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NASA TM X- 70561

SYSTEM DEFINITION
FOR
"COMETARY EXPLORER"

A MISSION TO INTERCEPT THE COMETS GRIGG-SKJELLERUP
(1977) AND GIACOBINI-ZINNER (1979).

NOVEMBER 1973
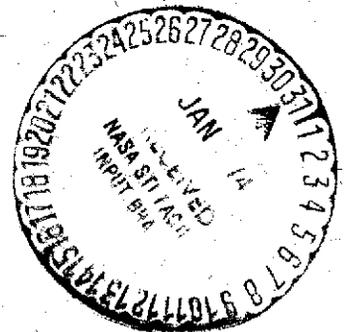
GODDARD SPACE FLIGHT CENTER ⸺
GREENBELT, MARYLAND

GSFC

SYSTEM DEFINITION FOR "COMETARY EXPLORER"

A Mission to Intercept the Comets Grigg-Skjellerup (1977) and Giacobini-Zinner (1979).

Cometary Study Office

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November 1973

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

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A Mission to Intercept the Comets Grigg-Skjellerup
(1977) and Giacobini-Zinner (1979).

FOREWORD

This document was prepared by the Cometary Study Office, Goddard
Space Flight Center. Its purpose was to define a low cost dual-comet
intercept mission. Unfortunately budgetary constraints precluded
adoption of the program. However, the study established the framework
for investigating future ballistic intercept missions to comets.

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RELATIVE VELOCITY
(15.2 Km/sec)

COMETARY EXPLORER

Frontispiece

1. SUMMARY

There is now an unusually favorable opportunity to send a single direct probe to two short-period comets in the near future. This initial cometary mission will provide much useful information concerning the existence and physical nature of the cometary nucleus, the composition of the gaseous cometary atmosphere and its interaction with the solar wind, and the dust and micrometeoroid environment, thus providing a firm basis for more ambitious cometary missions in the 1980's. Goddard Space Flight Center is in a very favorable position to present a specific cometary mission by virtue of a decade of experience in the areas of cometary physics and chemistry, planetary atmospheres (especially, techniques for measuring ionized and neutral molecule composition), solar wind studies (especially, in-situ measurements of its composition and its interaction with the earth and moon), and in spacecraft and mission development, management, and analysis.

The primary scientific objectives of Cometary Explorer are to investigate the:

- Existence and physical nature of a cometary nucleus;
- Structure and composition of the cometary atmosphere;
- Characteristics of dust near the comet;
- Interaction of the comet with the solar wind; and
- Mechanisms of ion and radical production.

Comet Grigg-Skjellerup was selected as the primary mission target from a candidate group of short-period comets after much consideration of technical, scientific, and fiscal constraints. The flyby velocity at intercept is only 15.2 km/sec, and the distance from the earth at intercept is 0.2 AU. Furthermore, the exceptionally good sun-earth-comet viewing geometry prior to intercept allows the comet trajectory to be unusually well defined, resulting in a very small spacecraft targeting error. A spin-scan imaging system is anticipated for viewing the nucleus. It should be possible to use existing spacecraft instrumentation (designed for studying the atmosphere and ionospheres of the planets) to study the composition of the cometary atmosphere (coma). Instruments to study the solar wind are already well developed, as are micrometeoroid detectors and dust analyzers. A total of 68 kg of weight, 80 watts of regulated power (28 V ± 2%), and a telemetry bit rate of over 16,000 ibps are available and will support 8 - 12 experiments. Following the Grigg-Skjellerup encounter in April 1977, the spacecraft will execute a powered earth flyby and proceed to intercept a second comet (Giacobini-Zinner) in February 1979. Grigg-Skjellerup and

Giacobini-Zinner are an ideal set of target comets for the first spacecraft mission to the comets. Grigg-Skjellerup has some gas, very little dust, is probably a core-mantle type comet, and presents an unusually good opportunity for imaging the cometary nucleus. Giacobini-Zinner has some gas, a lot of dust, is probably a free-ice type comet, and presents a good opportunity for studying the composition and distribution of dust and micrometeoroids in the vicinity of a dusty comet. Thus, in a single mission, we can study examples of both major classes of short-period comets and fly by them in the proper order (low risk, first; higher risk, second). In addition, the Giacobini-Zinner flyby will enable NASA to assess the hazards of micrometeoroid impact to a spacecraft during fast flyby missions. These data are essential to the planning of a mission to intercept comet Halley in 1986.

The Cometary Explorer mission to the comets Grigg-Skjellerup in 1977, and Giacobini-Zinner in 1979, has been developed taking into account scientific, technical, and management considerations. Its scheduling and costs are realistic from several viewpoints. The mission utilizes as a "laboratory bench" for the instruments a spacecraft system already developed in the Interplanetary Monitoring Platform (IMP) program with modification of several subsystems, and addition of some subsystems already developed for other spacecraft. The only costs to be incurred are for fabrication of subsystems, rather than development of new subsystems. In addition, the use of an existing spacecraft program in which the scientific mission objectives have been related to studies of the solar wind, and its interactions with planetary objects, implies that the basic spacecraft concepts already developed provide for support of those experiments which are particularly relevant to the scientific objectives of a cometary mission. A realizable mission schedule is included in this report.

The basic spacecraft system, the same as that of Explorers 43 and 47, is sufficiently well developed that only a single flight spacecraft need be carried throughout the launch schedule. However, both a protoflight and flight spare instrument will be required for the scientific experiments. The proposed schedule takes into account the realities of project review and approval and presents the opportunity for an optimized mission through the use of a Science Steering Group (SSG). The final experiment selection is contingent upon final spacecraft design and total cost evaluations. The Science Steering Group may include not only experimenters interested in studies utilizing onboard instrumentation but also those investigators utilizing ground based facilities to observe various cometary phenomena. The closely coordinated effort between both ground based and space observations is essential for interpreting the in situ observational measurements and extrapolating them to other comets.

It should be noted that this mission satisfies all of the recommendations of the Cometary Science Working Group (1971) and the Comet and Asteroid Mission Study Panel (1972) for a first mission to a comet (a fast flyby to a short-period comet in the late 1970's with investigation of the nucleus, cometary atmosphere (coma), and solar wind interaction using an existing chemical propulsion system). This mission has been recommended to NASA by the Comet and Asteroid Science Advisory Committee (1973) as the best way to initiate an early program of exploration of the comets.

2. PROJECT OBJECTIVES

2.1 PRIMARY MISSION

The proposed mission to Comets Grigg-Skjellerup and Giacobini-Zinner will be the first mission to the comets. As such, it is necessarily exploratory and a precursor to subsequent comet missions. In this respect, it will be necessary to make a general survey of the matter and energy in the comet and its immediate environment. In principle, almost all regions of the comet (nucleus, coma, and tail) could be directly sampled in a single flyby depending on the spacecraft trajectory with respect to the comet. In the primary mission, the Cometary Explorer spacecraft will pass through the coma of Grigg-Skjellerup on the sunward side of the nucleus at a miss distance of ~1000 km, enabling study of the transition region between the coma and solar wind on entry to and exit from the coma, study of the coma itself by direct sampling, and study of the nucleus by remote sensing. In addition to providing basic descriptive measurements, which may generate many new scientific questions, the mission will provide answers to some long-standing problems that have been raised by astronomical studies.

Specifically, the primary scientific objectives of this mission are as follows:

1. Determine whether or not a nucleus exists; and if it exists, measure its size and major constituents.

2. Describe the structure, composition and motions of the cometary atmosphere.

3. Survey the characteristics of the dust near the comet.

4. Determine the nature of the solar wind-comet interaction.

5. Study the basic mechanisms which produce ions and radicals.

The following paragraphs discuss each of these objectives in more detail.

2.1.1   <u>Existence and Nature of the Cometary Nucleus</u>. Although it is generally agreed that a nucleus exists, having a size on the order of 1 - 10 km and the composition of a "dirty snowball", there is one worker, Lyttleton, who points out that the existence of a nucleus has not really been conclusively demonstrated. A relatively simple imaging system should suffice to resolve this controversy. The recent OAO-2 measurements gave strong support to the dirty snowball model by demonstrating the presence of very large amounts of OH and neutral hydrogen surrounding the coma. Mass spectrometer measurements made from a spacecraft could provide even stronger indirect evidence for or against Whipple's models and provide additional insights through direct measurement of the composition of the coma.

2.1.2   <u>Cometary Atmosphere (Coma)</u>. Our current knowledge suggests that at large distances from the sun, (>5 AU), the nucleus of a comet is in radiative equilibrium with the solar radiation field. As the comet approaches closer to the sun, the ices start to sublimate releasing micron size dust particles and parent molecules, such as H_2O, HCN, etc., which are the precursors of the observed radicals. The short wavelength light from the sun then dissociates these molecules into radicals, ions, and atoms. These fragments represent the only emitters that have been observed to date in cometary spectra. At the present time we do not have an adequate explanation of the degree of ionization of cometary molecules or of the motion of ions observed in comets.

A summary of the molecular, ionic, and atomic radicals identified in comets to date is given in Table 1 along with suggested parents of these unstable species. These suggested parents are taken from the list of observed interstellar molecules. Of this list, only H_2O is reasonably certain to be present in comets and even it has not been identified directly. Thus a major scientific question in cometary astrochemistry is the identity of the parent compounds. The answers to this question will be invaluable in increasing our knowledge of the early history of the solar system. Furthermore, the identity of the stable parent molecules present in comets must be known in order to understand how the unstable species (radicals) are formed in a cometary atmosphere.

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Table 1

Known and Inferred Atomic and Molecular Constituents of Comets

Observed Radicals	Possible Parent
H	H_2O etc.
$O\,(^1D)$	H_2O
OH	H_2O, CH_3OH
CN	C_2N_2, CH_3CN, HCN, HC_2–CN
CH	CH_4, CN_3CN, H_2C_2, $CH_3C_2H_2$
NH (Singlet)	NH_3, HNCO, NH_2HCO
NH_2 (α bands)	NH_3, NH_2HCO
C_2 (Singlet and triplet)	C_3, HC_2CN, CH_2C_2H, C_2H_2
C_3	$H_2C = C - CH_2$, $CH_3 - C = CH$, HC C - C = CH
CO+	CO
N_2+	N_2
Ni, Cu, Ca, Cr, Fe, Mn	Observed in sun grazing comets at less than 0.1 astronomical units where grain temperatures are $\sim 1000°K$

2.1.3   Dust Characteristics. A study of dust near a comet is not only of basic scientific interest; it is also important for the design of subsequent, more complex and more costly cometary spacecraft. The size distribution, velocity distribution, and composition of dust particles are of particular interest. Dust analyzers and micrometeoroid detectors, will be needed to provide information on the composition of the dust and the particle size, mass, and velocity distributions.

