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PLANNED FLIGHT TEST OF A MERCURY ION AUXILIARY PROPULSION SYSTEM PART II - INTEGRATION WITH HOST SPACECRAFT

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PART II - INTEGRATION WITH HOST SPACECRAFT

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ABSTRACT

This is part II of a three-part paper describing the approved flight test of a mercury ion auxiliary propulsion system. This part summarizes the objectives of the flight test and describes how those objectives are in support of an overall program goal of attaining user application. The approach to accomplishment is presented as it applies to integrating the propulsion system with the host spacecraft, USAF's STP P80-1. A number of known interface design considerations which affect the propulsion system and the spacecraft are discussed. Finally, analogies are drawn comparing the relationship of the organizations involved with this flight test with those anticipated for future operational missions. Parts I and III of the paper expand upon the objectives, system description, mission operations, and measurement of plume effects. Parts I and III reflect the principal investigator viewpoint whereas this part II represents the project office perceptions.

INTRODUCTION

Ion propulsion offers significant advantages over present chemical propulsion for auxiliary purposes (station keeping, attitude control, and station change). It uniquely features very high specific impulse and very low thrust levels. For certain classes of space missions, notably geosyncronous, long life, high power satellites, the high specific impulse feature can be employed to increase the weight available for useful payload by decreasing the auxiliary propulsion system weight. Also, the low thrust applied in a continuous fashion (compared to high thrust, pulsing chemical systems) can increase spacecraft pointing accuracy and attitude stability. These increases can be used to good advantage by improving

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overall spacecraft performance or by reducing total spacecraft system costs (ref. 1).

In recognition of these potential advantages, the technological development of an ion auxiliary propulsion system has been carried to the phase where a flight test has been approved. Organizations have been structured, objectives have been established, plans and approaches worked out, contracts let and agreements for a host spacecraft (USAF's STP P80-1) secured. A conceptual definition of the propulsion system-to-spacecraft interface has been accomplished, prior to selection of the actual spacecraft contractor and configuration. The planning phase is ending and the entire effort is on the brink of entering the execution phase. Such is the status at the time of this writing.

The project is described in a paper having three parts. Part I, Objectives, Systems Description and Mission Operations, and Part III, Measurement of Plume Effects (refs. 2 and 3), describe the flight test as perceived by the Principal Investigator. Part II (this paper) is oriented towards the project activities of integrating the flight test hardware with the host spacecraft.

PROGRAM OBJECTIVES AND APPROACH

NASA has a substantial and ongoing technology program in auxiliary electric propulsion. The approach used in the program relies heavily on ground based test and analyses efforts to accomplish the technology goals. These ground efforts have yielded substantial technology results and are to continue being the basis for future advancements.

One such technology result is the development of a thruster subsystem design adequate for flight. However, the transfer of technology will be incomplete until a flight test takes place. Flight tests are historically characteristic for any new propulsion technology transfer, whether electrical or chemical. Several flight tests of liquid hydrogen rocket engines (Centaur), and the need for a series of six Orbital Flight Tests of the Space Shuttle are but two examples.

FLIGHT PROJECT OBJECTIVES AND APPROACH

A major consequence of the overall technology program is that certain elements requiring flight have been identified and coalesced into a space flight test project. This project has the objectives stated below in support of the program goals

The primary objective is to accomplish the flight qualification of the ion auxiliary propulsion system by verifying in space its functional operation such as thrust duration, on/off cycles, and dual thruster operations.

The secondary objective is to confirm design and ground-based test information on system performance and on system-to-spacecraft interface requirements (with emphasis on thruster by-products-to-spacecraft interface).

The primary objective will assure user confidence in the ability of the technology to perform as intended. The secondary objective, in conjunction with ongoing ground efforts, will yield reliable engineering information to facilitate design application of ion auxiliary propulsion for a variety of mission types and strategies. In order to accomplish the flight test objectives, two classes of hardware are required on a single spacecraft; namely, an ion auxiliary propulsion system, and diagnostic instrumentation. Figure 1 shows a conceptual view of the hardware.

