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REFERENCE EARTH ORBITAL RESEARCH AND APPLICATIONS INVESTIGATIONS

(BLUE BOOK)

VOLUME VII • TECHNOLOGY

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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PREFACE

The purpose of the preliminary edition of the "Reference Earth Orbital Research and Applications Investigations" set forth in this document is to:

a. Provide criteria, guidelines, and an organized approach for use in the Space Station and Space Shuttle Program Definition Phase and ancillary studies in designing a flexible, multidisciplinary orbiting space facility and logistics system.

b. Define a manned space flight research capability to be conducted in earth orbital Space Stations and Shuttles.

c. Provide a basis for potential follow-on programs.

The term "Functional Program Element" (FPE) used in this document describes a gross grouping of experiments characterized by the following two dominant features:

a. Individual experiments that are mutually supportive of a particular area of research or investigation, and

b. Experiments that impose similar and related demands on the Space Station Support Systems.

The research and applications investigations as set forth herein depart from a heterogeneous collection of individual experiments and are designed toward a "research facility" and "module" approach. The term FPE and "module" are used somewhat interchangeably in this publication although this relationship is unintentional. Thus, a particular FPE may be described which does not fully utilize the capability of a complementary module but would, however, permit flexibility in experiment planning.

Functional Program Elements and experiments covered in this document are envisioned for flight with the initial Space Station and the Space Shuttle. Only those FPE's and experiments which can reasonably be expected to be accomplished during the first few years of the Space Station and Space Shuttle have been described in detail in this document. However, for the most part, these FPE's are considered to be open-ended so that their utility could be extended.

This publication is applicable to all NASA program elements and field installations involved in the Space Station and Space Shuttle program.

The supply of this document is limited. Therefore, for those procurement actions involving only a certain portion (or portions) of this handbook, the cognizant NASA installations shall abstract from this handbook only such portions as apply to a given RFP or contract action.

This publication was prepared in conjunction with NASA Headquarters Program Offices and field installations involved in payload planning and with industry participation. It is an updated and revised version of the Candidate Experiment Program for Manned Space Stations, NHB-7150.xx, dated September 15, 1969 and the changes thereto dated June, 1970. These earlier versions are hereby cancelled.

The material contained in each volume has been produced under the guidance of Review Groups composed of scientific personnel at NASA Headquarters, MSFC, LaRC, MSC, LeRC, GSFC and ARC. The purpose of this effort was not only to revise and update the experiment programs but also to establish the Space Shuttle as well as the Space Station requirements.

Volume I, Summary, presents the background information and evolution of this document; the definition of terms used; the concepts of Space Shuttle, Space Station, Experiment Modules, Shuttle-sortie Operations, and Modular Space Station; and in Section IV, a summary of the Functional Program Element (FPE) requirements is presented.

Volumes II thru VIII contain detailed discussions of the experiment programs and requirements for each discipline. The eight volumes are:

Volume I	Summary
Volume II	Astronomy
Volume III	Physics
Volume IV	Earth Observations
Volume V	Communications/Navigation
Volume VI	Materials Sciences & Manufacturing
Volume VII	Technology
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INTRODUCTION

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The five FPEs in this volume are devoted to the development of new technology for application to future generation spacecraft and experiments. Assignments of crew skills from Table 1 have been made to accomplish tasks such as experiment equipment installation, checkout, operation, monitoring, and evaluation.

CONTAMINATION. The objectives of the experiments in this FPE are to: (1) monitor and trace the movement of external contaminants; (2) evaluate the light scattering effects of these contaminants deposited on optical components, windows, etc.; (4) evaluate techniques of removing the contaminants; (5) evaluate techniques for reducing the amount deposited; and (6) evaluate active cleaning methods. The experiments can be accommodated as either Space Shuttle or Space Station payloads. The experiment equipment is of the "suitcase" type, and requires only a means of access to space, pointing and position means, and subsystems and crew support.

FLUID MANAGEMENT. Experiments included in the Fluid Management FPE are related to the understanding of fundamentals and optimization of design practices for advanced spacecraft fluid systems. These experiments are designed to yield parametric information over the entire range of flows, temperatures, acceleration levels, heat transfer rates, etc., which may be encountered in future vehicle designs.

EXTRAVEHICULAR ACTIVITY. The two experiments included in this FPE describe the development and evaluation of an Astronaut Maneuvering Unit (AMU) and a Maneuverable Work Platform (MWP). These experiments may be accommodated either as Space Station or Shuttle-sortie payloads.

ADVANCED SPACECRAFT SYSTEMS TESTS. This FPE describes typical types of tests which will be performed in orbit to develop and qualify hardware for future spacecraft. Analysis of the experiment requirements indicates a large measure of commonality in the need for support items such as airlocks, stabilized platforms, deployment booms, test cells, and instrumentation. A relatively small number of multipurpose support items will be incorporated in a spacecraft laboratory for widespread use. Specialized support equipment, as well as experimental devices, will be treated as "suitcase" payloads.

TELEOPERATIONS. The objective of the FPE is to develop and evaluate an experimental teleoperator system for use with future space activities. Such a system would be a precursor to an operational system and would provide a means for evaluating teleoperator system performance and applications.

Table 1. Crew Skills

1.	Biological Technician	15.	Optical Scientist
2.	Microbiological Technician	16.	Meteorologist
3.	Biochemist	17.	Microwave Specialist
4.	Physiologist	18.	Oceanographer
5.	Astronomer/Astrophysicist	19.	Physical Geologist
6.	Physicist	20.	Photo Geologist
7.	Nuclear Physicist	21.	Behavioral Scientist
8.	Photo Technician/Cartographer	22.	Chemical Technician
9.	Thermodynamicist	23.	Metallurgist
10.	Electronic Engineer	24.	Material Scientist
11.	Mechanical Engineer	25.	Physical Chemist
12.	Electromechanical Technician	26.	Agronomist
13.	Medical Doctor	27.	Geographer
14.	Optical Technician		

VOLUME VII

SECTION 1

CONTAMINATION MEASUREMENTS

SECTION 1

CONTAMINATION MEASUREMENTS

All of the manned spacecraft designed in the 1960s produce ejecta (i.e. waste and water dumps, RCS firings, outgassing, leakage, etc.) which contaminante their immediate environment in space. Gross effects of this contamination, such as window fogging encountered in past missions, can be controlled by appropriate changes in materials and operating procedures adopted for future spacecraft. As missions become longer and space experiment programs become more sophisticated, however, other subtle and persistent contamination problems will be evident.

Three types of contamination are expected to be of particular concern:

a. Deposition of nonvolatile substances (such as urine salts, or carbon or metals carried by RCS plumes, for example) on optical components thermal control coatings, or sensing elements.

b. Optical contamination (i.e., light scattering or absorption) due to particles and gaseous species near the spacecraft.

c. Chemical contamination, which can interfere with upper atmosphere studies, attempts to assay the composition of interplanetary matter, and physics and material processing experiments seeking to make use of the "vacuum of space."

Although leakage and outgassing can undoubtedly be reduced to insignificant proportions on future spacecraft, some sources of contamination will certainly remain. It will still be necessary to fire thrusters for attitude control (or to dump angular momentum from control moment gyros, which amounts to the same thing) and for stationkeeping. Occasional waste and water dumps will be required as a practical matter on very long missions. For the future, it will be necessary to purge the spacecraft atmosphere periodically to dispose of accumulated trace contaminants.

These major sources of contamination can be programmed to provide reasonably long periods of undisturbed operation for optical and other sensitive instruments, since ejecta will be swept away from spacecraft in low earth orbit quite rapidly by atmospheric drag. Nevertheless, it will be highly desirable to develop means of monitoring the environment to determine when contamination is within acceptable limits and also to study the composition and distribution of the ejecta so that troublesome components and unexpected sources can be eliminated. The results will help to increase instrument life and reliability and can provide correction factors for operational sensing data. In high altitude or cislunar missions the dispersal times of ejecta will be much longer than in near earth orbits and the spacecraft will not be shielded by the ionosphere and thus may attract a cloud of ionized particles. It will be of considerable importance to have sophisticated instrumentation ready to identify the sources of problems which may arise.

Instruments for contamination measurements will be included in the payloads of future spacecraft. The following are typical experiments which will be conducted:

a. Measuring the amount of light scattering due to environmental contamination, to identify "good-seeing" conditions, and to provide calibrations for other viewing experiments.

b. Measuring the amount of material deposited on optical components, windows, and thermal control surfaces, and evaluating its effects and identifying its composition.

c. Monitoring the composition of the spacecraft's external environment and determining how contaminants move after they are released.

d. Evaluation of techniques devised to remove contamination.

e. Evaluation of contamination control measures.

1.1 GOALS AND OBJECTIVES

The objectives of this group of experiments are:

a. To identify the types, quantities, spatial distributions, and effects of contaminants in the spacecraft-induced external environment.

b. To provide operational support to the manned earth orbital experiment program.

c. To develop the design data needed to control or eliminate contamination effects on future spacecraft and instruments.

1.2 PHYSICAL DESCRIPTION

This Functional Program Element (FPE) is comprised of a set of measuring instruments and exposure apparatus which are employed in an experiment program based upon a two year mission duration.

Table 1-1 lists the experiments which will be conducted; it also indicates the types of instruments which will be employed.

Holding devices will position material samples and sensors for exposure to the combined effects of the natural space environment and the contaminant cloud induced by the spacecraft. The test samples will be located at various distances from contamination sources, generally within the range of 0 to 12 meters (40 ft) from the surface of the spacecraft.

Viewing instruments which measure light scattered from particles in the contaminant cloud surrounding the spacecraft will be deployed from the spacecraft through scientific airlocks. These instruments will be extended out to distances ranging from 0 to 2.4 meters (8 ft) from the surface of the spacecraft and will look out through the contaminant cloud at various angles.