2.1.4   Nature of the Interaction. The solar wind interacts with the gases and plasmas in the coma. Two radically different types of interactions have been proposed recently, neither of which can be excluded at present. Biermann and his colleagues have developed models which postulate a bow shock and contact surface analogous to those of the earth and its magnetoshpere (Figure 1). In particular, these models imply a discontinuous transition from supersonic to subsonic flow. Wallis (1971) on the other hand, has suggested that the transition from supersonic to subsonic flow is continuous, over a very broad region, occurring without a bow shock. These two models are diametrically opposite, indicating how little we actually know about the interaction.

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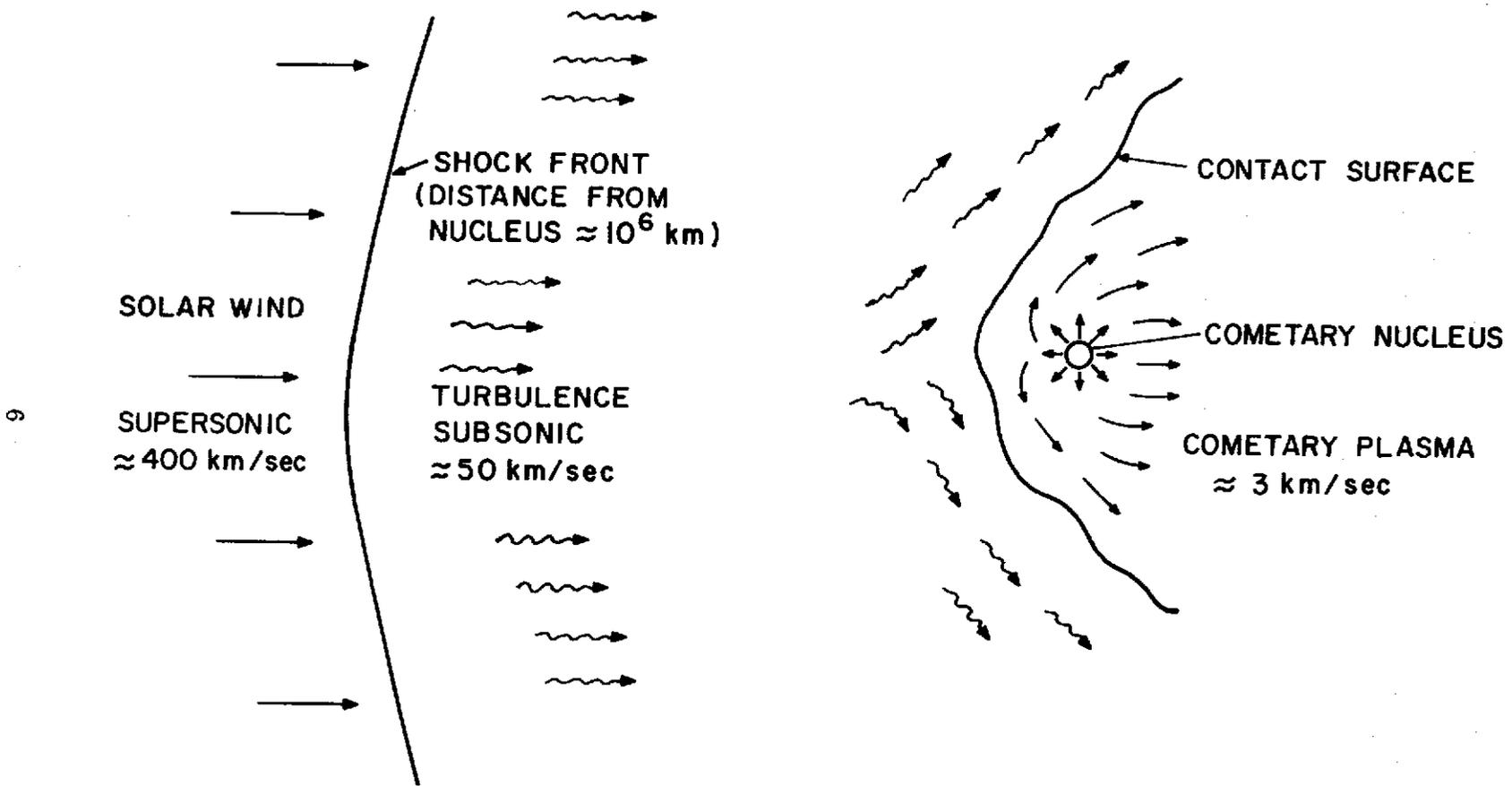
Figure 1. Bow Shock and Contact Surface

Of the two models just mentioned, the bow shock-model has been developed in greater quantitative detail. It predicts a standoff distance for the shock of (1 to 2) X 10^6 km and a corresponding distance for the contact surface of (1 to 5) X 10^5 km (Brosowski and Wegman, 1972). The latter is comparable to the typical size of a visible coma. The introduction of a contact surface is an idealization and its validity may be questioned. For example, by definition a contact surface implies no flux through the surface, but observations (Wurm, 1963) indicate that filaments of ionized material from near the nucleus probably penetrate the "contact surface" on the sunward side, and then bend back into the tail region.

The magnetic field probably plays a key role in the structure and behavior of comets, as suggested first by Alfven (1957). Given the flow pattern, it is possible to calculate the magnetic field configuration - if the field is frozen into the plasma. However, it is possible that in the coma the field is not frozen into the plasma. The transition region between "frozen" and "unfrozen" conditions is of basic physical interest as well as being important for understanding cometary ion tail dynamics. The configuration of the magnetic field in the coma is strongly affected by (and may strongly affect) the flow pattern. For example, if the flow past the coma is analogous to the flow past the magnetosphere, as Biermann suggests, then the field is draped around the coma on the sunward side. Unlike the earth's magnetosphere, however, the coma probably has no magnetic field of its own, so the configuration should be unstable with respect to the Rayleigh-Taylor instability, i.e., a stable contact surface will not persist. In this case, the solar wind might penetrate more deeply into the coma than Biermann's models suggest, and conversely the instability might explain how ionized matter can flow outward from the nucleus.

The basic measurements needed to determine the dynamics of the MHD interaction are of velocities, densities and temperatures of ions and electrons and the magnetic and electric fields, ideally on the sunward side of the comet, from a few times 10^6 km to 10^4 km or less from the nucleus.

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2.1.5   Production of Ions and Radicals. The ionization process in comets must be understood in order to present a complete picture of the chemistry of comets and the solar wind-comet interaction. To fully understand the ionization processes, it will be necessary to determine which ions are present and from which neutrals they are derived. An ion mass spectrometer with a mass per charge range from 1 to approximately 80 and a speed range between 0 and 300 km/sec and a neutral mass spectrometer are needed for this purpose. Ideally, one would like to survey the distribution of these materials in the coma, tail, and the region outside the visible coma.

Current theories of production do not account satisfactorily for the observed ions and radicals. Photoionization is undoubtedly important in comets as is charge exchange between the solar wind and cometary atmosphere material. Recent measurements indicate that the latter mechanism is more important than photoionization, the rate of charge transfer reactions being 3 times that of photoionization (Biermann and Lust, 1972). Photoionization and charge exchange alone, however, cannot explain all of the observations of ions (Delsemme, 1971), so other processes must be considered.

Energetic (kev) electrons are a particularly effective and a likely ionizing agent (Delsemme, 1971). Thus, it is essential to survey as least the population of energetic electrons in the range of 3 eV to 50 kev in and near the coma. Just how they are accelerated is not known. Current theories include acceleration in the bow shock (if it exists) and possibly acceleration by particle-wave interactions in the coma. A survey of high frequency electric and magnetic field fluctuations would be essential on an early comet mission to determine whether particle-wave interactions are important.

Laboratory experiments (Danielsson, 1972) show that when a collisionless magnetized plasma interacts with a neutral gas, the gas becomes ionized. The ionization process is not understood, but it is clearly a plasma mechanism rather than a classical ionization process. It is important to determine to what extent such plasma or collective ion-field processes occur in comets and, ultimately, to understand these processes.

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2.2 EXTENDED MISSION

After the encounter with Grigg-Skjellerup the spacecraft will return to the earth, perform a powered earth flyby, and proceed to an encounter with comet Giacobini-Zinner. The spacecraft trajectory will cross the geomagnetic tail at about 120 - 150 earth radii on approaching the earth and again at about 2700 earth radii after powered earth flyby. The geomagnetic tail is thought to "break up" somewhere between 80 earth radii (where it is known to be well defined) and 500 earth radii (where it is known to be filamentary). Thus, the trajectory of Cometary Explorer provides an opportunity for making measurements in an unexplored and interesting region of earth's tail.

The scientific objectives for the encounter with comet Giacobini-Zinner are essentially similar to those for Grigg-Skjellerup except for greater emphasis on the dust experiments, and except for down-grading of the nuclear imaging experiment due to the much larger miss distance. Unusual meteor showers have been associated with Giacobini-Zinner. The Giacobinid (or Draconid) meteor showers have probably been the most spectacular meteor displays of the present century. The showers were particularly strong in 1933 and 1946; lesser showers were observed in 1926, 1952, and 1972. Jacchia, et al. (1950) concluded that meteors of the 1946 shower appeared at abnormally great heights, had abnormally short trails, large atmospheric decelerations and emitted at least 100 times more luminous energy per unit mass than ordinary meteors. They suggested that the Giacobinid meteors are composed of soft, feather-like material.

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3. RELATED STUDIES

A number of detailed investigations of the motion of Comet Grigg-Skjellerup have been carried out. Definitive orbital characteristics including non-gravitational effects have been determined by Marsden, Sekanina and Yeomans (1973). The application of these results to a comet intercept mission has been made by Yeomans (1972). The significance of these results for the present proposal is given in the appropriate section.