The ion auxiliary propulsion system consists of two identical thruster subsystems (TSS). Two TSS's were selected for flight because two TSS's form a basic building block, or system, in an operational mission. Many missions would use two pair. Correct selection of the proper pair of thrusters allows the spacecraft to achieve any of the three auxiliary propulsion functions of station keeping, attitude control, or station change (ref. 4).

The TSS to be used as a baseline design is that developed by Lewis Research Center and Hughes Research Laboratory under the NASA technology program for auxiliary electric propulsion. This baseline design will be modified, as discussed later, to adapt interfaces to the host spacecraft.

The diagnostic instrumentation is needed to measure selected thruster plume by-products. These measurements in space are expected to confirm and refine the envelopes derived in ground tests and analyses. The envelopes thus defined will permit future users to confidently place sensitive surfaces near the thruster.

The flight plan is to operate the propulsion system in a manner to verify that it functions as required by an operational mission, and to obtain information confirming system performance. Throughout the flight the diagnostic instrumentation will collect thruster plume by-product information with accuracies unobtainable in ground facilities. This information will be correlated with ground data.

DESIGN AND INTEGRATION CONSIDERATIONS

Successful design and integration of the propulsion system and P80-1 will require several considerations. These considerations are discussed below and the schedule for their accomplishment is shown in figure 2.

Thrust Subsystem Configuration

The following sections will summarize and reference the TSS design extant at the start of the flight project, as well as discuss the known modifications required and the need for these modifications.

Engineering model thruster subsystem. - The starting point of the TSS to be flown is the 8-cm mercury ion bombardment Engineering Model Thruster Subsystem (EMTS) design previously developed by Lewis Research Center and Hughes Research Laboratory. It consists of a thruster/gimbal unit, a propellant tank unit, a power electronics unit, and a digital interface unit, as shown in figure 3, and has the interface and performance features summarized in table II. It is described in detail in reference 5.

Considerations motivated by user acceptance needs. - Perhaps the most significant configuration change is to expand the current digital interface unit design to include self contained logic for startup and operation of the thruster in its various modes. This addition of capability recognizes that future operational spacecraft employing ion auxiliary propulsion will demand simple start-stop type command interfaces and otherwise autonomous propulsion system operation. This change, then, is to provide future users with easy application of the propulsion system for functions of stationkeeping, attitude control, or station change.

A second addition to the basic EMTS starting point design is that of a beam shield. The beam shield provides a large region in the downstream hemisphere in which surfaces sensitive to thruster by-products can be safely mounted. Studies have shown (ref. 4) that beam shields are required in all symmetrical spacecraft configurations where body mounted auxiliary electric propulsion systems are to be employed. Thus the beam shield was added because it constitutes a necessary part of future propulsion systems to be flown. It was not added specifically to ease integration with P80-1. Whether or not it will be used for the later purpose remains to be seen.

Considerations motivated by P80-1 interface requirements. -At this conceptual phase in the integration planning, one major study effort and two needed additions to the EMTS design have been identified. They must be accomplished to meet the requirements of the spacecraft.

The study effort consists of accurately assessing the impact (if any) of the thruster by-product interfaces with P80-1 and with the two other payloads which will also fly on P80-1. This is a significant task necessary to assure the acceptability of time shared in-space operations of the propulsion system with each of the other two payloads.

The present digital interface unit design is several years old and was intended for a different spacecraft computer interface. Consequently a redesign for compatability in communicating with the host spacecraft in the proper digital format is essential. This interface change in conjunction with the previously mentioned need for a simple command interface and autonomy requires a design and development effort. The resulting end product will no longer be called a digital interface unit but will instead become a digital control and interface unit (DCIU).

To the propellant tank outlet must be added a normally closed valve to confine the mercury propellant to the tankage during appropriate times. This valving is needed to:

Comply with STS manrated safety requirements

Prevent any ascent acceleration force, in combination with normal tank pressurization forces, from causing mercury intrusion of the porous vaporizer plugs of the thrusters

Provide a mercury seal so that the thruster may be removed and handled separately from the pressurized propellant tank and propellant lines during ground handling

Stop the flow of mercury in the event that becomes necessary.