Table 1-1. Experiment List

Experiment No.	Experiment Name	Primary Instrument
1.4.1	Sky Background Brightness Measurement	Photoelectric Polarimeter
1.4.2	Real-time Contamination Measurement	Quartz Crystal Contaminante Gage
1.4.3	Surface Degradation Experiment	Portable Spectroreflectometer
1.4.4	Contaminant Cloud Composition Measurement	Mass Spectrometer
1.4.5	Contaminant Dispersal Measurement	Cameras
1.4.6	IRTCM: Optical Module Evaluation	Optical Properties Evaluation Module
1.4.7	Active Cleaning Technique Evaluation	Active Cleaning Device
1.4.8	Contamination Control Evaluation	Contamination Control System

The instruments used for defining the composition and spatial distribution of the external spacecraft environment will be deployed on extendable booms, or may be carried on "clean" sub-satellites (if available).

In the design of the experiments and apparatus, emphasis was given to obtaining real-time readouts of contamination levels. During the conduct of the mission, experiment objectives will shift from the early engineering studies to the later real-time monitoring activities in support of other experiments.

Experiment deployment concepts minimize the need for EVA by employing airlocks for instruments which have use periods ranging from a few hours to a few days. However, for exposure apparatus which is to be deployed for periods ranging from weeks to years, EVA may be necessary for installing and retrieving the test apparatus and test samples. The integration of these experiments should strive to minimize routine EVA.

Several of the instruments described in this FPE will be employed in combination to yield real-time data on contaminant composition, quantity, buildup rate, and optical effects. The instruments are:

a. Contaminate Gage (Experiment 1.4.2)

b. Mass Spectrometer (Experiment 1.4.4)

c. Optical Properties Evaluation Module (Experiment 1.4.6)

The Optical Properties Evaluation Module (OPEM) provides the means for exposing sample materials under controlled conditions and for evaluating the effects of contaminant deposits on optical properties, i.e., transmittance, reflectance, and scattering. The sample holding table also accommodates contaminant gages which measure rate and total amount of deposition. A mass spectrometer will be physically integrated with the OPEM to determine contaminant composition and quantity.

This combination of instruments is defined as an "Integrated Real-Time Contamination Monitoring System" (IRTCMS). A concept which may be employed for the physical integration of the components is discussed in Section 1.4.6.2.

1.3 EXPERIMENT REQUIREMENTS SUMMARY

The design requirements which the contamination measuring experiment equipment/ instruments impose on the carrying spacecraft are summarized in Table 1-2.

1.4 EXPERIMENT PROGRAM

The experiment program includes a number of periodically scheduled observation periods, and many random observations which may be required on short notice to support other experiments or to obtain engineering data on subjects of opportunity. Some of the observation programs require the simultaneous operation of several instruments in order to obtain data which will be correlated in post-experiment data-reduction programs. Table 1-3 presents a summary of the experiment program. For each experiment, one instrument is indicated as the primary measurement means; others are indicated as complimentary measurements which, when correlated in post-experiment data-processing programs, improve the overall measurement accuracy and reduce the uncertainty in each instrument performance.

Observations which require the use of controlled waste dumps or the release of tracer gas will be operationally coordinated with viewing experiments, space physics experiments, and materials science and manufacturing experiments.

Several of the instruments which will be employed are advanced versions of instruments which are presently planned for Skylab. The primary changes are those required to present the measurement data as an electronic signal which will permit real-time display as well as permanent recordings. Real-time contamination monitoring is required to determine when contamination is below the limiting values permissible for the conduct of other experiments.

The individual experiments which will be conducted are described in the following sections.

1.4.1 SKY BACKGROUND BRIGHTNESS MEASUREMENTS

1.4.1.1 Objective. The objective of this experiment is to measure the sky back-

Table 1-2. Experiment Requirements Summary

EXPERIMENT	MASS (WEIGHT)		VOLUME		ENVELOPE	POWER REQUIREMENTS	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS	DATA REQUIREMENTS	STABILITY AND CONTROL	ORBITAL DATA	EXPERIMENT PECULIAR REQUIREMENTS
	kg	(lb)	m^3	(ft^3)	m (ft)	watts			hours				
1.4.1 Sky Background Brightness Meas.	18	(40)	0.08	(3.3)	Photometer (stowed): 36 × 36 × 50 cm (14 × 14 × 20 in.) Control Panel: 36 × 25 × 25 cm (14 × 10 × 10 in.)	Continuous = 15 Peak = 60	Electromechanical Technician	No extraneous light permitted from spacecraft during dark side viewing	Avg. observation time is 96 hrs/month, on duty cycle ≃ 13%	Data Rate: 3.1 kbps	Pointing (re. solar vector): $\pm 8.7 \times 10^{-3}$ rad (±0.5 deg) Stability: 8.7×10^{-4} rad/sec (0.05 deg/sec)	Any spacecraft operational altitude. View during both light and dark sides	Deployed from scientific air-lock
1.4.2 Real-Time Contamination Meas.	17.7	(39)	0.03	(1.0)	Gages (stowed): 20 × 25 × 15 cm (8 × 10 × 6 in.) Control Panel: 25 × 36 × 25 cm (10 × 14 × 10 in.)	Continuous = 25	Electromechanical Technician Physicist	Maintain gages in inert gas atmosphere during storage	Measurement System: In use continuously Individual Gages: Variable - a few *minutes to several years*	Data Rate: 20.4 kbps (From 12 gages sampled sequentially.)	NA	Any spacecraft operational altitude	
1.4.3 Surface Degradation Meas.	24	(53)	0.1	(3.6)	Samples (stowed): 38 × 46 × 20 cm (15 × 18 × 12 in.) Racks (stowed): 15 × 40 × 40 cm (6 × 16 × 16 in.) Spectroreflecto-meter 14 × 23 × 26 cm (5.5 × 9 × 11 in.)	40 watts for 10 hours for each battery charge. Duty cycle = 1/10	Electromechanical Technician	Maintain samples in inert gas atmosphere during storage	Sample exposure times vary from a week to 2 years	Data Rate: 3 kbps (During playback of spectroreflectometer internal recorder.)	NA	Any spacecraft operational altitude Specimens in sunlight	EVA deployment and periodic measurements
1.4.4 Contaminent Cloud Composition Meas.	24	(54)	0.06	(2.1)	Sensors (each): 10 cm dia × 15 cm l. (in. dia×6 in. l.) Electronics (each): 20 × 20 × 10 cm (8 × 8 × 4 in.) Control Panel: 25 × 35 × 25 cm. (10 × 14 × 10 in.)	Each Sensor: Avg = 60	Electromechanical Technician Physicist	Sensors cannot be operated at atmospheric pressure	Variable - ranging from a few minutes to several hours	Data Rate: 20.4 kbps (From 2 sensors simultaneously.)	8.7×10^{-2} rad (±5 deg)	Any spacecraft operational altitude	Deployed from scientific airlock
1.4.5 Contaminant Dispersal Meas.	72	(160)	0.21	(7.2)	Camera (each): 30 × 35 × 50 cm (12 × 14 × 20 in.) Film Meas. (each): 5 × 10 × 15 cm 2 × 4 × 6 in.) Control Panel: 35 × 40 × 35 cm (14 × 16 × 14 in.)	Each camera, in film and TV mode: Avg = 200	Electromechanical Technician	NA	Variable - ranging from a few seconds to a few hours	10 MH_z TV bandwidth (for 2 cameras simultaneously) plus film	Pointing: $\pm 3.4 \times 10^{-2}$ rad (±2 deg) Stability: 0.34×10^{-2} rad/sec (0.2 deg/sec)	Any spacecraft operational altitude	
1.4.6 IRTCM Optical Module	17	(37)	0.04	(1.4)	Module: 25 cm dia× 50 cm l. (10 in. dia×20 in. l. Control Panel: 25 × 35 × 15 cm (10 × 14 × 6 in.)	Avg = 100	Electromechanical Technician Physicist	Instrument cannot be operated at pressure above atmospheric pressure	Variable - ranging from a few minutes to several months	Data Rate: 20.4 kbps	NA	Any spacecraft operational altitude	

Table 1-2. Experiment Requirements Summary (Continued)

EXPERIMENT	MASS (WEIGHT) kg	(lb)	VOLUME m^3	(ft^3)	ENVELOPE m (ft)	POWER REQUIREMENTS watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS hours	DATA REQUIREMENTS	STABILITY AND CONTROL	ORBITAL DATA	EXPERIMENT PECULIAR REQUIREMENTS
1.4.7 Active Cleaning Technique Evaluation	2.3	(5)	0.002	(0.08)	ACT Device: 20 cm dia×45 cm l. (8 in. dia×18 in. l.)	Avg = 50 Peak = 300	Electromechanical Technician Physicist	NA	Variable - ranging from a few minutes to several hours	Data Rate: 20.4 kbps (sensors sampled sequentially)	NA	Any spacecraft operational altitude	ACT device is installed in the IRTCM or is used as a portable tool during EVA
1.4.8 Contamination Control Evaluation	20	(45)	0.14	(4.8)	Panels (stowed): 22 × 45 × 60 cm (9 × 18 × 29 in.) Control Console: 60 × 45 × 22 cm (24 × 18 × 9 in.)	Avg = 75	Electromechanical Technician	Maintain samples in enert gas atmosphere during storage	Variable - ranging from a few hours to several months	Data Rate: 20.4 kbps (sensors sampled sequentially)	N/A	Any spacecraft operational altitude	Deployed from scientific airlock and/or via EVA

Table 1-3. Experiment Program Summary

Experiment: No.	Experiment: Name	Measurement Means (Primary: ● Supporting: ○): Photoelectric Polarimeter	Contaminate Gage	Portable Spectro-reflectometer	Mass Spectrometer	Cameras	Optical Module	Active Cleaning Device	Contamination Control System	Data Mode: Real-Time Display	Post-Experiment Data Analysis	Specimen Retrieval and Analysis	Deployment Mode: Airlock	EVA	Other	Remarks
1	Sky Background Brightness	●								x	x		x			Day and Night Measurements.
2	Real-Time Contam. Meas.		●							x	x		x	x		Multi-purpose.
3	Surface Degradation Meas.		○	●		○					x	x		x		
4	Contam. Cloud Comp. Meas.		○		●					x	x		x	x	x	Multi-purpose.
5	Contam. Dispersal Meas.		○		○	●				x	x				x	View from interior.
6	IRTCM Optical Module Eval.		○			○	●			x		x	x	x		Multi purpose.
7	Active Cleaning Eval.		○		○	○	○	●		x			x	x		
8	Contam. Control Eval.		○		○				●	x		x	x			

ground brightness caused by solar illumination of the particulate contaminants found in the vicinity of the spacecraft.