Although the orbit of Comet Grigg-Skjellerup is quite accurately known (for the last two returns, perihelion occurred within 0.02 days of its predicted time) observations as early as possible are highly desirable. A ground-based observing program for early recovery and position determination will be developed. Because of the location of the comet in the sky only observatories in the southern hemisphere with large telescopes will be able to carry on the required task. Fortunately, several observatories in Africa, Australia and South America have these capabilities.

Laboratory research related to the interpretation of the data obtained by a flight neutral mass spectrometer will be required because of the high relative velocity between the comet and the spacecraft. The principle questions that have to be resolved are whether fast neutral molecules with energies greater than 10 eV will fragment upon collision with the surface of the mass spectrometer and if fragmentation occurs is it significant in terms of gross distortion of the observed mass spectrometer cracking pattern? Because the relative energies of impact will exceed ionization energies of most molecules, the ionization yield should also be measured.

Finally, the extensive study by Yeomans (1970) of the orbital motion of the extended-mission target Giacobini-Zinner should be noted. This study demonstrates that the nongravitational effect in the motion of the comet is actually increasing with time. With rare exceptions, nongravitational forces acting on comets have been observed to decrease with time, as was the case for Grigg-Skjellerup.

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2. Yeomans, D. K. (1970), "Nongravitational Forces Affecting the Motion of Comet Giacobini-Zinner," Ph. D. Dissertation, University of Maryland.

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4. TECHNICAL PLAN

4.1 MISSION AND GENERAL APPROACH

The Cometary Explorer will be a single spacecraft mission launched from the Eastern Test Range on a Delta vehicle in late 1976. It will intercept the Comet Grigg-Skjellerup in April 1977, retarget with a powered earth flyby, and intercept the comet Giacobini-Zinner in February 1979.

4.1.1   Mission. The orbital parameters for the 1977 apparition of Comet Grigg-Skjellerup are given in Figure 2. It is estimated that the initial sighting (recovery) of the comet will occur by mid-February 1977. However, because of the extremely favorable sighting conditions for this apparition, recovery could occur as early as November 1976. An early recovery is desirable because it will reduce the fuel expenditure for spacecraft trajectory corrections caused by comet ephemeris errors.

Observation of the comet from a northern hemisphere site will be very difficult from mid-January 1977 to the end of April 1977. Therefore, it will be necessary to rely on sightings located in the southern hemisphere during this period. Quick reduction of the new observational data will be required to improve the accuracy of the comet's orbit prior to encounter.

The nominal mission profile is outlined in Figure 3. To minimize the launch-energy requirement (C_3), the intercept point has been located in the ecliptic plane. The comet crosses the ecliptic plane about a half day after its perihelion passage. At encounter, the relative velocity between the comet and the spacecraft is 15.2 km/sec; and the angle between the relative velocity vector and the spacecraft's nominal spin axis is 24.6°. This angle, which is termed the relative aspect, is an important parameter for some of the experiments and, depending upon the actual experiments flown, may be changed.

Cometary Explorer will be retargeted to the comet Giacobini-Zinner after the encounter with Grigg-Skjellerup. The orbital parameters for Giacobini-Zinner are given in Figure 4. Although the orbital geometry for this comet is not as favorable as that for Grigg-Skjellerup, it is acceptable for an extended mission.

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EPOCH   APR. 7.0, 1977
TIME OF PERIHELION   APR. 11.017, 1977
PERIHELION DISTANCE   0.993 AU
APHELION DISTANCE   4.932 AU
ECCENTRICITY   0.665
INCLINATION 21.10°
PERIOD   5.10 YEARS
LONGITUDE OF NODE 212.64°
ARGUMENT OF PERIHELION 359.32°

EARTH AT 2 AU
INTERCEPT
4/11/77

50
100
150
200

SUN

GRIGG - SKJELLERUP

EARTH AT LAUNCH
11/4/76
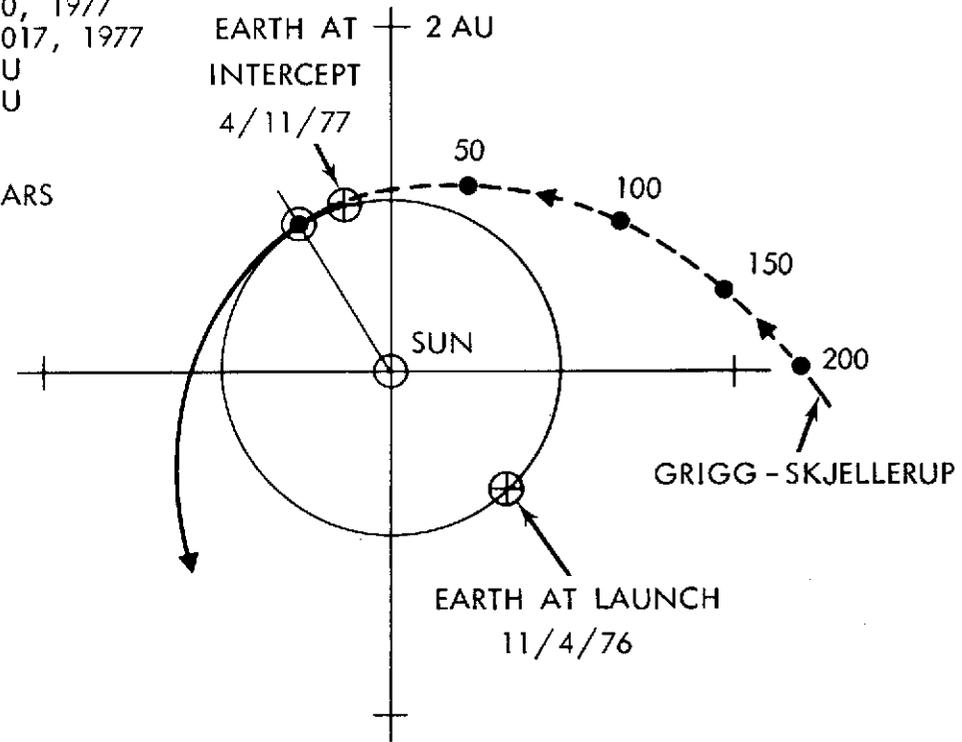
——————— ABOVE ECLIPTIC

– – – – – – BELOW ECLIPTIC

●   COMET AT STATED NUMBER OF
      DAYS BEFORE PERIHELION

◉   COMET AT PERIHELION AND
      ECLIPTIC INTERSECTION

Figure 2. Orbital Parameters for Comet Grigg-Skjellerup

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LAUNCH NOV. 4, 1976

$$C_3 = 2.37 \text{ Km}^2/\text{sec}^2$$

COMET INTERCEPT APRIL 11, 1977

EARTH DISTANCE = 0.20 AU

RELATIVE VELOCITY = 15.2 Km/sec

RELATIVE ASPECT = 24.6°

EARTH RETURN OCT. 26, 1977

GRIGG - SKJELLERUP INTERCEPT

0.20 AU

0.10

TO SUN

SUN - EARTH LINE

EARTH

SPACECRAFT TRAJECTORY
(Ecliptic - Plane Projection)
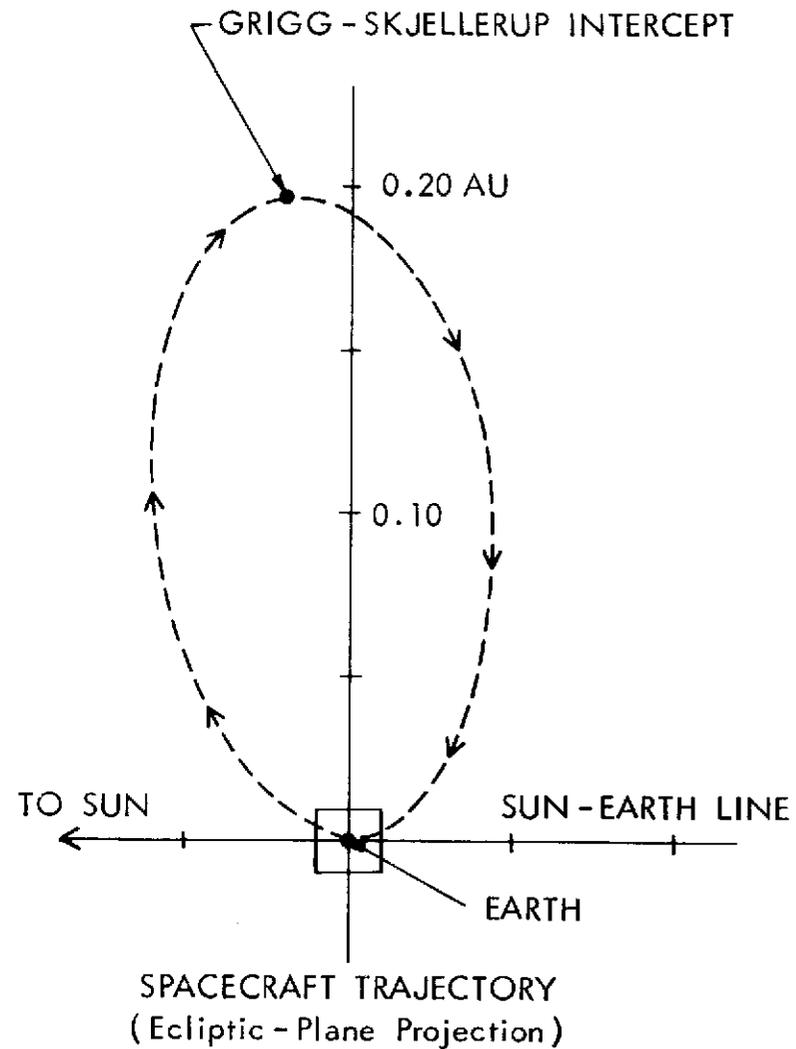
Figure 3. Nominal Mission Profile – Primary Mission

EPOCH   FEB. 16.0, 1979

TIME OF PERIHELION   FEB. 13.083, 1979

PERIHELION DISTANCE   0.996 AU

APHELION DISTANCE   5.986 AU   ORBIT PROJECTION IN
                                                          ECLIPTIC PLANE
ECCENTRICITY   0.715