Spacecraft Design Considerations Motivated by Propulsion System Requirements

The propulsion system also levies requirements upon the spacecraft design. A study of the following will show that these requirements are for the most part intentionally those requirements which would exist in an operational use. These requirements are described more fully in reference 1. However, the key requirements and their anticipated impact on the P80-1 design are summarized below:

1. Housekeeping services such as power, command and control and compatible thermal design are required. Note that for this flight test a separate attitude control system is also needed to maintain sun and earth orientation, as the propulsion system is not planned for use for that purpose.

These requirements are rather modest and are easily within routine spacecraft design practices and available hardware. However, it should be noted that the energy requirement to continuously cycle one TSS on and off, drawing nearly 200 watts of power when on, is somewhat larger than that of the two other P80-1 payloads, and so is expected to influence the spacecraft power system size.

2. The thrust vectors of both thrusters are to be alined through the spacecraft center of gravity, one radially outward away from Earth, the other parallel

to the spacecraft velocity vector. For the flight test, this will permit unrestricted thrusting without introducing disturbance torques; for operational missions this, with selection of the proper pair of thrusters and using the existing gimballing capability, will achieve the desired functions of either stationkeeping, attitude control or station change (ref. 4).

The two thrust vectors are additionally required to form an approximate 90° angle and have other specific spatial and angular relationships to each other. This geometry provides for the gathering of meaningful dual thruster operational data which will be most useful to a variety of future configurations, as well as provides for ease of integration with P80-1.

3. Spacecraft surfaces sensitive to thruster by-products are constrained from being within regions known to contain that efflux. Specifically, line of sight to thruster grids or to inside of the beam shields is restricted.

The combination of 2. and 3. above are requirements which can readily be met if P80-1 has a box-like shape with most of the radially outward side (from the Earth) and the front or back side (relative to the orbital velocity vector) dedicated to the thruster mountings.

4. The flight test will require approximately 20 months to accomplish all objectives. This places a lifetime requirement on the P80-1. However, with the high-reliability approach selected for P80-1 (redundancy), this requirement does not appear to be a large driver of the P80-1 design.

Spacecraft Integration Activities

Integration activities with P80-1 take place during three sequential phases (fig. 2). First is a conceptual planning phase between STP and Lewis Research Center. This phase, now complete, permitted both organizations to scope the integration task technically, schedularly, and financially. It resulted in permitting both organizations to write compatible contracts to accomplish the necessary work. Award of these contracts marks completion of the conceptual phase.

The second phase is that of defining a firm and detailed interface between the propulsion system and P80-1. This phase will involve both the propulsion system contractor and the P80-1 spacecraft contractor, as well as STP and Lewis Research Center. It will result in finalized interface control documentation from which hardware can be compatibly designed on both sides of the interface.

The third and final phase is that of verification. This will be accomplished by integration of the propulsion system and diagnostics with P80-1. The other two payloads will be similarly integrated with P80-1. The assembly will then be subjected to performance and environmental tests to assure that the hardware is as designed and that the designs are compatible.

The only unique feature of this verification phase is expected to be that of a thruster checkout strategy. Thruster testing at the component level and at the subsystem level will take place at the propulsion system contractor's facility. However, the thruster will not be operated while on P80-1 during ground testing to preclude mercury contaminating both vacuum tanks and the spacecraft. Thus, a strategy for some effective in situ checkout is required. A conceptual approach has been established which would substitute mass and power load simulators for the thrusters during most of the interface verification testing. At some point close to launch, it is planned, the flight thrusters will be installed. Checkout techniques to assure a proper final mating of the propellant line field joint and of some of the thruster electrical connections have been established. As of this writing, it is planned that checkout of the remainder of the thruster final electrical connections be conducted according to aerospace techniques such as are used for pyrodevices. As this conceptual approach matures by implementation, it is expected to produce a checkout strategy which will be available for operational users.

HOST SPACECRAFT DESCRIPTION

Approval has been secured to conduct the flight test aboard USAF's STP P80-1. This will be the first scheduled flight of a USAF spacecraft onboard Shuttle. Salient characteristics of P80-1 are shown in figure 4.

Note that there are two other payloads aboard, in addition to the ion auxiliary propulsion system. Each of the three payloads is funded and managed by separate organizations. Each has its own set of objectives which are independent of one another. A conceptual view of the P80-1 configuration showing relative placements of the three payloads is given in figure 5.

