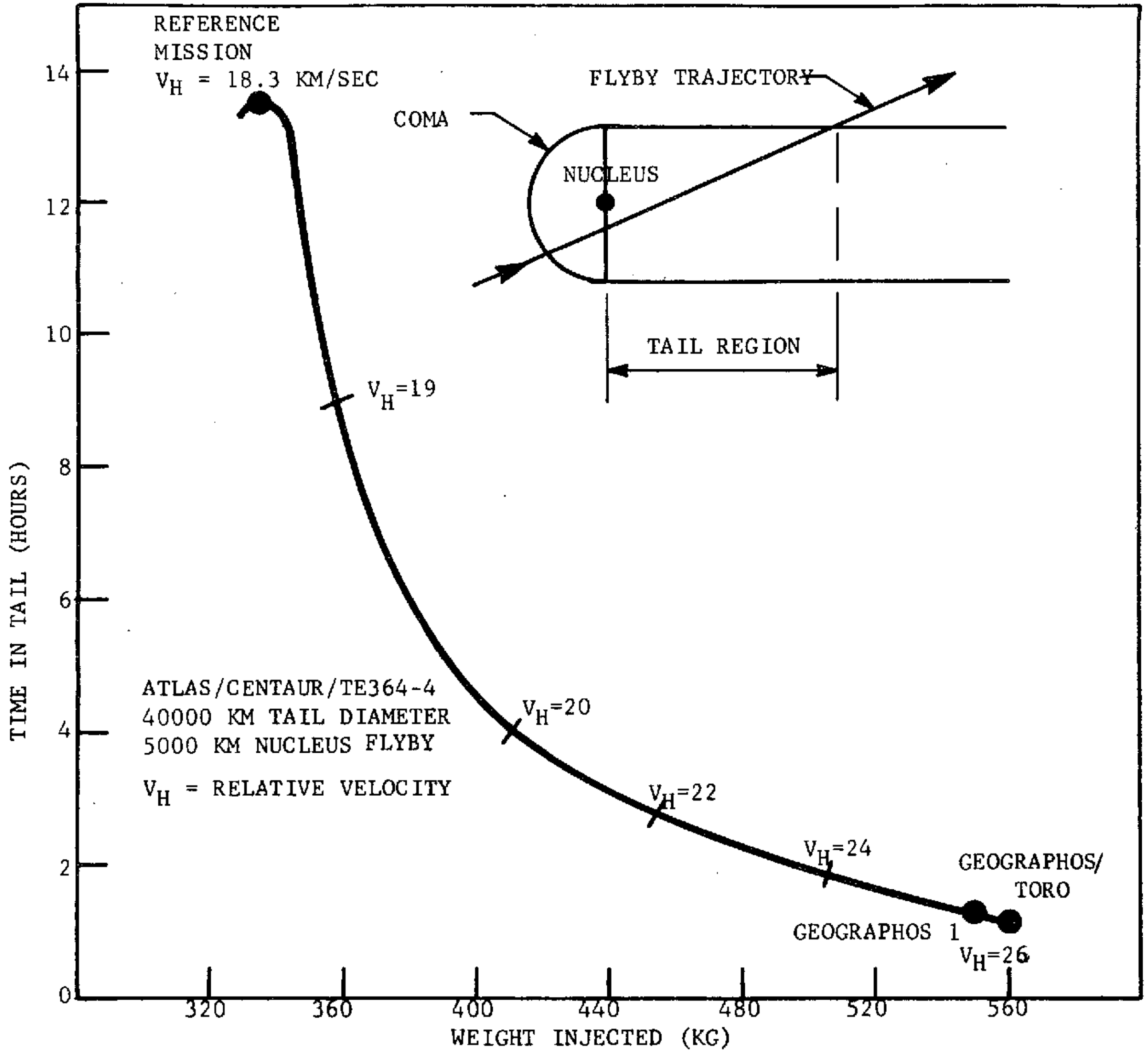


FIGURE 12 EFFECT OF SPACECRAFT WEIGHT ON TIME IN COMET TAIL

V. CONCLUSIONS AND RECOMMENDATIONS

Two general conclusions were reached as a result of this study:

- Ballistically-launched, spin-stabilized spacecraft can feasibly support a broad-based instrument complement for the effective accomplishment of scientific goals in the exploration of comets and asteroids.
- A number of Encke pre-perihelion, fast-flyby mission options during the 1980 apparition are feasible for consideration by the scientific community and NASA program planners.

The Atlas/Centaur/TE364-4 launch vehicle provides the capability to perform the following missions with spacecraft incorporating a high degree of current technology:

- Encke-Dedicated Flyby - No Probe
  - Unique opportunity to combine coma and nucleus observations with 9-13½ hours of tail observation.
  - Shortest mission time (3 months).
  - Ground-based navigation probably adequate.
- Encke-Dedicated - With Probe
  - Tail observation time reduced to ~5 hours - still adequate for science objectives.
  - Coma observations to within at least 500 km of nucleus with probe are feasible.
  - On-board navigation required for best probe targeting.
- Encke-Geographos - With or Without Probe
  - Tail observation time about 1 hour - acceptable
  - Relative velocity at Encke increases from 18.3 to 26.3 km/sec.
  - Excess launch-vehicle capability. (550 kg vs. 400-450 kg for spacecraft with probe).
  - On-board navigation required for targeting at Encke (probe) and asteroid.
  - Mission maneuvers performed by RCS

- Encke-Geographos-Toro - Without Probe
    - Tail observation time about 1 hour - acceptable.
    - Triple-target opportunity
    - On-board navigation required
    - Main propulsion system added for major maneuvers

The Encke-Geographos-Toro mission with a probe at Encke can be considered only if space-storable propulsion is used to perform the major course-change maneuvers. Of the configurations studied, only the lightest-weight concept (No. 5), incorporating spin-scan imaging, could meet launch-vehicle constraints. It was concluded, however, that existing-technology cameras of this type were not adequate.

The key technical issue, common to all of the concepts considered, is the acquisition and tracking of the comet nucleus and the asteroids. This issue concerns the interrelationships between imaging system characteristics (e.g., sensitivity and resolution), imaging system installation, and the collection and processing of data within the attitude control system. Each concept approached the latter aspect differently. It is recommended that a comprehensive study of these interrelationships be made to determine the preferred concept for implementation in detailed spacecraft design.

A concerted effort is needed between now and 1980 (and during the mission) to improve Earth-based ephemeris knowledge of Comet Encke and the target asteroids. Preliminary analysis indicates that on-board navigation capability can provide adequate data for final probe targeting at Encke and spacecraft targeting at the asteroids. However, it is recommended that a detailed navigation analysis of the Encke/asteroid missions to define specific sensor requirements and mission operations procedures be made.

Three scientific instrument categories require development for specific application to comet/asteroid missions. These are the neutral and ion mass spectrometers, the cosmic dust analyzer, and the IR spectrometer.

Reference:

1. Arrhenius, G., Alfvén, H., and Fitzgerald, R., Asteroid and Comet Exploration, NASA CR-2291, July 1973.