INCLINATION   31.70°

PERIOD   6.52 YEARS

LONGITUDE OF NODE   195.07°

ARGUMENT OF PERIHELION   171.97°

——— ABOVE ECLIPTIC

----- BELOW ECLIPTIC

● COMET AT STATED NUMBER OF DAYS
  BEFORE OR AFTER PERIHELION

◉ COMET AT PERIHELION AND ECLIPTIC INTERSECTION
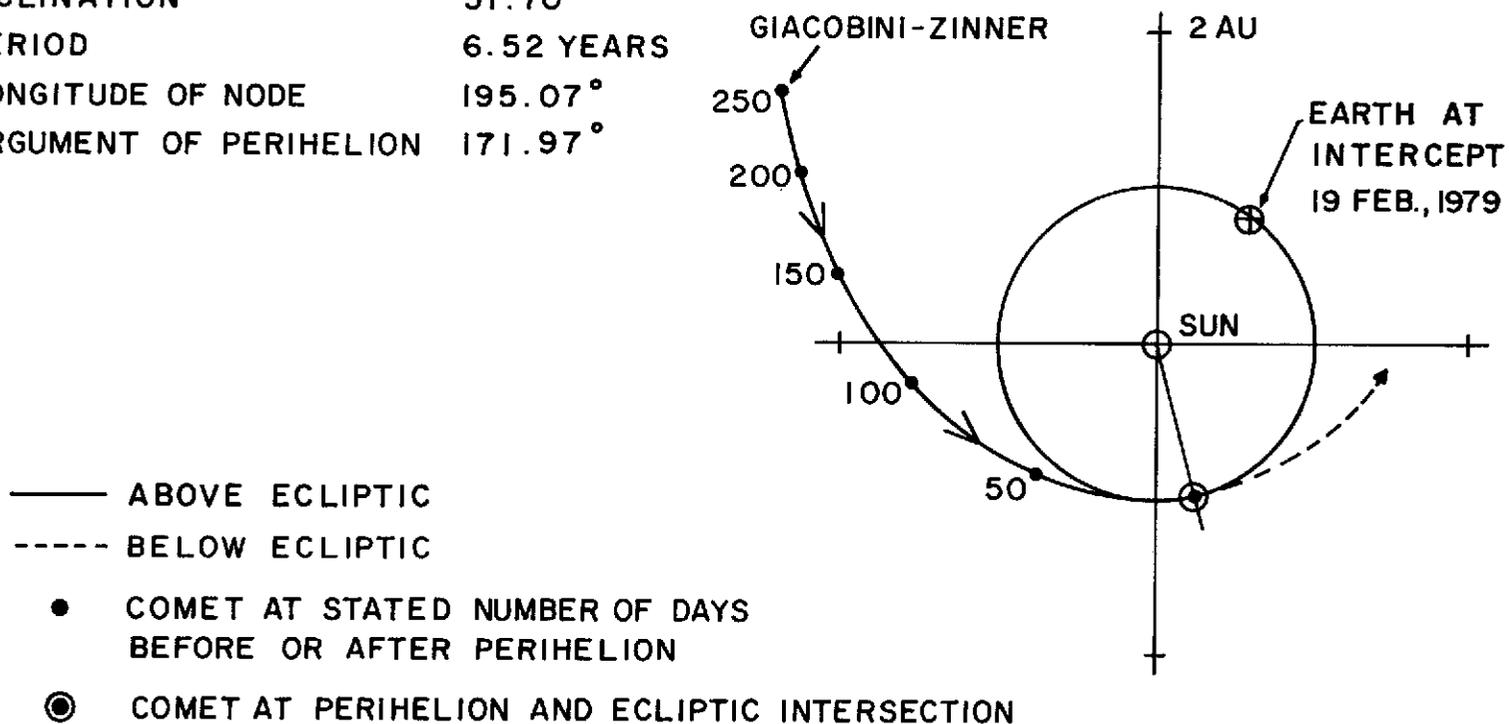
Figure 4. Orbital Parameters for Comet Giacobini-Zinner

The extended-mission sequence is depicted in Figure 5. In Figure 3 it can be seen that the spacecraft is placed into a trajectory that not only intercepts Grigg-Skjellerup, but also returns to the earth. By performing a powered earth-swingby maneuver (with the help of a small solid kick-motor), the spacecraft is put into an orbit that intercepts Giacobini-Zinner on February 19, 1979. Details of the earth-swingby and subsequent encounter with Giacobini-Zinner are given in Figure 5.

The launch window for accomplishing both the primary and extended-mission objectives is about 10 days. If necessary, an additional 20 days of the launch window can be gained for the primary mission by off-loading about 19.1 kg of the hydrazine fuel that has been allocated for the extended-mission phase.

The spacecraft will use the structural design of the IMP-H, I and J series of spin stabilized spacecraft. This basic design will be supplemented by extracting useful design concepts from International Ultraviolet Explorer (IUE), the German Solar Probe (HELIOS) and other appropriate spacecraft. The spacecraft is a 16 sided drum 1.8 meters high and 1.4 meters in diameter. The spacecraft with the inclusion of the propulsion systems will weigh approximately 450 kilograms. Table 2 shows the weight breakdown by subsystem and Figures 6 through 9 present various views of the spacecraft.

4.2 SUBSYSTEMS

4.2.1   Experiments. A typical complement of experiments for the Cometary Explorer spacecraft is shown in Table 3. Experiments marked with an asterisk would also be suitable for conducting interplanetary measurements, for example during the two crossings of the geomagnetic tail.

The data return by these experiments would allow a marked improvement in our knowledge of the properties of comets and their interaction with the solar radiation field and the solar wind. For example, the optical imaging system, the dust detector, and the neutral mass spectrometer would be used to study the size, shape, and albedo of the nucleus, and the molecular and dust composition of the nuclear region. The magnetometer, plasma spectrometer and electron detector would provide data on the shock or charge exchange interaction between the comet and the solar wind and would hopefully shed light on the mechanisms by which species become ionized. An ion spectrometer

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GRIGG-SKJELLERUP INTERCEPT II APRIL 1977

EARTH

SUN-EARTH LINE   SUN

GIACOBINI-ZINNER INTERCEPT 19 FEB.1979

EARTH DISTANCE = 1.83 AU
RELATIVE VELOCITY = 20.8 km/sec
RELATIVE ASPECT = 10.3°

26 OCT 1977
E

POWERED EARTH-SWING BY
PERIGEE = 3.26 EARTH RADII
ΔV = 370 MPS

TOTAL MISSION TIME = 2.3 YEARS

APHELION = 1.46 AU
29 JUNE 1978

SPACECRAFT TRAJECTORY
(ECLIPTIC-PLANE PROJECTION)
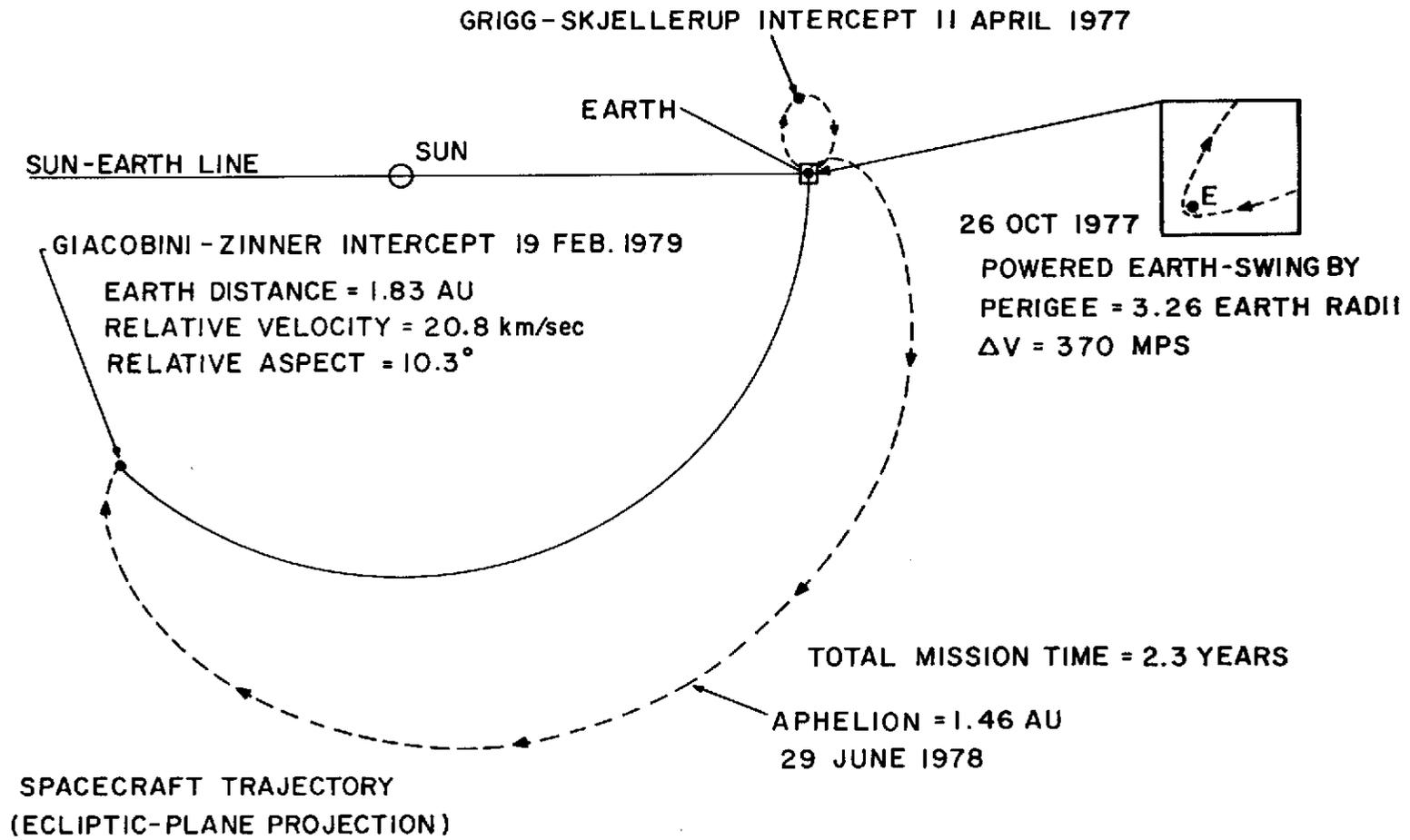
Figure 5. Nominal Mission Profile—Extended Mission