ORGANIZATIONAL RELATIONSHIPS

The roles and relationships of the four participating organizations are in many respects like those which might be found in future operational missions which employ ion propulsion. Thus the experiences and management techniques developed to conduct the flight test on P80-1 are fore runners of those to be used operationally. Figure 6 depicts the relationships to be discussed below.

For example, the USAF's STP/P80-1 contractor team serves as Program Manager and thus has responsibilities analogous to those of a program/spacecraft manager of a mission where ion auxiliary propulsion is operational. The two other payload agencies represent payload agencies similar to those of an operational mission. And finally, the LeRC/Contractor team is for this flight a payload but has responsibilities analogous to the operational supplier of the ion propulsion system. The experiences to be gained will be of inestimable value for future operational missions.

CONCLUSIONS

A flight test is necessary to transfer the auxiliary electric propulsion technology developed under a NASA program. The need for a flight test follows a historical pattern observed in other propulsion system technology developments. An ion auxiliary propulsion system will be flown and will function in space as it would be called upon to do operationally. Engineering information will be obtained for use in designing future applications. Also to be flown is appropriate diagnostic instrumentation to confirm and refine thruster plume by-products within the envelopes predicted by the ground program.

This flight test will be conducted on USAF's STP P80-1 spacecraft which will in turn be deployed by the Shuttle. The relationships of the various organizations represented on P80-1 will provide experiences very much like and of great value to future operational missions employing ion propulsion systems. A number of design considerations have been identified which when addressed, will assure compatibility of the flight test objectives and hardware with the P80-1 flight

REFERENCES

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2. Power, John L., "Planned Flight Test of a Mercury Ion Auxiliary Propulsion System, Part I, Objectives, Systems Descriptions, and Mission Operations," AIAA paper 78-647, Apr. 1978.

3. Power, John L., "Planned Flight Test of a Mercury Ion Auxiliary Propulsion System, Part III, Measurement of Plume Effects," to be published.

4. "8-Cm Mercury Ion Thruster Subsystem Users Manual," TRW Defense and Space Systems Group, July 1977.

5. Herron, B. G., Hyman, J., Hooper, D. J., Williamson, W. S., and Collett, C. R., "Engineering Model 8-cm Thruster System," AIAA paper 78-646, Apr. 1978.

TABLE I. - DEFINITIONS AND ACRONYMS

DCIU	Digital controller and interface unit
DIU	Digital interface unit
EMTS	Engineering model thruster subsystem
HRL	Hughes Research Laboratory
LeRC	Lewis Research Center (NASA)
P80-1	USAF's STP spacecraft, host to the ion auxiliary propulsion system flight test
STP	Space Test Program (USAF)
TSS	Thruster subsystem

TABLE II. - EMTS INTERFACE AND PERFORMANCE FEATURES

Parameter	
Thermal	Mounting in SC interior or mounting on sun-oriented, thermally isolated appendages
Mass reservoir capacity (Hg)	15.7 kg dry 8.75 kg (13 000 hr)
Electrical	70 ±20 V dc, 160.3 W 28 ±1 V dc, 4.7 W Efficiency at 70 V dc, 74.5 percent
Command and data	16 bit serial interface to be replaced by interface compatible with P80-1
Thruster by-product/SC interface	No sensitive surfaces may view thruster grids (downstream hemisphere); sensitive surfaces in upstream hemisphere generally acceptable. The beam shield to be added will permit sensitive surfaces to be located in its shadow.
Thrust vector gimballing	$\pm 10^{\circ}$ in each of two directions
I_{sp}	2700 sec
Startup time	$\leq$ 15 min
Restarts[a]	$\geq$ 10 000 cycles
Thruster operational lifetime[a]	$\geq$ 20 000 hr

[a]Goal, not demonstrated.