1.4.1.2 Description. A photoelectric-polarimeter system will be used to measure the sky background brightness (which includes sunlight scattering from particles) and polarization in the sunward hemisphere of the celestial sphere as a function of angular displacement from the sun.

The photoelectric polarimeter measures instantaneous radiance and polarization of the sky background brightness and provides an output which may be displayed as a real-time contamination monitor, as well as a permanent recording on magnetic tape, along with instrument pointing angles and time of observation. The polarimeter measures the apparent radiance of the sky background, both in the day side and night side of the orbit. The difference between the two radiance values is due to light scattering from particles in the spacecraft contaminant cloud, and is related to the contamination cloud column density.

The photoelectric-polarimeter system consists of the following major elements:

a. Photoelectric-polarimeter assembly

b. Operating panel

The photoelectric-polarimeter assembly consists of a photoelectric-polarimeter mounted on a two-axis orientation table. A sun shield and knife-edge baffles are used to reduce stray light. A wheel with three apertures is rotated to define either a 10×10^{-2} rad (6°), 5×10^{-2} rad (3°), or 1.6×10^{-2} rad (1°) field of view. A Glan-Foucault polarizer provides polarization information. The polorimeter incorporates a filter wheel which will enable the radiance measurements to be made in six spectral bands from the XUV to visible. The wheel will also have one "unfiltered" position. A shutter will close off the aperture to protect against contamination of the optics. Figure 1-1 illustrates the photoelectric polarimeter assembly.

The operating panel, located in the carrying vehicle, provides the controls and displays for the polarimeter system operation, and interfaces the system with vehicle power, control, and data handling systems.

The physical characteristics of the photoelectric polarimeter system components are as follows:

	Polarimeter Assembly	Operating Panel
Size	30 × 30 × 45 cm (12 × 12 × 18 in.)	36 × 25 x 25 cm (14 × 10 × 10 in.)
Weight	9 kg (20 lb)	6.8 kg (15 lb)

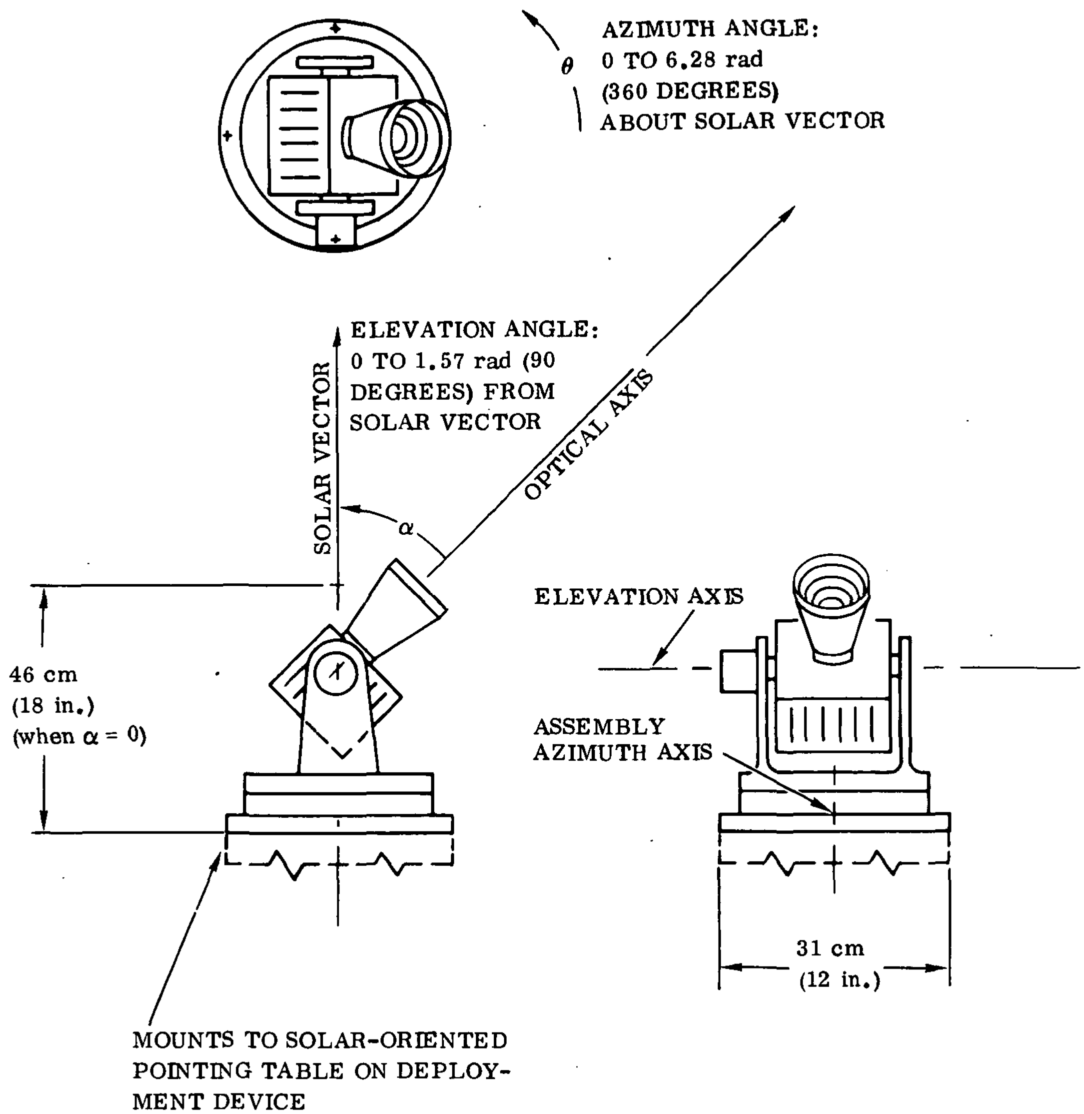


Figure 1-1. Photoelectric Polarimeter Assembly

The polarimeter is mounted on a remotely controlled deployment system, which will extend the instrument far enough away from the spacecraft surface to provide utility. The deployment system provides a solar-oriented, two degree-of-freedom pointing head which aligns the polarimeter assembly azimuth axis along the solar vector within 8.7×10^{-3} rad (0.5 degree).

The polarimeter is extended out through an airlock located in a normally inhabited, shirtsleeve environment area of the spacecraft. The deployment device canister mates with the airlock to provide cabin pressure integrity, and provides the electrical interface required for commands, feedback signals, and data.

The experiment is manually controlled by a crewman from the operating console for extending and retracting the deployment mechanism, for instrument checkout, and for special measurements. The experiment is automatically operated for long-term scanning sequences and long-term, real-time contamination monitoring, with command signals originating from a computer, and with observation data stored in a data handling system. An alarm system with local and remote displays and annunciators will warn when preselected background illumination levels are exceeded, so that a decision can be made to either continue or terminate viewing experiments.

The polarimeter may remain mounted on the deployment device, withdrawn into the canister when not in use. Electronics may be in a standby mode, if required, so that the instrument may be deployed and quickly put into use for real-time contamination monitoring in support of other viewing experiments.

1.4.1.3 Observation/Measurement Program. Both periodic and random observations will be conducted to determine the effects of spacecraft outgassing, dumps of known contaminants, and P/RCS operation.

Each periodic observation event will require four days of measurement activity. The first event will take place within the first week of spacecraft operation, and additional periodic events will be conducted each month during the first year of operation, and each second month during the second year of operation. During each four-day observation event, the photometer system will be operating under a crewman's control for two hours per day, and under automatic control for 14 hours per day.

Special observations may be requested at random intervals on short notice to support viewing experiments and to observe subjects of opportunity at any time during the two year period. Random observation events will be conducted, on the average, for 32 hours per month during the first year of observation, and 64 hours per month during the second year of operation.

In summary, polarimeter observations over the two year mission will be conducted as follows:

Mission Year	Type of Observation	Average Observation Hours Per Month		
		Manually Controlled	Automatically Controlled	Total Time
1st	Periodic	8	56	64
	Random	4	28	32
2nd	Periodic	4	28	32
	Random	8	56	64

1.4.1.4 Interface, Support and Performance Requirements

Crew Support. A crewman initially deploys the polarimeter assembly through an airlock and retrieves it for inspection and servicing approximately once a week. The operating panel remains installed in a spacecraft console during the two year period. The crewman extends (by remote control) the instrument for measurement or monitoring tasks, performs calibration check, and starts the sky scanning sweep. He operates the system controls and observes the displays for special measurements conducted under manual control.

Crew Skills - Electromechanical Technician. Twenty hours of preflight training are adequate.