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Table 2

Cometary Explorer Weight Summary

Subsystem	Weight	
	(kg)	(lbs)
Structure (including shielding)	94.6	209
RF	7.6	17
Antenna (including electronics)	15.2	33
Data Handling	8.2	18
Command	0.8	2
Programmers	3.6	8
Power (with 6 mil cover glass)	27.3	60
Attitude Determination	5.3	12
Thermal Control	16.8	37
Propulsion Dry Weight		
Kick Motor	8.1	17
Hydrazine Subsystem	25.8	57
Harness	13.6	30
Experiments	68.0	150
Subtotal	294.9	650
Growth Contingency	33.5	74
Propulsion propellant		
Kick Motor propellant	54.4	120
Hydrazine propellant	70.8	156
Total Spacecraft	453.6	1000
Vehicle Attach Fitting	10.0	22
Delta Capability ($C_3 = 2.7\,km^2/sec^2$)	463.6	1022

OMNI ANTENNA

MEDIUM GAIN ANTENNA

ROTATING HIGH GAIN ANTENNA REFLECTOR

MOTOR DRIVE

STATIONARY ANTENNA FEED

THERMAL BLANKET ON SURFACES

HYDRAZINE THRUSTERS

MAGNETOMETER

ELECTRIC FIELD ANTENNA

UPPER THERMAL SHIELD

SOLAR CELLS

INSTRUMENT SECTION

INSTRUMENT COVERS

STRUTS (8)

METEOROID SHIELD

SCADS

BOOM MOUNTING PAD

TE-M-479 KICK-MOTOR

FUEL TANKS (8)

PLASMA WAVE DETECTOR

EXPERIMENT

Figure 6. Cutaway View of Cometary Explorer Spacecraft

Figure 7. General Layout

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OMNI ANTENNA

MEDIUM GAIN ANTENNA

2.08m

STATIONARY ANTENNA FEED

1.09m

ROTATING HIGH GAIN ANTENNA REFLECTOR

.58m

MOTOR DRIVE

HYDRAZINE THRUSTERS (6 PLACES)

SOLAR CELLS

1.82m

INSTRUMENT COVER

INSTRUMENT SECTION

FUEL TANKS (8)

SCADS

METEOROID SHIELD

EXPERIMENT

TE-M-479 KICK MOTOR

Figure 8. Side View

ELECTRIC FIELD ANTENNA

61.0 m

MECHANICALLY DESPUN ANTENNA

MAGNETOMETER SENSOR

PLASMA WAVE DETECTOR

4.06m

4.06m

Figure 9. Top View

Table 3

Typical Complement of Cometary Explorer Experiments

1.	Optical Imaging System
2.	*Ion Mass Spectrometer
3.	Neutral Mass Spectrometer
4.	*Solid Particle Analyzer
5.	*Dust Detector
6.	Calibrated Photometer - Polarmeter
7.	. H-Lyman Alpha Photometer
8.	UV Spectrometer
9.	*Plasma Ion Probe
10.	*Plasma Electron Spectrometer
11.	*DC and AC Magnetometer
12.	*DC and AC Electric Field Detector

*Experiments also suited for interplanetary measurements.

will be required to carry out studies of the coma. The two
particulate-matter related experiments will yield data on the
dust distribution and its characteristics.

4.2.2   Spacecraft

4.2.2.1   Structure. The Cometary Explorer structure is a modification
of proven spacecraft design. Geometrically the structure is
a 16-sided drum measuring 1.4 meters across flats and 1.8
meters in overall height. It consists of an aluminum honey-
comb shelf, eight struts and a 0.5 meter diameter thrust tube
on the underside. The experiment and instrument modules are
mounted on the shelf. To satisfy the stringent RF and thermal
requirements, the experiment and instrument section is fully
enclosed by a metallic cover and side panels. Three solar
array rings are used to supply power to the experiments and
electronics when in orbit. Two of the rings are mounted for-
ward and one aft of the instrument section. Appended to the

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exterior of the structure are experiment booms approximately 3 meters long, designed to fold alongside the spacecraft at launch and to be deployed at a preselected time and sequence. The spacecraft may have four 61 meter experiment antennas to be deployed after separation from the launch vehicle for the electric field measurements.

The experiment and instrument modules are mounted in the instrument compartment on the honeycomb shelf. Some of these modules (primarily instruments) may be used as integral members of the structure. Experiment packages need not provide structural support and if requirements dictate, odd shaped packages may be accommodated. Modular geometry if used will be similar to that employed in previous Explorer-type spacecraft.

The present qualified structural design will be added to for this mission. These additions will include:

- The use of an S-band antenna system;

- The addition of shielding on the aft end (kick motor) of the spacecraft for protection from the expected micrometeoroid flux within the cometary environment;

- A hydrazine propulsion system for trajectory adjustment and orientation;

- A solid propellent kick-motor to re-target to Giacobini-Zinner after encounter with Grigg-Skjellerup.

4.2.2.2   RF Subsystem. The telemetry, command, and ranging functions are implemented by a redundant S-band transponder system. Each system consists of a phase-lock receiver, eight watt transmitter, and a diplexer. RF switches provide access for either transponder to two of the three antennas. This permits selection of the better receiver output for command processing. Figure 10 shows the subsystem block diagram.

Operating modes are: Command reception, telemetry transmission, command reception and telemetry transmission, and range and range rate. The subsystem is cross-compatible with the Spaceflight Tracking and Data Network (STDN) and the Deep Space Network (DSN). Uplink and downlink frequencies are approximately 2115 and 2295 MHz respectively.
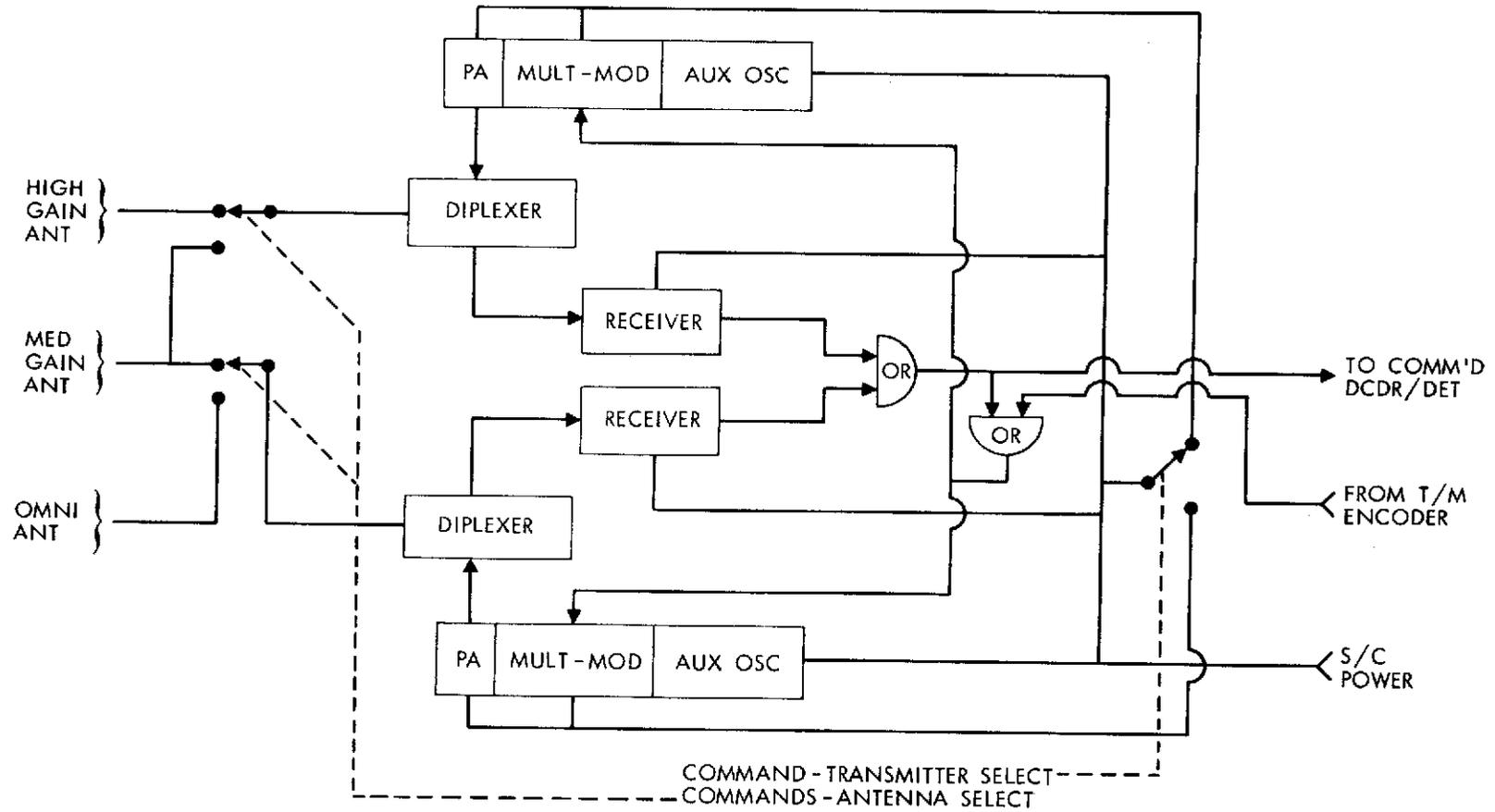
Figure 10. Cometary Explorer S-band Subsystem

A combination of microwave integrated circuit (microstrip) and discrete component techniques is used. Microstrip subassemblies reduce the size and weight at S-band and intermediate frequencies as well as provide uniformity where dimensions are small and critical. Discrete component techniques are used at low frequencies, in dc circuits, and in the transmitter power amplifier. At low frequencies microstrip techniques often result in larger assemblies. Power amplifier designs have demonstrated high efficiency and superior thermal conductivity where using discrete assemblies.