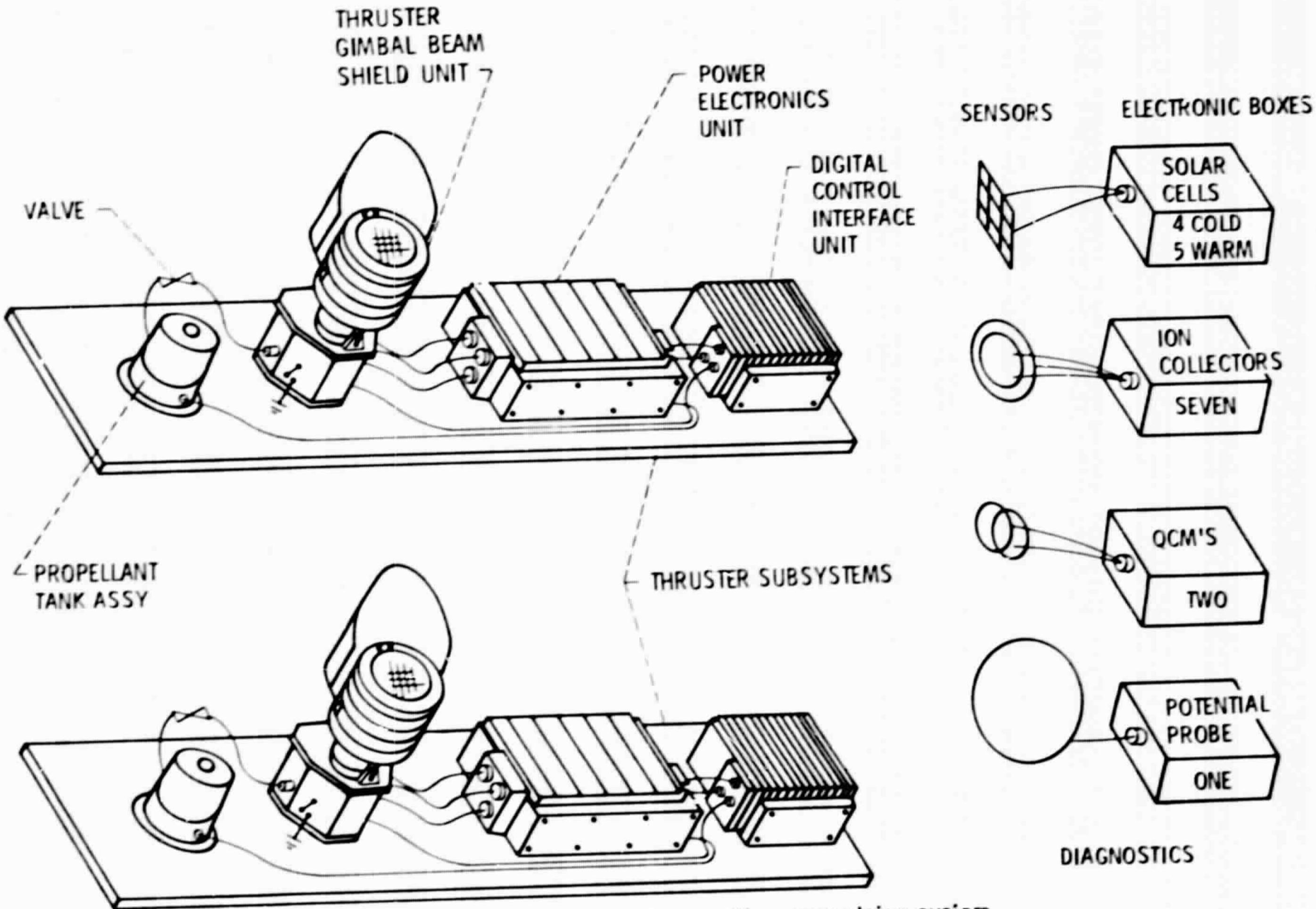

Figure 1. - Flight package ion auxiliary propulsion system.