Subsystems Support

	Polarimeter Assy.	Operating Panel
a. Size	36 × 36 × 50 cm (14 × 14 × 20 in.) (stowed in container)	36 × 25 × 25 cm (14 × 10 × 10 in.)
b. Weight	11 kg (25 lb) (stowed in container)	6.8 kg (15 lb)
c. Power	(from operating panel)	28 ±4 Vdc 15 watts continuous 60 watts peak (during orientation table drive system operation)

d. Deployment System: Provides airlock canister, deployment boom, and solar-oriented pointing table.

e. Data - The digital data rate for housekeeping and scientific data are:

1. Housekeeping
   - a) Azimuth drive system temperature
   - b) Elevation drive system temperature
   - c) Photomultiplier temperature

   } 0.1 kbps

2. Photometer Data
   - d) Azimuth angle
   - e) Elevation angle
   - f) Aperture
   - g) Photomultiplier current

   } 3 kbps

h) Photomultiplier gain

i) Filter Wheel Position

j) Polarizer Position

k) FOV Wheel Position

} 3 kbps

Constraints

a. Altitude - 185 to 555 km (100 to 300 n.mi.) is the expected operational range.

b. Field of View - Measurements shall not be made with the Sun, Earth, Moon, Space Station, Space Shuttle, experiment modules, etc., within the polarimeter's field of view.

c. Pointing - $\pm 8.7 \times 10^{-3}$ rad (± 0.5 deg) from solar vector.

d. Stability - 8.7×10^{-4} rad/sec (0.05 deg/sec).

e. Thermal Control (stored) - 244° K to 344° K (-20° F to +160° F), all elements.

(operating) - The polarimeter assembly will be designed for use in the space environment. The operating panel will be designed for 294 ± 11° K (70 ± 20°F).

f. Sun Angle - The angle between the deployment boom axis and the solar vector should be less than 0.7 rad (40 deg).

g. Special Environments - All external spacecraft lights should be de-energized, and no light should be allowed to escape from viewing ports during polarimeter measurements. Some volume within the spacecraft, adjacent to the scientific airlock, should be available for assembly, deployment, and retrieval of the polarimeter.

h. Computer Support - Computer support will be required to control the polarimeter system in the automatic mode and to provide pointing commands.

i. Operational Data - Spacecraft operational data will be required by the Principal Investigator for assessment of the influence of contamination-producing events such as rocket firings or waste dumps.

1.4.1.5 Potential Role of Man. A crew member will be required for assembly, deployment, and retrieval of the polarimeter assembly through a scientific airlock. He will perform the initial start up and checkout procedures of all equipment, monitor the experiment during its active phase, and operate the polarimeter system during special events. A crew member will also be required to clean or replace optical components when they become contaminated. Periodic servicing and calibration will be required.

1.4.1.6 Available Background Data

a. Experiment Integration Requirements Document, "T027 Contamination Measurement," Revision C, June 17, 1969.

b. "Potential AAP Cluster or Apollo Contamination Monitor in Support of ATM," Document No. MCR-68-78, Martin Marietta Corp., March 1968.

1.4.2 REAL TIME CONTAMINATION MEASUREMENTS

1.4.2.1 Objective. The objective of this experiment is to provide real-time measurements of the buildup of contaminants which are deposited on instruments or spacecraft thermal control surfaces.

1.4.2.2 Description. The quartz crystal contaminant gage is a real-time contamination monitoring instrument which consists of a sensing element, power supply, and signal conditioner, all contained in a protective housing. The instrument provides an electrical output signal which is directly related to the mass of contaminant material deposited on an exposed quartz crystal. Differentiation of the output signal may be employed to determine the rate of contaminant buildup or migration, and to indicate whether the contaminant is in the solid, liquid, or vapor state. Typical contaminant gages cover mass ranges from 5×10^{-5} to 5×10^{-9} g/cm^2, however, instruments covering other mass ranges may be employed for some experiments. The instrument is conceptually shown in Figure 1-2.

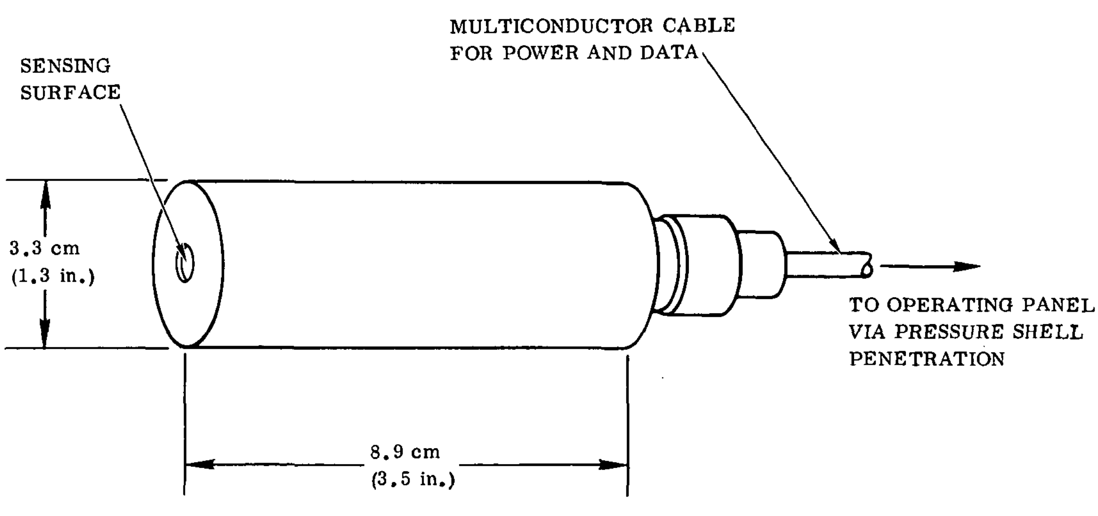


Figure 1-2. Quartz Crystal Contaminant Gage

Contaminant gages will be used in a real-time contamination monitoring system at various locations on the external surfaces of the spacecraft, and both externally and internally with astronomy instruments and earth observations sensors.

Suitable mounting devices must be provided for each gage application. Clamps which engage the central portion of the housing are permissible, but compressive loads must not exceed 3.44×10^4 N/m^2 (5 lb per square inch) of projected area.

Electrical feedthroughs and instrumentation cabling are required to supply power to the instruments and to transmit data from the instruments. These feedthroughs should be located as close as possible to the intended instrument location to minimize the length of electrical cable exposed to the external environment, and thus minimize outgassing from the cables.

A contamination measuring system control and display panel will be located in a spacecraft data handling console. The panel will be capable of operating with up to 12 contaminant gages simultaneously, providing both real-time displays and data outputs for tape recording and/or transmission. The control and display panel will sample the contaminant gages at repetition rates established by the crewman operating the monitoring system. The sampling rate may be varied in accordance with the rate of contamination buildup. The recorded measurements will be correlated with the time code supplied by the spacecraft communications and data management subsystems.

When used with free-flying observatory modules, the contaminant gage system would operate in conjunction with the module command and data subsystems. The contamination deposition rate measured by the system may be used as one of the decision elements in the command of the telescope protective cover.

The physical characteristics of the elements of the contaminant gage system are as follows:

Item	Size	Weight
Contaminant Gage	3.3 cm dia $\times$ 8.9 cm long	0.23 kg
(16 required)	(1.3 in. dia $\times$ 3.5 in. long)	(0.5 lb) each
Operating Panel	25 $\times$ 36 $\times$ 25 cm	6.8 kg
(1 required)	(10 $\times$ 14 $\times$ 10 in)	(15 lb) each
Transit Case	20 $\times$ 25 $\times$ 15 cm	2.3 kg
(4 required)	(8 $\times$ 10 $\times$ 6 in.)	(5 lb) each

The contaminant gages will be deployed individually via EVA for long term exposure periods and through airlocks for short term exposure periods.

This type of instrument is one of the elements of the Integrated Real-Time Contamination Monitoring System Experiment Package described in Section 1.2.

1.4.2.3 Observation/Measurement Program. Contaminant gages will be installed at various external locations on the spacecraft. They will be used in conjunction with other contamination sensing and measuring instruments to perform other experiments in this FPE, and will also be used as supporting instruments for other FPEs where contamination may affect the experiment or observation. Examples of these supporting applications are: on and within telescope modules, near space physics experiments, and near external vents for materials science and manufacturing experiment apparatus.

The contaminant gages will be used for both short-term (up to five days) and long-term (up to two years) observation periods.

1.4.2.4 Interface, Support and Performance Requirements

Crew Support

a. Preparation. An astronaut deploys the instruments through an airlock or via EVA, depending upon the exposure location and type of experiment conducted. Suitable clamping devices, electrical feedthroughs, and instrumentation cables must already be provided by the spacecraft.

b. Use. A crewman periodically observes the control and display panel during routine monitoring periods. Normal system operation is automatic. During special measurement events he will attend the system more frequently, correlating mass deposition rates and optical degradation rates, and notifying contamination-sensitive experiments when limiting levels are approached. He will transfer tape recorded data to the spacecraft data subsystem for relay to the ground data handling center.

c. Retrieval. An astronaut retrieves the instruments through an airlock or via EVA. The instrument will be protected in a transit case which is purged with an inert gas until it is examined in the spacecraft supporting laboratory or returned to a ground laboratory for analysis.

d. Servicing. Instruments which are reused will be cleaned, rehabilitated, and stored in a clean transit case. Cleaning requirements will be equivalent to the requirements of Specification MSFC No. 164, LOX service.

e. Crew Skills. Electromechanical Technician; 20 hours of preflight instruction are adequate.

Subsystems Support

	System Operating Panel
a. Weight	6.8 kg (15 lb)
b. Size	25 × 36 × 25 cm (10 × 14 × 10 in.)
c. Power (system) 28 ±4 Vdc	25 watts

d. Data

1. Housekeeping. One temperature measurement, 0.2 kbps, from each of 12 instruments sampled sequentially.

2. Contamination Quantity. One channel, 0.2 kbps, from each of 12 instruments sampled sequentially.

3. Contamination Rate. One channel, 20 kbps, from each of 12 instruments sampled sequentially.

4. Storage. Storage space must be provided for four transit cases, each of which can hold four contaminant gages.

5. Purge Gas. Provisions are required for supplying clean, dry inert gas for back-filling the transit case after instrument exposure and after instrument cleaning.