The transmitter provides eight watts of S-band power output and requires 35 watts of spacecraft power. The auxiliary oscillator is used during periods of telemetry transmission and one way Doppler tracking when no uplink signal is present. The multiplier modulator applies phase modulation while multiplying from 19 to 2295 MHz. The output of 250 milliwatts then drives the power amplifier whose eight watt output is filtered in the diplexer. The diplexer of each transponder is switchable between two antennas. The diplexer further filters the antenna signals to apply the uplink signal to the receiver input. The receiver has a 7 dB noise figure. The loop bandwidth ($2 B_{LO}$) is 20 Hz.

4.2.2.3   Antenna Subsystem. The spacecraft antenna system consists of three antennas:

- Omni Antenna (omni);

- Medium Gain Antenna (MGA);

- High Gain Antenna (HGA).

The omni with a quasi omnidirectional antenna pattern is used for transmitting and receiving during the Near-Earth-Phase, primarily before initial spacecraft attitude orientation.

The omni consists of dipole on top of the spacecraft antenna boom and a horn on the bottom of the spacecraft, both fed through a power divider. The gain in the equatorial plane will be 0 dbi for the uplink and +0.5 dbi for the downlink. Over 80% of the spherical coverage, the gain will exceed -5 dbi.

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The MGA, consisting of a collinear array, is used for transmitting and receiving. The antenna pattern (pancake shape) will be omnidirectional in the equatorial plane; the maximum deviations shall not exceed ±0.5 deg. The 3 db beamwidth parallel to the spin axis will be 7.5 deg ±1 deg. The polarization is linear vertical, and the gain for the uplink is 8 dbi and for the downlink is 7 dbi.

The HGA, for transmitting only, consists of a cylindrical parabolic reflector, a subreflector and a slot feeder. The spot beam pattern has a 3 db beamwidth of 5.5 deg ±0.5 deg in the equatorial plane and 14 deg ±1 deg vertical to it. The polarization is linear vertical and the gain will be +23 dbi.

The reflector is mounted on the housing of a brushless DC-motor such that it remains stationary with respect to the spacecraft sun line. Since the angle between spacecraft sun line and spacecraft earth line changes slowly but continuously during flight, the pointing with respect to the spacecraft sun line can be updated semiautomatically and by ground command. The dry lubricated bearings to be used to support the motor housing have been used in a similar application before (Orbiting Solar Observatory (OSO)).

4.2.2.4   Data Handling Subsystem. A universal data system is being designed for future Explorer-type spacecraft, and will be flown on the IMP-J as an engineering test. The heart of the data system will be a Data Multiplex Unit (DMU), which will be equipped with a maximum of four fixed format memories and two variable format memories capable of being loaded by ground command. The format to be telemetered is selectable by ground command. Each DMU will be capable of working at bit rates from 512 to 16,384 ibps in binary incremental steps selectable by ground command. Tentatively it is planned to allow only four bit rates with specific values appropriate to this mission. The DMU's will be built using parts and techniques developed on IMP's and IUE.

The DMU can be interfaced with a general purpose computer, or data storage device if it is determined that one of these should be available on-board.

The data rate at the Grigg-Skjellerup encounter is greater than 16,000 ibps based on a 8w transmitter, a 23 db high gain antenna, and a 210-foot Deep Space Network (DSN) antenna. The data rate for the Giacobini-Zinner encounter (extended mission) will be about 500 ibps, without a data storage device. An on-board data storage device is being considered.

GSFC document X-714-72-215, "Data System Design for Advanced IMP," contains a more detailed description of this subsystem.

4.2.2.5 Command Subsystem. The Command Decoder Unit (CDU) will be designed so that hardware modifications required to adapt it to different missions will be minimal (International Magnetospheric Explorer Mother/Daughter - Heliocentric and the Cometary Mission).

The CDU will contain two independent but identical Pulse Code Modulation (PCM) command decoders except that each will have separate addresses. Each decoder will contain an analog section, a digital section and a power supply. The decoders produce pulse type commands and serial data commands for control of experiments and spacecraft subsystems.

4.2.2.6 Programmer Subsystem. The spacecraft will employ a hydrazine system for maneuvering and attitude control. The system will be operated by ground control. The electronics associated with this system will use a star sensor for attitude determination in addition to the standard IMP optical aspect sensor system.

The attitude control electronics provides the timing and control functions required in the three operating attitude control modes. The control modes are selected by commands to the spacecraft. Each command is redundant.

Three additional electronic packages will be used in conjunction with the spacecraft command subsystem for control.

A system programmer will provide switchable power lines to the spacecraft subsystem electronics. The package will also contain sense circuitry for telemetered spacecraft housekeeping parameters. It will also incorporate an automatic circuit breaker to remove the majority of spacecraft loads from the power system in the event an overload occurs.

An experiment programmer will provide fused switchable power lines to all experiments.

A deployment programmer will be used to switch power to the on-board electro-explosive devices and the EFM antenna mechanisms on command.

4.2.2.7   Power. The power subsystem will be a direct energy transfer type similar to that used on previous Explorer spacecraft and is illustrated in the simplified block diagram of Figure 11.
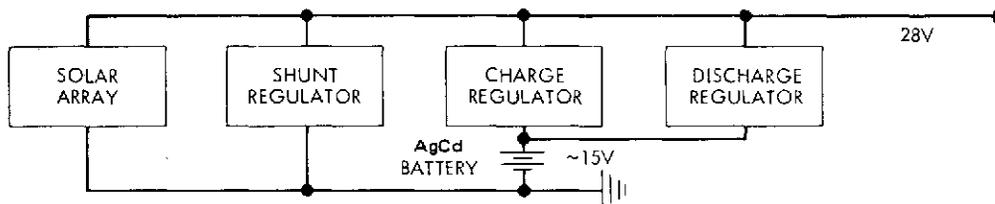
Figure 11. Power Subsystem Block Diagram

Power demand under three conditions of the mission are outlined in Table 4; (1) Cruise modes which occur until return to earth; (2) an encounter mode which might last up to five hours in duration and (3) near aphelion during the extended mission. A reasonable degree of power demand balancing can be obtained between the cruise and encounter modes by shifting loads appropriately. The estimate of heater power given in Table 4 represents an upper limit based on simultaneous, continuous operation of all heaters. During most, if not all of the cruise period, the actual heat dissipation will be considerably lower.

4.2.2.7.1 Battery. A 10AH silver cadmium non-magnetic battery can provide the necessary power leveling and peak demand for the

Table 4

Cometary Explorer Power Requirements

	CRUISE MODE	COMET ENCOUNTER	NEAR APHELION (Extended Mission)
Spacecraft housekeeping#	30 w	30 w	30 w
Transmitter	*35 w	35 w	†35 w
Experiments	40 w	80 w	0
Hydrazine System Heaters:			
Tanks	*<16 w	0	†<16 w
Valves	*<10 w	0	†<10 w
Catalyst Beds	*<20 w	0	†<20 w
Lines	*<10 w	0	†<10 w
Kick-Motor Heater	*9 w	0	0
SCADS	2 w	2 w	2 w
Despun Motor	5 w	5 w	5 w
Hydrazine Pwr. Req.	*30 w	0	0
Battery Heater (ON only prior to kick-motor firing)	9 w		
		152 w	

*Variable loads. Total load at any one time is not to exceed 152w.

#Housekeeping loads are considered to be the encoder, command reciever, optical aspect sensors, attitude control system, charge regulator, and programmers.

†Variable loads. Total load at any one time is not to exceed 84w.

mission through comet encounter. There is a great deal of confidence in being able to provide up to 1 year wet life with a silver cadmium battery. Wet life starts at the time the electrolyte is introduced to the cells, so it includes ground time as well as flight time. Should the battery be required for the extended part of the mission, then silver cadmium cells might be used up to 30 months total life by careful temperature (0 to 10° C) and charge control. If the total life requirement exceeds 30 months, then a heavy magnetically shielded nickel cadmium battery will be considered with the associated weight penalties, but longer life capabilities.

The battery, needed during launch and possibly during certain peak power demand periods such as kick-motor ignition, etc., is charged during the cruise mode using excess solar array power. Also, should some unforeseen impact occur at comet encounter which would degrade the solar arrays, the battery could provide about one hour of spacecraft operation. The battery capacity is 150 watt-hours.

- The 10 AH silver cadmium battery weighs 5 kg (11 pounds) developing 1.1 v/cell.

- The 10 AH nickel cadmium battery with magnetic shield weighs 10 kg (22 pounds) developing 1.2 v/cell.

4.2.2.7.2 Solar Array. The body mounted solar panels for the Cometary Explorer will be 47 cm by 26 cm in size and will weigh approximately 2.5 kg/m² (0.5 lb/ft²). A weight saving is accomplished over previous designs by using a ligher weight magnesium substrate covered with a Kapton film skin. The solar cells will be 200 microns (8 mils) thick. A 150 micron (6 mil) coverglass thickness should be adequate to handle the major radiation damage problem; low energy protons. Dust particles are thought to be mostly a micron or smaller in size and a few larger ones would cause little damage to the solar arrays. Actually, it would be better to allow the few large particles to penetrate the coverglass and enter the solar cell than to shatter a thicker coverglass.

The Cometary Explorer passes through the radiation belt once prior to encounter and twice during the earth-swingby maneuver. After 10 passes through a much more intense part of the radiation belts, the IMP-I suffered about a 6% degradation in power

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output. Since the thinner 200 micron (8 mil) cells will be more
radiation resistant and the total dose of energetic particles will
be less than on IMP-I, a 6% degradation allowance for the array
output through comet encounter should be sufficient.

The Cometary Explorer array, consisting of 3 rings of 16 panels
each, containing 252 2 X 2 cm solar cells, will produce 162 w
of buss power within 10° of normal incidence to the sun. To al-
low for a 6% solar array degradation in twelve months, the maxi-
mum power which can be derived from the array may not exceed
152 watts. It is estimated that the power requirements during
comet encounter will be close to this. Therefore, the solar
array may not be oriented more than ± 10° from normal incidence
to the sun. Also, there is no need for heating or operating the
hydrazine propulsion subsystem during comet encounter. It is
understood that the spacecraft appendages, booms, etc., will
not shadow the solar arrays through comet encounter.