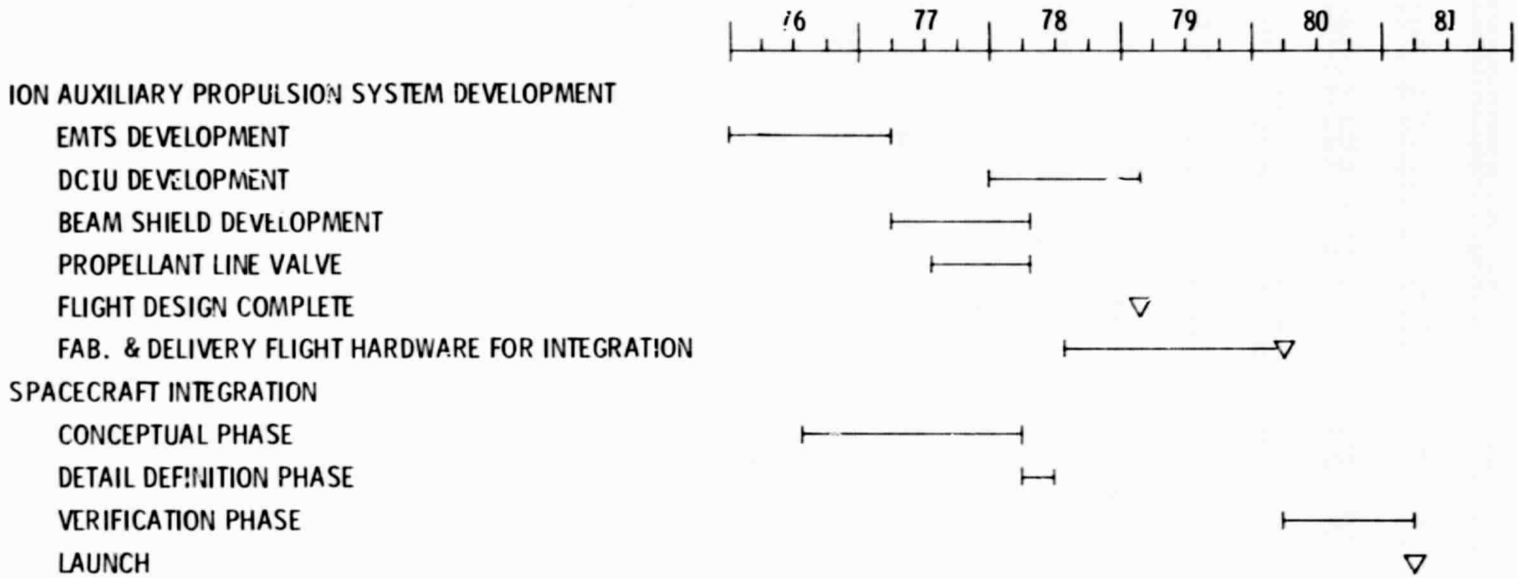

Figure 2. - Design development and spacecraft integration schedule.

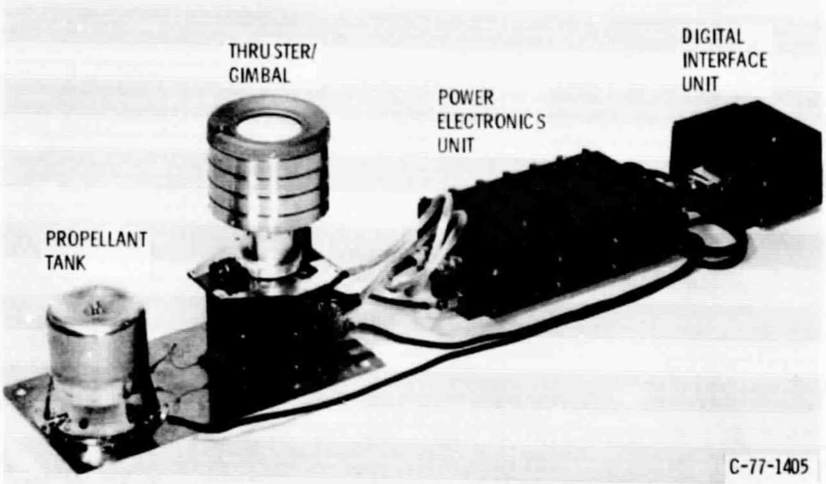

Figure 3. - Engineering model thruster subsystem.