Constraints

a. Altitude. Any spacecraft operating altitude is permissible.

b. Pointing Accuracy. Not applicable. The instruments are fixed in place.

c. Pointing Stability. Not applicable.

d. Thermal Control. The contaminant gages will be designed for space environment operation and will incorporate internal thermal controls. The control/display panel will be designed for the normal cabin environment.

e. Holders. Instrument clamping devices must be designed for ease of installation and removal under EVA mobility conditions.

f. Spare Units. A total of 16 instruments should be carried. This will allow for 12 units to be in use simultaneously, two units to be in the cleaning/calibration cycle, and two units to be available as spares.

g. Resupply. Any units returned to the ground for inspection or repair should be replaced with a like unit.

h. Special Environments. The instruments must be maintained clean prior to use in inert gas purged transit cases.

1.4.2.5 Potential Role of Man. A crewman will be required to deploy and retrieve the instruments, either through an airlock or via EVA, to operate the control and display panel during observations and to interpret the measurements. Cleaning and recalibration of instruments will be performed in a supporting laboratory.

1.4.2.6 Available Background Data

a. Paper by R. L. Chuan of Atlantic Research Corp., and W. Moore and R. Naumann of MSFC, presented at American Optical Society conference on Optical Contamination in Space, 14-16 August 1969.

b. Modules for Real-Time Contamination Monitoring, Report No. GDC PIN 70-143, 1 May 1970.

1.4.3 SURFACE DEGRADATION EXPERIMENT

1.4.3.1 Objective. The objective of this experiment is to determine the long term effects on the reflectance properties of various types of thermal control surfaces and optical materials by the combined natural and spacecraft-induced environments.

1.4.3.2 Description. Four exposure racks will be attached to the exterior surface of the spacecraft by an astronaut via EVA. The spacecraft must already be provided with installation pads which accommodate the specimen holding racks at the preplanned exposure locations. Each exposure rack will accommodate a sample holding strip about 5 cm (2 in.) wide and 30 cm (12 in.) long to which is affixed 10 samples of various types of thermal control paints and optical materials. Each paint sample will be applied over a 2.5 cm (1 in.) diameter area on a type of material which is employed for spacecraft structures. Figure 1-3 illustrates the sample strip and exposure rack concepts.

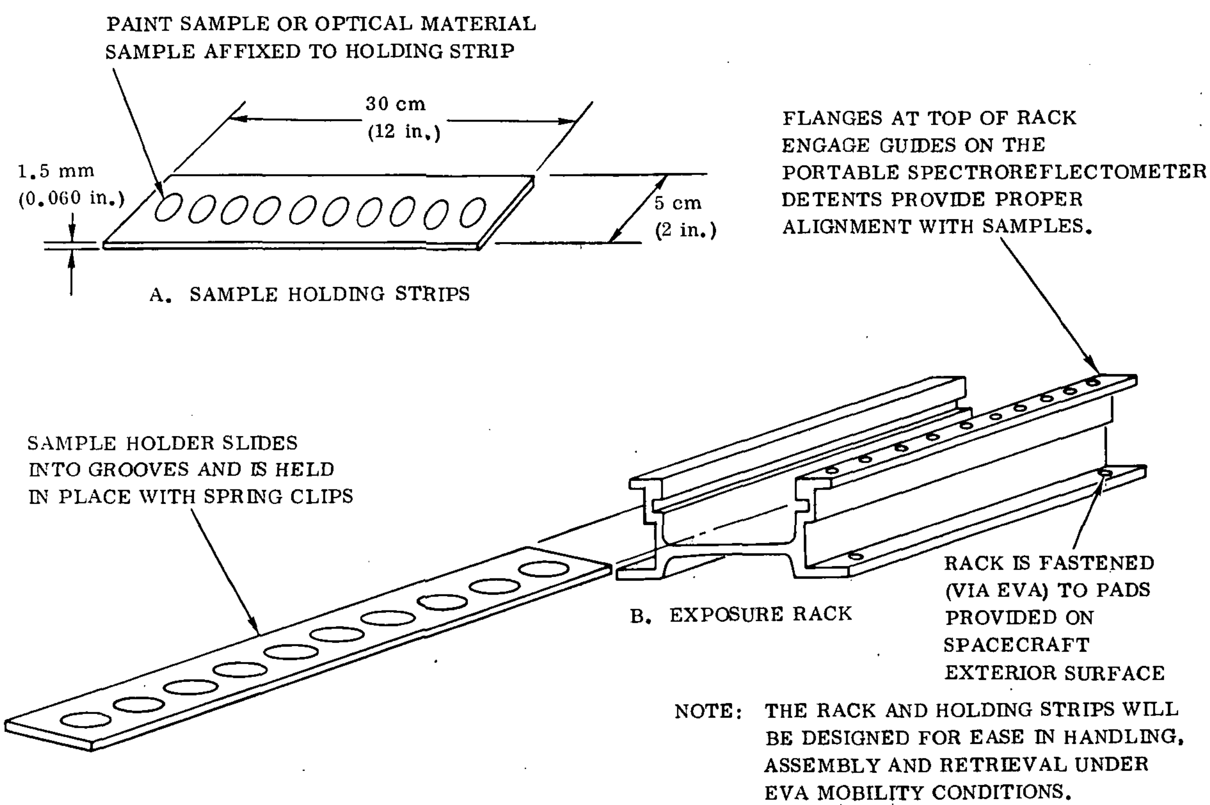


Figure 1-3. Long-Term Exposure Device Concept

During the exposure periods, in situ measurements of the spectral reflectance properties of the test samples will be periodically obtained using a portable, hand-held spectroreflecometer. This instrument is battery powered and is completely selfcontained. The reflectometer will be equipped with guides which engage with the exposure racks and and allow the instrument to slide along the rack, properly positioned for making reflectance measurements on each sample. The portable spectroreflectometer is conceptually shown in Figure 1-4, and the optical system principles are illustrated in Figure 1-5. Reflectance data for each sample measurement is encoded and stored on a digital recorder within the instrument. The recorded information must be transcribed to another recorder aboard the spacecraft and/or relayed to the ground.

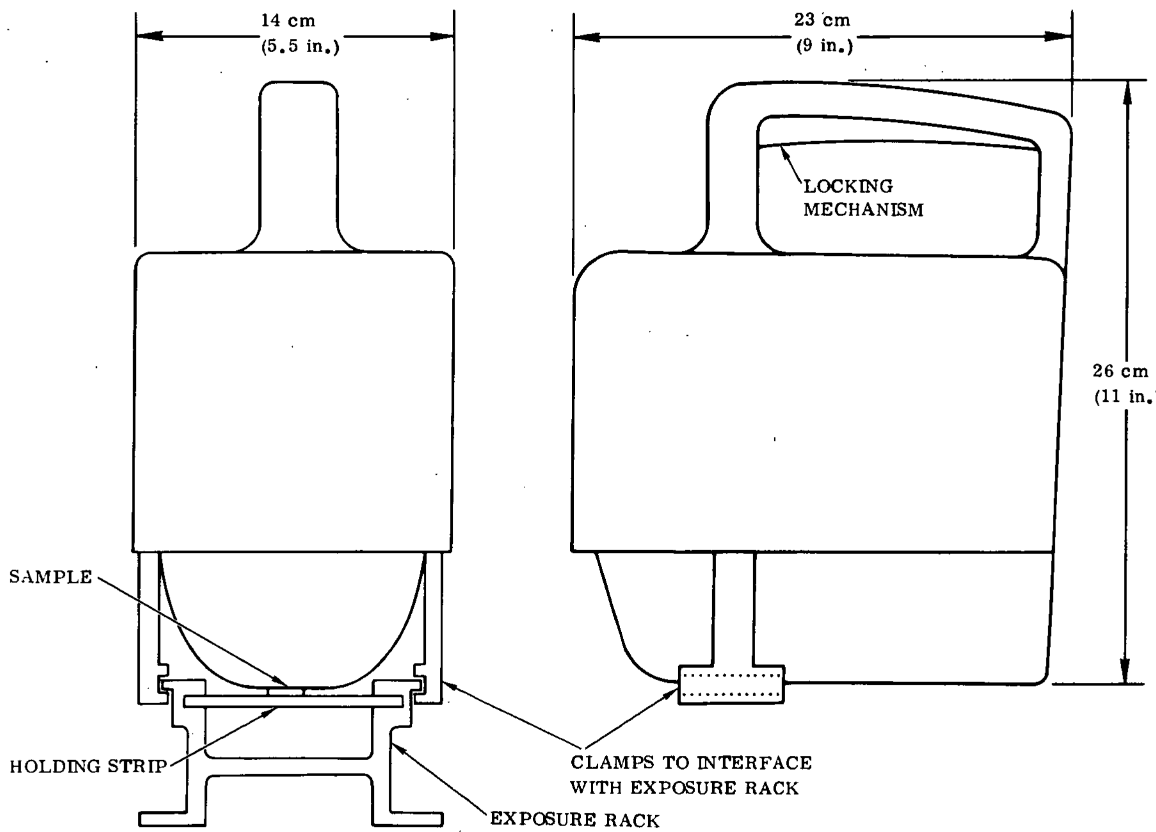


Figure 1-4. Portable Spectroreflectometer Concept

The unit employs a programmer which automatically sequences the operation of the light sources, flip mirrors, and filter wheel after the crewman positions the instrument over a sample and initiates the measurement cycle. The measurement cycle for each sample requires 60 seconds.