4.2.2.8   Attitude-Determination Subsystem (Optical Aspect and SCADS).
The attitude-determination subsystem will consist of a star-
field sensing system which will provide a highly accurate source
of attitude data, and a sun-sensor system which will provide
elevation and azimuth information with respect to the solar disk.
The sun-sensor system will also include the spin-synchronous
clock which generates a series of pulses synchronized to the
spin rate.

The attitude-determination subsystem will have three primary
components: the star-field sensing system with its electronics,
the sun-sensor, and the spin-synchronous clock electronics.

The candidate star-sensor system is the SCADS, (Scanning
Celestial Attitude Determination System), which was utilized
on Explorer 45 (S^3-A). The star-field sensing subsystems will
be redundant; they will contain two star sensors and one set of
electronics. The optical axis at each sensor will be set in a
direction that is the best compromise for three objectives:
scanning of a large field of stars, shielding against impingement
of direct sun and avoidance of obscuration by the spacecraft
appendages. Considering the locations available and the various
obstructions presented by the spacecraft design, an angle of 45
to 50 degrees between the optical axis of the sensor and the spin
axis of the spacecraft is recommended.

4.2.2.9   Thermal Control. The basic objective of the spacecraft thermal
design is to maintain component temperatures within the follow-
ing design limits:

- Propulsion subsystem: +5° C to +40° C;

- Battery: 0° C to 30° C;

- Solid state detectors: -10° C to +40° C;

- Subsystems: -15° C to +50° C; and

- Boom-mounted components: -40° C to +60° C.

The thermal design of Cometary Explorer will be active, employ-
ing flight proven louvers, coatings, and insulation, supplemented
by small heaters where necessary, to maintain all spacecraft
components and experiments within acceptable temperature limits.
The design must consider the complexity of a hydrazine propulsion
system, a despun antenna reflector, and a kick-motor which will
not be fired until almost a year after launch.

The temperature level of the spacecraft interior is controlled
primarily by the thermal louver assemblies which are mounted
to the rear side of the equipment platform. Sufficient internal
coupling is achieved by using high emittance coatings on the
structure and equipment boxes. The inside of the solar array
and experiment panels are insulated to decouple the panels,
whose temperatures vary substantially during the mission life-
time, from the spacecraft interior. The inner layer of blanket
on the upper array will be coated with highly specular vapor-
deposited aluminum to facilitate heat rejection from the louvers
to space. Heat loss from the bottom end of the spacecraft is
minimized by placing a high temperature superinsulation blanket
on the outside of the micrometeoroid shield. Similarly, a sepa-
rate blanket will cover the kick-motor nozzle exit plane. With-
out insulating the lower end, the heater power required to main-
tain acceptable temperatures on such items as hydrazine tanks,
lines, SCADS, rocket motor, etc., may be excessive in spite
of these items being insulated separately. By decoupling the
lower interior of the spacecraft from the space environment
these components can maintain temperatures near the spacecraft
bulk level. Small heaters, however, are included to insure
reliable operation.

The kick-motor will be conductively isolated from the spacecraft structure to minimize heat soak-back after firing. The rocket cools off after firing by radiation to space from the exposed nozzle (whose exit plane blanket was blown off).

The despun antenna assembly will be insulated and contain a small heater and thermostat to maintain a narrow operating temperature range at all times. The antenna, which protrudes out into space, will be thermally insulated to maintain approximately the same temperature level as the assembly, thereby minimizing the chance of inducing an adverse temperature gradient across the bearings. The construction of the antenna reflector and support structure is to be similar to that of HELIOS, i. e., struts, tubes, and RF grid wires. This configuration eliminates any significant thermal effect on the louver assemblies which would be present with the more conventional solid dish reflector.

The expected average spacecraft interior temperature will vary from 10°C to 25°C based on a variation in internal power of approximately 70 to 150 watts.

4.2.2.10   Propulsion Subsystem. The design of the liquid propulsion system was enhanced by the work accomplished during the GSFC Planetary Explorer program and the current ongoing International Ultraviolet Explorer (IUE) (SAS-D) program. The GSFC Planetary Explorer program yielded the first design of a hydrazine (N_2H_4) velocity correction system to be utilized on a spin-stabilized spacecraft. This required that the attitude not be changed during the cruise mode to the planet, allowing the solar array to remain normal to the sun and the electronically de-spun antenna to remain pointed at earth. This resulted in the use of radial and/or tangential engines in conjunction with axial engines.

The system will consist of a monopropellant hydrazine propulsion subsystem to perform midcourse corrections, attitude control, and spin rate control. The selection of the body-mounted engine arrangement allows for center-of-mass excursions, plume disturbances, and solar array shadowing. The engines (ten thrusters, 3.3 kilograms thrust each, with Shell 405 catalytic beds) will be fully redundant. The propulsion system will be modular and may be preassembled, tested and mated to the spacecraft.

The nominal spin rate during cruise will be 15-30 rpm. Although the spin rate is sufficient to force fuel over the outage ports, an increased spin rate during the first trajectory-correction maneuver to optimize fuel consumption is being considered.

Because of perturbations to both the spacecraft thermal and power subsystems, the spacecraft spin axis should remain perpendicular to the sun vector during maneuvers. Precession of the spin vector about the sun line will point the thrust vector, and radial thrusters will be used for trajectory correction. Figure 12 shows the thruster arrangement. Detailed thruster arrangement studies were conducted under GSFC-sponsored contracts (References 1 and 2). As more detailed information becomes available, the relative advantages of axially-oriented thrusters used with radial thrusters will be analyzed and compared with the presently recommended arrangement. The velocity correction vector orientation will greatly influence the relative merits of using a combination of axial, radial, and/or tangential thrusters.

Reference 1 - Planetary Explorer Liquid Propulsion Study, F. X. McKevitt, R. F. Eggers, C. W. Bolz, et al., Rocket Research Corporation, June 1971 RRC-71-R-249, NAS-5-11296

Reference 2 - Planetary Explorer Liquid Propulsion Study, J. E. McCabe and V. J. Sansevero, Hamilton Standard, February 1971 SP 07R70-F

4.2.2.10.1 Operation. The spacecraft spin rate must be sufficient to force the fuel over the tank outage ports and to optimize propulsion system performance and maneuver accuracy. The amount of residual fuel required to ensure outage-port coverage will depend on the level of spacecraft accelerations if solid-body rotation is assumed. The residual volume becomes very small when the spin load is greater than spacecraft accelerations by a factor of two. A worst-case factor of 10 has been assumed pending detailed study of test information regarding dynamic propellent motions. Based on this assumption a minimum spin rate of 15 rpm during cruise will be adequate. The spin rate at encounter will be based on experiment requirements.
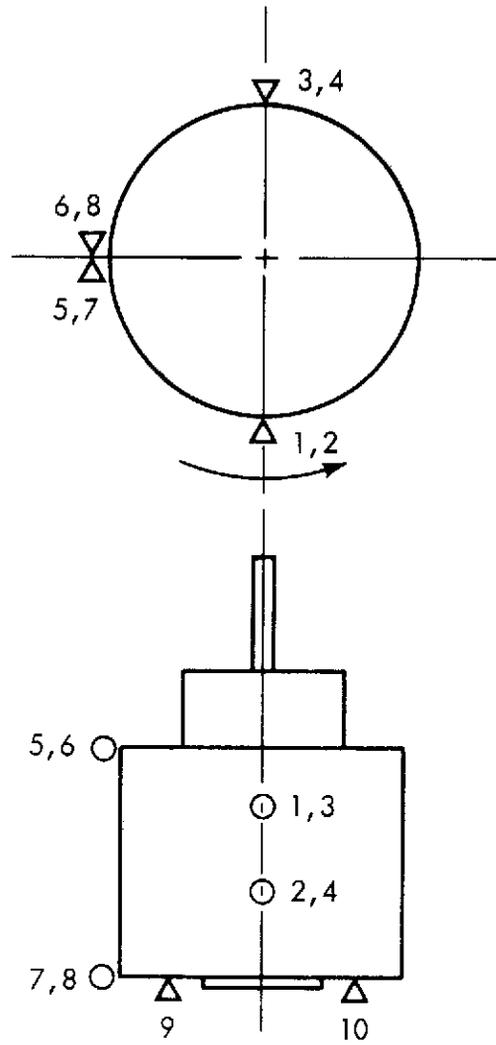
FUNCTION	PRIM	SECOND.
ΔV	1-2	3-4 9-10
ACS	5-8	6-7
+SPIN	6;6-8	8;6
-SPIN	5;5-7	7;5

Figure 12. Engine Placements

Table 5 lists typical maneuver fuel allocations. Two hundred forty-five (245) m/sec are allocated for the total trajectory correction maneuver for the primary mission and earth return. A total of 12 m/sec are allocated for spin and attitude correction and an additional one hundred ten (110) m/sec for extended-mission trajectory corrections. The total fuel allocation of 70.77 kg is for a ΔV of 367 m/sec.

Table 5

Maneuver Budget

	ΔV (mps)	Fuel Expenditure (Kilograms)
Trajectory Corrections (Primary Mission)	135	28.12
Spin/Attitude Corrections	6	1.30
Trajectory Corrections (Earth Return)	110	22.71
Spin/Attitude Corrections	6	1.06
Trajectory Corrections (Extended Mission)	110	17.58
Total	367	70.77

Values used in all fuel calculations are:

- I_{sp} = 226 average for trajectory corrections and 200 average for spin and precession maneuvers;
- Rotational efficiency = 0.95 average;
- Moment arm = 0.61 meters;
- Nominal firing angle = 45 degrees;
- Blowdown Ratio = 3:1.

Figure 13 is a schematic of the propulsion subsystem.