MISSION OBJECTIVE: TO SERVE AS HOST SPACECRAFT FOR 3 PAYLOADS-
TEAL RUBY, ION AUXILIARY PROPULSION SYSTEM AND EXTREME
ULTRAVIOLET PHOTOMETER

NOMINAL ORBIT: 400 n. m. CIRCULAR, NEAR POLAR

LAUNCH VEHICLE: SHUTTLE TO LOW EARTH ORBIT, 2 SOLID ROCKET MOTORS
TO FINAL ORBIT

RELIABILITY: DESIGN GOAL OF 3 YEARS

LAUNCH DATE: MARCH, 1981

Figure 4. - P80-1 mission characteristics.

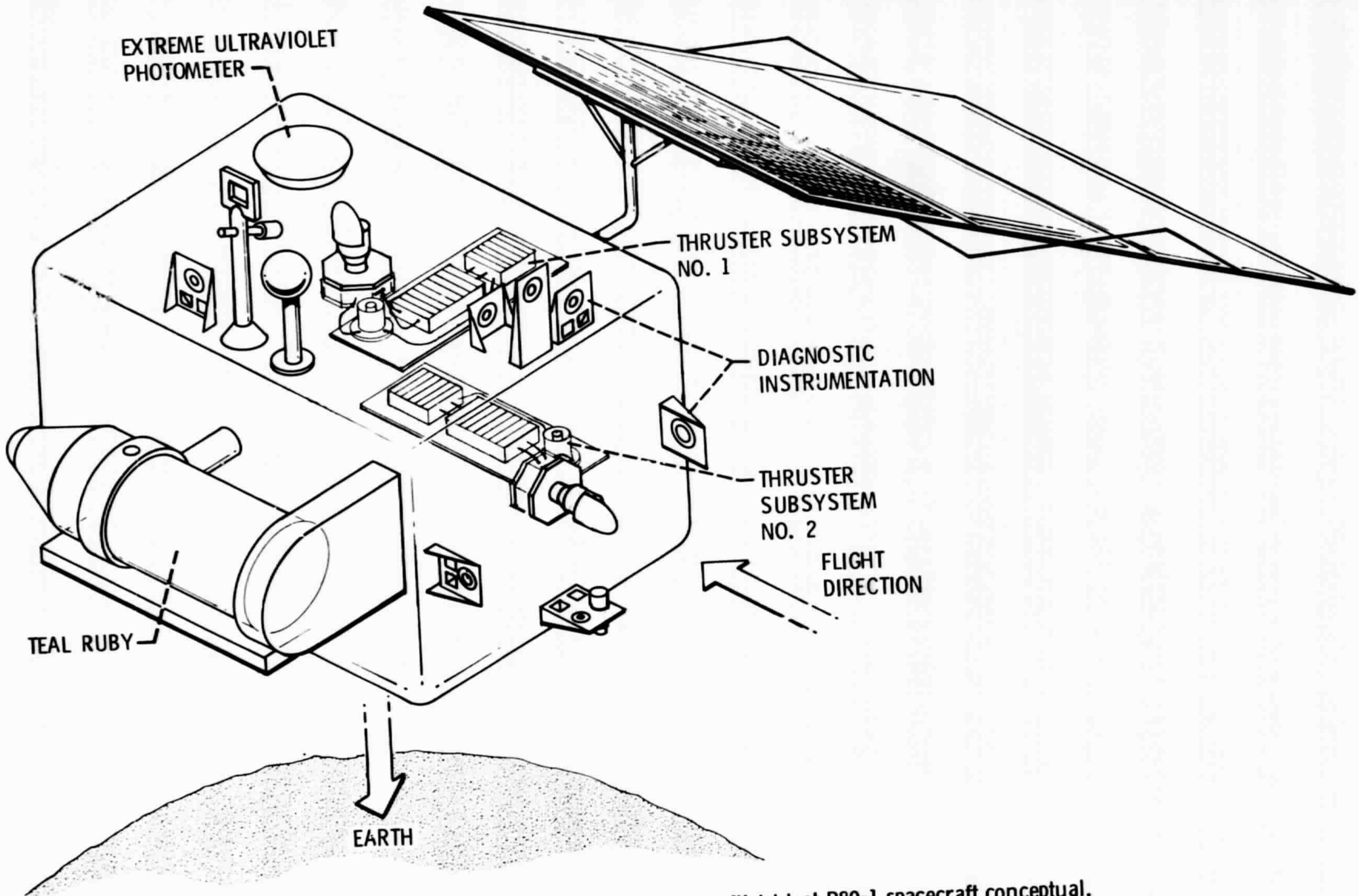

Figure 5. - Ion auxiliary propulsion system flight test P80-1 spacecraft conceptual.