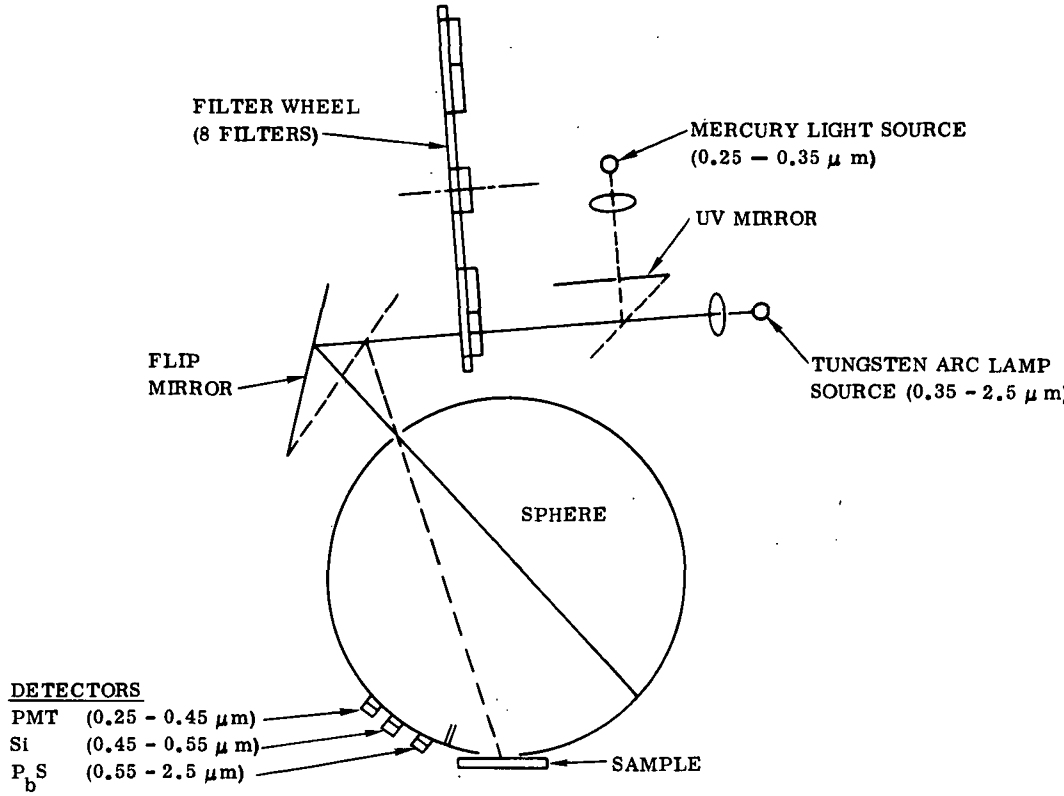


Figure 1-5. Spectroreflectometer Optical System

A quartz crystal contaminant gage will be installed adjacent to each of the exposure racks. Contaminant mass deposition measurements will be correlated with optical properties degradation measurements in post-experiment analyses.

Protective containers will be provided for return of exposed samples to Earth for analysis. The containers will be hermetically sealed and back-filled with high purity argon gas. Container size is 7.6 × 38 × 25 cm (3 × 15 × 1 in.); weight is 0.23 kg (0.5 lb), for each sample strip. A transit case 38 × 46 × 30 cm, 0.067 m^3 (15 x 18 x 12 in.) (1.9 cu ft) will be used to transport and store 30 sample holding strips in their protective containers for ground transportation, launch, orbital storage, and for return to Earth. The transit case empty weight is 4.5 kg (10 lb).

1.4.3.3 Observation/Measurement Program. The exposure period for the material samples will be controlled by varying the exposure time for the 5 × 30 cm (2 × 12 in.) holding strips. Exposure times will vary from five days to two years. Each type of material will be tested for various exposure periods by mounting test samples on approximately 10 different holding strips, each of which is exposed for a different total exposure time, in accordance with a pre-planned schedule. It is estimated that 30 specimen holders will be exposed for varying periods of time during the initial two-year mission period. The ultimate experiment design will be statistically derived, depending on the number of samples to be exposed, orientation to sources of contamination, and other variables.

1.4.3.4 Interface, Support and Performance Requirements

Crew

a. Preparation. Install exposure racks on spacecraft exterior surface. Install sample holders in exposure racks.

b. Use. Use hand held reflectometer to measure and record reflectance properties of samples. Retrieve exposed samples, place in protective containers, and backfill with argon. Install new samples. Transcribe data from instrument recorder. Recharge batteries.

c. Termination. Retrieve exposure rack from spacecraft exterior.

d. Special Skills. Electromechanical Technician.

Subsystems Support

a. Storage. Space must be provided to store the following:

   1. Four exposure racks (packed) - Size: $10 \times 15 \times 40$ cm ($4 \times 6 \times 16$ in.) - Weight: 2.3 kg (5 lb).

   2. Transit case (containing 30 sample holding strips in protective containers - Size: $38 \times 45 \times 30$ cm ($15 \times 18 \times 12$ in.); 0.054 m^3 (1.9 cu ft) - Weight: 11.4 kg (25 lb).

   3. Portable Spectroreflectometer - Size: $14 \times 23 \times 26$ cm ($6 \times 9 \times 12$ in.) - Weight: 3.6 kg (8 lb).

b. Power. The exposure racks and samples are passive. The only power required for experiment equipment is that required to recharge the batteries for the hand-held reflectometer (40 watts for 10 hrs per charge).

c. Data. Reflectance information recorded in the reflectometer will be transcribed at 3 kbps. The measurements will be time correlated with recordings of the astronaut's verbal identification of the samples.

Constraints

Sun Angle - The test samples should be in sunlight as much as possible, and it is desirable that they be in sunlight for at least 10 minutes prior to the start of the measurements so that the specimens are too warm to be coated with ice crystals resulting from cryopumping of water vapor.

1.4.3.5 Potential Role of Man. A crewman will be required for installing and retrieving exposure racks and test samples, for making in situ reflectance measurements, and for servicing the spectroreflectometer.

1.4.3.6 Available Background Data

a. Experiment Integration Plan (NASA Form 1347) for Expt. T031, Spacecraft Surfaces, undated.

b. Experiment Integration Plan (NASA Form 1347) for Expt. DO24, Thermal Control Coatings.

1.4.4 CONTAMINANT CLOUD COMPOSITION MEASUREMENT

1.4.4.1 Objective. The purpose of this experiment is to measure the chemical composition of the contaminant gases surrounding the spacecraft at various locations and orientations as a function of time.

1.4.4.2 Description. Two identical mass spectrometers having a mass range of 0 to 300 AMU will be used to perform the measurements. The instruments will be capable of making the following measurements:

a. Neutral particle concentration versus mass number in the range of 0 to 300 AMU.

b. Total concentration of all neutral constituents having masses greater than 300 AMU.

c. Total neutral particle concentration.

Each of the instruments is comprised of two units: an electronics package and a sensor head which can be located remote from the electronics package.

Two operating panels, located in the spacecraft, provide controls and displays for the simultaneous use of two mass spectrometers.

The mass spectrometer is conceptually shown in Figure 1-6.

The physical characteristics of the experiment equipment are as follows:

Item	Description	Quantity	Size (ea)	Weight (ea)
1.	Sensor Head	2	10 cm × 15 cm (4 in. dia × 6 in.) long	0.9 kg (2 lb)
2.	Electronics Package	2	20 × 20 × 10 cm (8 × 8 × 4 in.)	2.7 kg (6 lb)
3.	Operating Panel	2	25 × 35 × 25 cm (10 × 14 × 10 in.)	6.8 kg (15 lb)

The mass spectrometers will be deployed at various distances out into the contaminant cloud surrounding the spacecraft. Various deployment methods will be employed.

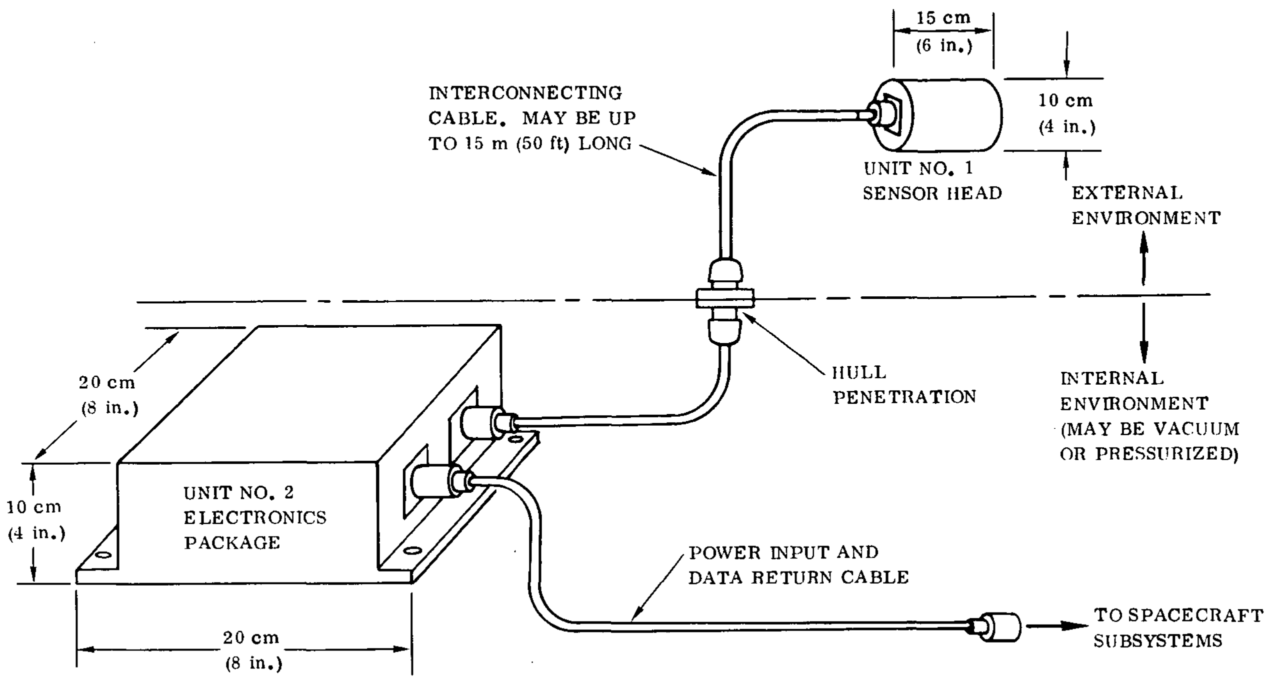


Figure 1-6. Mass Spectrometer Concept

Typical methods are:

a. Hardmounted to spacecraft exterior surface.

b. Airlock deployment systems.

c. Installed on "clean" subsatellites.