FILL/DRAIN VALVE (4 places)

13.0 DIA. TANK
(8 places)

GN₂
N₂H₄

NO NO

NO NO

NO NC

NO

5 8 1 2   9 10   6 7 3 4

TANGENTIAL RADIAL   AXIAL   TANGENTIAL RADIAL

⊗ LATCHING VALVE
    NC - NORMALLY CLOSED
    NO - NORMALLY OPEN

F FILTER
P PRESSURE TRANSDUCER
T THERMOCOUPLE
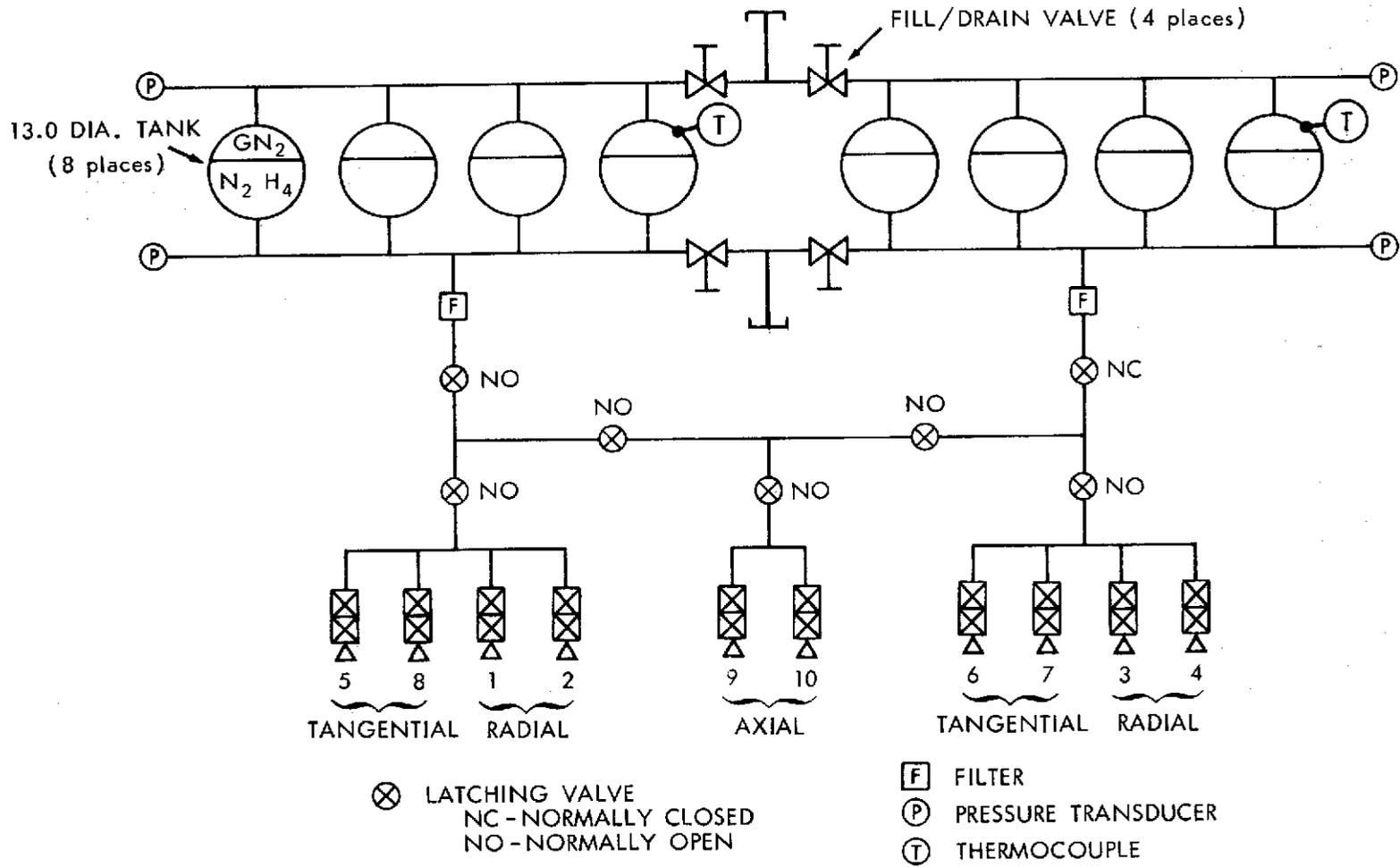
Figure 13. Liquid Propulsion Subsystem

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Use of a nutation damper to aid in the control of the spacecraft is being considered. In a preliminary arrangement, the dampers are located symmetrically in the propulsion bay. Viscous ring dampers were sized for optimum wobble Reynolds number for the cruise configuration. The diameter was restricted to 0.28 meters to facilitate damper packaging. The damper configuration has an 0.013 meter tube radius, contains 0.417 kilograms of number 200 silicone oil, and weighs 0.73 kilograms. Three symmetrically arranged dampers were considered. The time constants for this damper system will be:

Spacecraft Configuration	Time Constant at 25°C
Cruise	67 minutes
After Hydrazine Depletion	90 minutes

4.2.2.10.2 Kick-Motor. A solid-propellent rocket motor will be utilized during the earth-swingby phase after the encounter with Grigg-Skjellerup. The motor to be used has been flown successfully on the Radio Astronomy Explorer (RAE) Program. (Explorers 38 and 49). It will impart a velocity of about 400 mps.

4.2.2.11 Spacecraft Wiring Harness. The primary consideration in wiring harness design is the suppression of conducted and radiated interference. Since the spacecraft is expected to contain a number of sensitive electromagnetic field experiments, as well as noise producing experiments and digital systems, isolation of various wiring harness elements is exceedingly important. Exceptionally sensitive or noisy leads are individually shielded. Sensitive leads are also routed in their own shielded bundle of subharness to minimize coupling. Special care in shielding and filtering is given to all harness components on the exterior of the main spacecraft structure. Cables from the experiment boom units plug directly into the outside faces of the experiment spacecraft assembly to further minimize coupling. Isolation between power currents and signal leads is usually maintained by using power converters with isolated primary and secondary windings to avoid generation of stray magnetic fields.

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4.2.2.12 Electric Field Measurement Antennas. The Cometary **Explorer**
spacecraft may contain four (4) antennas to be used for **electric**
field measurements subject to final experiment selection. If
used, these antennas will be located on the main spacecraft shelf
and will deploy to form an array of four antennas at 90 degrees
to each other lying in a plane that is perpendicular to the spin
axis of the spacecraft.

Each antenna will be 61 meters long and will be composed of a
stainless steel cable made up of seven strands of 0.019 cm dia-
meter wire. The inboard 46 meters of each antenna will have
an insulation coating of black FEP Teflon. The antenna wire
will be stored on a drum inside an RF tight housing in the space-
craft and upon ground command the motor driven mechanism
will deploy the antenna at the rate of about 0.05 meters per se-
cond. Retraction capability is built into each mechanism. The
antennas will be deployed in alternating pairs with appropriate
spin-ups provided by the spacecraft attitude control system be-
tween deployment increments to prevent the spacecraft spin
rate from dropping below 15 rpm.

After deployment all power to the deployment mechanisms is
shut off, and the antennas serve to gather electrical field data
for several experiments on-board the spacecraft.

4.3 GROUND CHECKOUT SYSTEMS

The equipment used to operate and evaluate the performance of the space-
craft during integration and environmental testing is similar to that used on
previous Explorer programs and is provided in two major sections: (1) the
spacecraft and experiment control, and (2) the spacecraft and experiment
electrical support equipment. The following paragraphs describe the basic
function of the two sections.

4.3.1 Spacecraft and Experiment Control. The computer ground sys-
tem consists of a digital computer with special peripheral equip-
ment for reception of telemetry and generation of commands.
It contains all the equipment necessary to control the spacecraft
and experiments via the RF command link; the system also re-
ceives, processes, displays, and evaluates data received via
the RF telemetry link. Reduction and display of experiment data

is made similar to that which the experimenter will use subsequent to launch to provide continuity of experiment calibration data, help in training experimenter personnel in interpreting the data they will receive in flight, and reveal any data processing problems which might be encountered during post launch operations.

4.3.2   Spacecraft and Experiment Electrical Support Equipment. The electrical support equipment is located at the spacecraft and primarily provides electrical power to simulate the output of the solar array and equipment to stimulate spacecraft and experiment sensors so that the associated flight hardware can be exercised and evaluated via the computer ground station. Each experimenter provides the equipment to stimulate his instruments. Because many experiments are synchronized to spacecraft spin, provision is made to generate control signals that are phase-locked to an artificial spin sequence. These control signals can be used to synchronize stimulus to the spin rate and thus check functions that are sensitive to spin or spin azimuth.

5. SCHEDULE AND CRITICAL MILESTONES

A tentative schedule attempting to take into account realistic time requirements for instrument, experiment and spacecraft fabrication as well as project review and approval is presented in Figure 14. The general concept of the schedule is based upon the following critical milestones.

1. January 1974 - Selection of SSG (ground based and spacecraft experimenters)

2. July 1974 - Final experiment selection and initiation of funding

3. August 1975 - Start spacecraft integration

4. November 1976 - Launch

5. April 1977 - Arrival at Comet Grigg-Skjellerup

6. February 1979 - Arrival at Comet Giacobini-Zinner

MILESTONE SCHEDULE

CENTER _____
RESPONSIBILITY:
  APPROVAL _____
ACCOMPLISHMENT _____

PROJECT   COMETARY EXPLORER (GRIGG-SKJELLERUP-GIACOBINI-ZINNER)

2 LEVEL

ORIG. SCHED. APPR. _____ (DATE)
LAST SCHED. CHG. _____ (DATE) (NO.)(INITIALS)
STATUS AS OF ___ 8/1/73 (DATE) (INITIALS)

MILESTONES	1972	1973	1974	1975	1976	1977

1.
2.
3. EXECUTION PHASE PP TO HQS
4. SSG RECOMMENDATIONS TO HQS
5. SYSTEM DEFINITION
6. FINAL EXPERIMENT SELECTION
7.
8.
9.
10. EXPERIMENT INTERFACE FREEZE
11. FAB. PROTOFLIGHT S/C & HARNESS
12. PROTOFLIGHT SUBSYSTEM TESTS
13. INTEGRATE PROTOFLIGHT S/C
14. PROTOFLIGHT S/C TESTS
15. LAUNCH OPERATIONS
16. GRIGG-SKJELLERUP INTERCEPT
17. GIACOBINI-ZINNER INTERCEPT
18.
19.
20.

SYSTEM DEFINITION PHASE

EXECUTION PHASE

FEBRUARY 1979

NOTES:

NASA Form 1384b (MAY 1968)

GPO 896-750

Figure 14.   Cometary Explorer Milestone Schedule