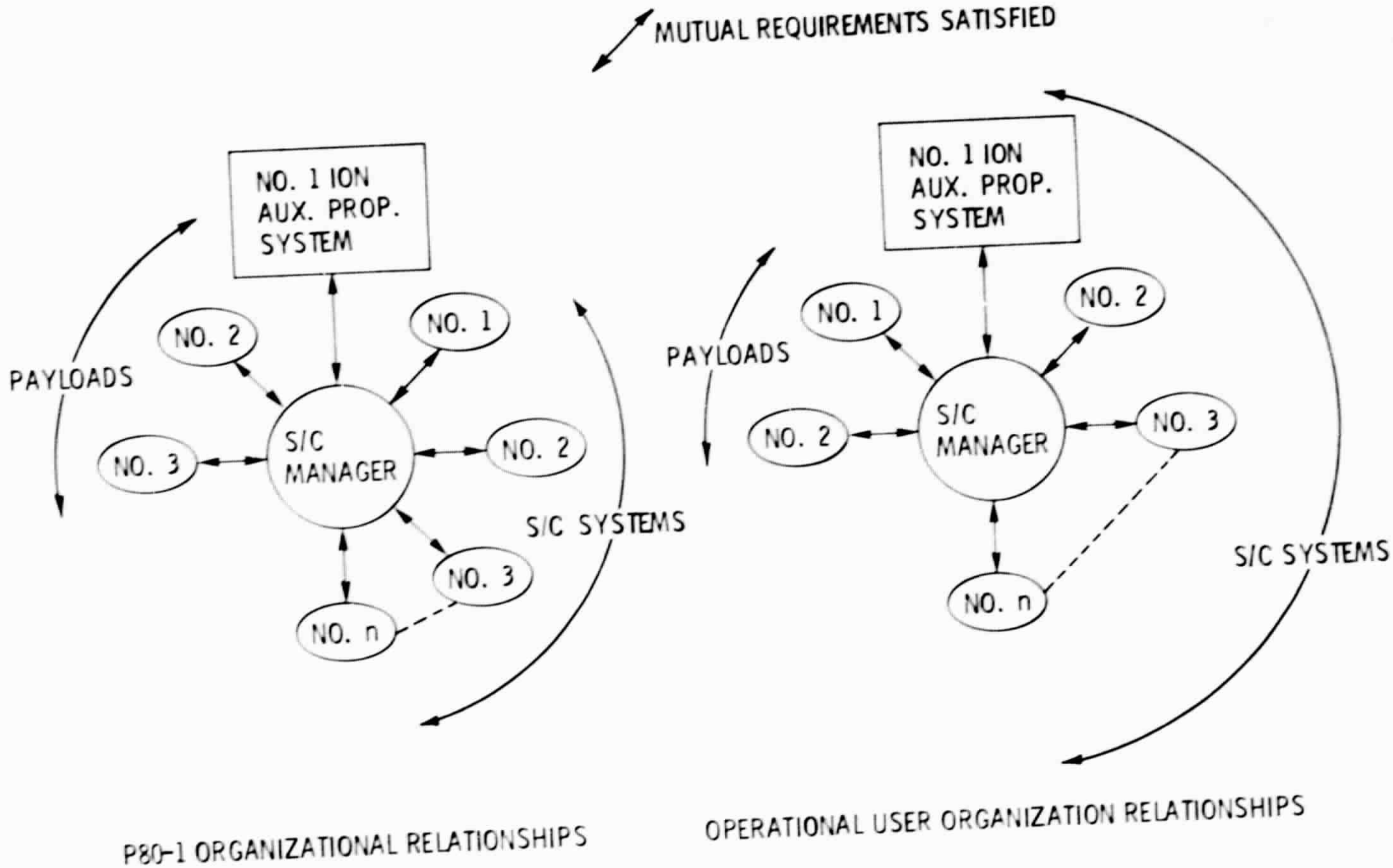

Figure 6. - Organizational relationships.