It is desirable to map the contaminant cloud out to approximately 100 meters from the spacecraft, but achieving this range is dependent upon the availability of a proven deployment system.

The mass spectrometer is one of the elements of the Integrated Real Time Contamination Monitoring (IRICM) System described in Section 1.2.

1.4.4.3 <u>Observation/Measurement Program.</u> The mass spectrometers will be employed for periodic measurements to support engineering studies and for random measurement as a real-time contamination monitor to support other experiments.

In addition, special studies may be conducted in which tracer gases or other fluids are purposely leaked from the spacecraft, and the migration of these molecules mapped through the local atmosphere.

For contaminant cloud mapping, a deployment system will position the instruments at specific locations and angular orientations about the spacecraft under pre-programmed, computer controlled search patterns. The spectrometer output data, along with location and orientation data, housekeeping data, and a time reference, will be recorded on magnetic tape and dumped to ground stations. Real-time displays of these data will also be provided at the control panel.

One or both instruments will be in use for approximately four days every two weeks, for six hours per day.

1.4.4.4 Interface, Support, and Performance Requirements

Crew Support. One crewman is required during operation of one or both instruments.

a. Preparation. Crewman installs instruments and deploys it through airlock.

b. Use. Crewman supervises computer-controlled search patterns, and monitors real-time readouts from spectrometer(s).

c. Retrieval. Crewman retrieves instrument through airlock, removes instrument from deployment device, stows instrument in storage case, secures airlock.

d. Servicing. The mass spectrometers will require periodic cleaning to remove contaminants which become trapped within the analyzing section or on the collector assembly.

e. Crew Skills. Electromechanical Technician. 40 hours of preflight training is required.

Subsystems Support

a. Volume. Space must be provided in a spacecraft console to house two operating panels. Space must also be provided to store three mass spectrometers.

b. Power.

   1. Mass Spectrometer (each) - Average 35 watts. This power is provided from the operating panel.

   2. Operating Panel (each) - 25 watts continuous plus mass spectrometer power.

c. Data. Housekeeping: 0.210 kbps (each).
   Spectrometer: 10 kbps (each).

d. Computer Support. A computer will be required to control the mass spectrometer in accordance with preprogrammed instructions. Repositioning of the spectrometer with respect to the spacecraft will be done by computer control of the deployment system.

e. Deployment System. A means must be provided by the spacecraft to position the mass spectrometers at the desired locations, and oriented along the desired axes.

Constraints

a. Altitude. Any spacecraft operating altitude is permissible.

b. Pointing. $\pm 8.7 \times 10^{-2}$ rad (5.0 deg) relative to spacecraft.

c. Stabilization. $\pm 0.87 \times 10^{-2}$ rad/sec (0.5 deg/sec) is satisfactory.

d. Thermal Control - Stored: -40° C to +75° C
- Operational: The instrument shall be designed for operation in the space environment.

e. Pressure - Stored: Approximately 100 k N/m^2 (1 atmosphere)
- Operational: 13 m N/m^2 (10^{-4} torr) and lower.

f. Humidity. 50 percent maximum, non-operating.

1.4.4.5 Potential Role of Man. A crew member will be required for assembly, deployment, and retrieval of the instruments. He will be required to perform the initial startup and checkout procedures and to monitor the experiment during its active phases. He will perform periodic inspections, calibration checks, and routine maintenance of the instruments.

1.4.4.6 Available Background Data

a. "Potential AAP Cluster or Apollo Contamination Monitor in Support of ATM," Martin Marietta Corporation, MCR 68-78, March 1968.

b. Richard J. Leite (University of Michigan, January 31, 1968) and Bill J. Duncan (MSFC, February 2, 1968), Experimental Gas Composition, T030, Experiment Proposal, NASA Form 1346.

1.4.5 CONTAMINANT DISPERSAL MEASUREMENTS

1.4.5.1 Objective. The objective of this experiment is to determine how contaminants move about the spacecraft after they are released.

1.4.5.2 Description. This experiment is addressed to photographic investigation of dispersal of waste dumps, leakage of fluids, and expansion of RCS engine plumes. Observations will be conducted employing motion picture cameras and high resolution television cameras with cabin monitors and video tape recorders. Two identical cameras will be employed.

Cameras will use 35 mm film and be capable of operating at frame rates variable over the range from 1 to 100 frames per second. Film will be packed in magazines of 15 m (50 ft) capacity. A remotely controlled zoom lens will be used, and will mount a sunshield and filter holder. Neutral filters will be used for protection of lenses from contamination and erosion.

A high resolution (1000 line) television camera will be integrated into the photographic camera with through-the-lens viewing of the subject to assist the operator with pointing and focusing the camera, and optimizing the field of view. The television monitor will be located in the operating panel which is supplied for each camera. The operating panels, located in the supporting spacecraft, provide controls and displays for camera operation as well as the television viewing screens.

The operating panels also provide an output to a video tape recorder elsewhere in the spacecraft so that the television image can be stored for later analysis or relayed to the ground.

The physical characteristics of the experiment equipment are tabulated as follows:

Equipment Item	Envelope Size		Weight	
	In Use	Stored	In Use	Stored
Camera (each)	25 × 30 × 45 cm (10 × 12 × 18 in.)	30 × 35 × 50 cm (12 × 14 × 20 in.)	9 kg (20 lb)	11.3 kg (25 lb)
Film Magazine (each)	N.A.	5 × 10 × 15 cm (2 × 4 × 6 in.)	1.8 kg (4 lb)	2.3 kg
Operating Panel (each)	35 × 40 × 35 cm (14 × 16 × 14 in.)	35 × 40 × 35 cm (14 × 16 × 14 in.)	16 kg (35 lb)	16 kg (35 lb)

The contamination-producing events which are to be investigated will normally be observed from within the spacecraft. The cameras will be installed on suitable mounts adjacent to viewing ports equipped with glass of high optical quality. Electrical power and a TV circuit must be available at the viewing location. Command signals to start and stop the photographic camera and a time code reference signal must be provided.

Alternatively, the camera assemblies could be deployed external to the spacecraft in order to improve viewing angles or accessibility. Typical methods would be:

a. Install on hardmounted, remote controlled pan and tilt head.

b. Install on a "clean" sub-satellite with suitable pointing control system.

c. Hand-held by Astronaut using an Astronaut Maneuvering Unit (refer to Section 6). This would require a portable power pack and a TV RF link to the supporting spacecraft.

d. Install on a Maneuvering Work Platform (refer to Section 6).

Use of these alternate external deployment methods would depend upon availability of the required support equipment.

1.4.5.3 Observation/Measurement Program. Observations will be made of the various operational activities which release contaminants into the external spacecraft environment. Examples of such activities are waste dumps, P/RCS engine plumes, venting of test cells, purging of test equipment, leakage of fluids at connectors during re-supply, etc.

Special observations will also be made of controlled dumps to gain a better understanding of how particles move relative to the spacecraft after they are released, and the influence of nozzle shapes and release velocities on the dispersal pattern and density decay time. Fluorescent dye particles may be included in the ejecta to improve the visibility of the particulate cloud.

If the laser is aboard the spacecraft, the camera could trace along the laser beam to determine the spatial density along the path of the directed laser beam.

The nature of the phenomena under investigation, e.g. size of particles, density of particulate cloud, velocity of particle motion, expansion velocity of cloud front, etc., will determine the type of film and the frame rate to be used. Wherever possible, the information will be recorded on video tape instead of on film.

When metric data are required, two cameras will view the subject orthogonally, and a time code will be recorded on the frame for correlation.

1.4.5.4 Interface, Support and Performance Requirements

Crew Support

a. Preparation. Install camera assemblies on pointing heads. Load film magazines.

b. Use. Operate cameras and TV system. Monitor TV and control pointing heads.

c. Terminate. Remove camera assemblies and store in transit cases. Remove film magazines, process film and reload magazines.

d. Evaluate. Review films and recordings. Edit film and tape. Relay data to Earth.

e. Volume. Space must be provided in a spacecraft console to house two operating panels each 35 × 40 × 35 cm (14 × 16 × 14 in.), 0.1 m^3 (3.6 cu ft total) and 32 kg (70 lb) total weight. Space must also be provided to store 2 cameras 0.11 m^3 (4.0 cu ft) and 23 kg (50 lb) total weight.

Subsystems

a. Power. Camera: - Television only: 25 watts
- TV and motion picture: 150 watts

Operating Panel: 50 watts

b. Pointing. Accuracy: 3.4×10^{-2} rad (2 deg); Stability: 0.34×10^{-2} rad/s (0.2 deg/sec).

c. Data. Photographic: 8 magazines will be carried. They will be loaded and unloaded aboard the spacecraft. Film use rate will be an average of 120 m (400 ft) per month: 60 m (200 ft) color, 30 m (100 ft) B.&W., 30 m (100 ft) IR and other special film.
Television: All TV pictures will be recorded on video tape. 10% will be relayed to the ground. All tape will be erased and reused. High resolution TV bandwidth is 10 MH_Z for two cameras simultaneously.

e. Command. Provide camera controls, pointing commands, and time code reference.

Constraints. It is assumed that the spacecraft will have the capability for loading film magazines. On-board processing and editing would also be desirable on long term missions.

Alternate Uses. In addition to supporting this experiment program, the film/TV camera system will be used to support several other experiments and may also be employed for observing astronauts in EVA, for inspection of external experiment equipment, and similar operational functions.

1.4.5.5 Potential Role of Man. A crewman installs the camera assemblies to their mounts, operates the system to position and point the cameras, operates the cameras and video tape recorder in coordination with other crewmen who control the subject contaminant release or RCS firing. He will also provide service and maintenance of cameras and camera controls.

1.4.5.6 Available Background Data: None

1.4.6 INTEGRATED REAL-TIME CONTAMINATION MONITOR: OPTICAL MODULE EVALUATION. The integrated Real-Time Contamination Monitor contains three distinct, modular experimental packages for monitoring the contamination environment about a spacecraft:

a. Quartz Crystal Contaminant Gages (1.4.2)

b. Mass Spectrometer (1.4.4)

c. Optical Properties Evaluation Module (1.4.6).

1.4.6.1 Objective. The immediate objective of this experiment is to obtain real-time measurements of the degradation of optical properties of sample materials exposed to the spacecraft local environment as a function of exposure time. These data will be used to assess the effects of contamination on optical instruments and on thermal control coatings and will provide insight for the selection of materials and operating modes for advanced spacecraft and instruments.

This experiment will also be conducted in conjunction with the ACT experiment (see 1.4.7) to evaluate the effectiveness of the cleaning process on optical surfaces.

1.4.6.2 Description. A variety of material samples will be exposed for specified time intervals to the contaminant cloud adjacent to the spacecraft, and changes in the optical properties of the samples will be periodically measured. An Optical Properties Evaluation Module (OPEM) performs the required exposure and measurement functions. The material samples are mounted on a table which is rotated to alternately expose a selected sample to the contaminant cloud or position it in place for optical properties measurements. The essential elements of the optical properties evaluation module are shown in the cutaway illustration of Figure 1-7. The sample table will provide for mounting up to eight material samples plus three contaminant gages of the type described in Experiment 1.4.2.

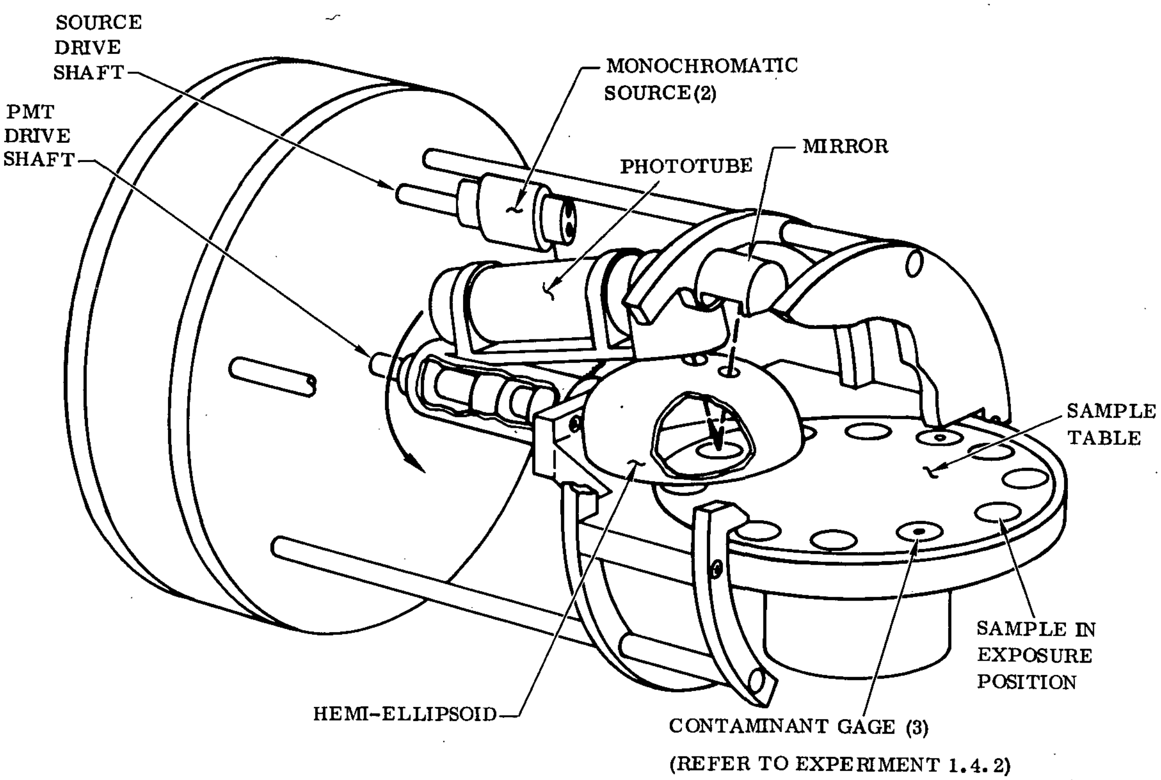


Figure 1-7. Optical Properties Evaluation Module Cutaway

The basic operating principles of the Optical Properties Evaluation Module are illustrated in Figure 1-8.

In the sample measurement position, the sample sits at one of the two focii of a hemi-ellipsoid and is illuminated by a beam of monochromatic radiation, I_o. Light from

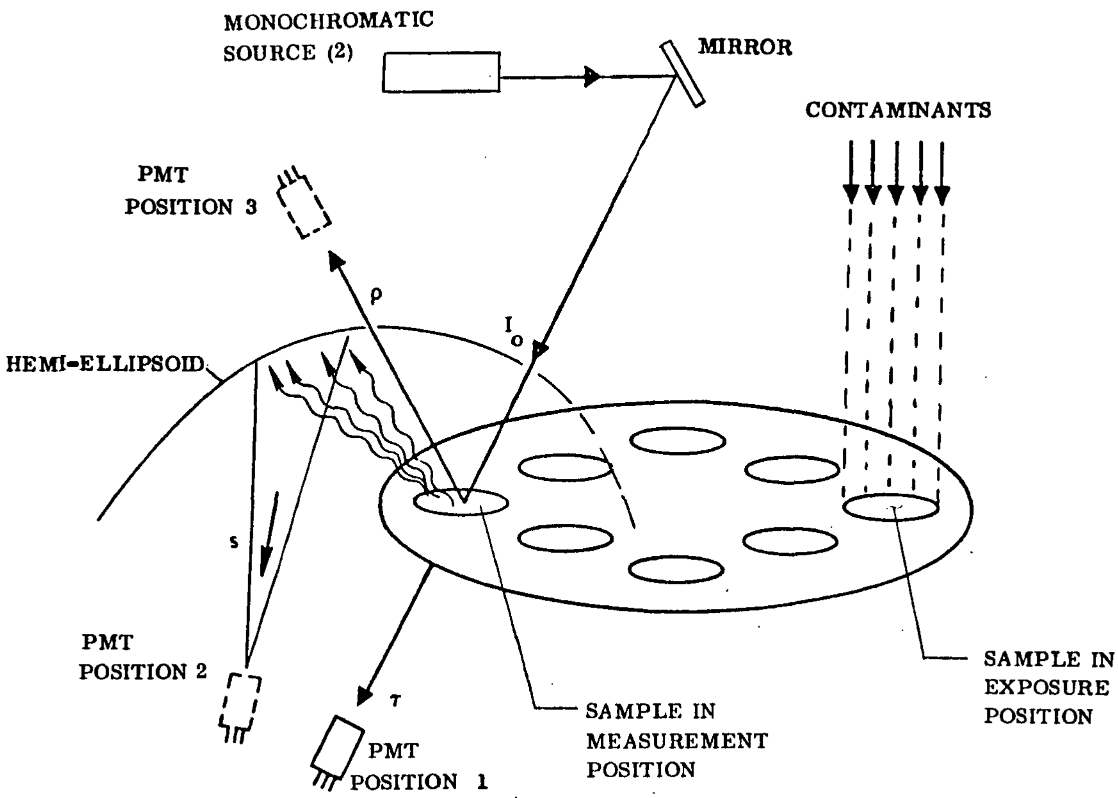


Figure 1-8. OPEM Measurement Principles

one of two monochromatic sources (1236Å and 1849Å) is selected by rotation of the source holder. The beam I_0 is directed incident on the sample and the transmitted, reflected, and scattered beams follow the paths shown in Figure 1-8.

The transmitted beam, τ, passes through the sample and the reflected beam, ρ, leaves the sample at the specular angle. Scattered radiation, s, can leave the sample in any direction, however it tends to be concentrated about the specular angle.

The beams are all detected by one photomultiplier tube (PMT) that is repositioned to successively measure each beam. The three PMT positions are shown in Figure 1-8.

To normalize the system - that is, to check the stability of the source and phototube and to determine the 100% (I_0) - the sample is rotated out of the measurement position, and the incident beam goes directly through an open sample position to the phototube located in Position 1. To determine the transmission, the sample is rotated into the measurement position, and a photometric reading is made with the phototube in Position 1. To measure scattered radiation from the front surface of an opaque or transparent material, the tube is translated to Position 2, and a measurement made. In Position 3, intensity of the specularly reflected beam is measured.

In operation, the four intensities I_0, τ, ρ, and s, are measured on the clean sample, the contaminants are allowed to collect on the sample, and the optical measurements are repeated. If the sample is opaque (thermal control coating, aluminized mirror, or similar component) the transmission measurement is, of course, not required.

An operating panel, located in a spacecraft console, provides the controls and displays for the Optical Properties Evaluation Module. The operating panel also provides the interface with the spacecraft electrical power and data subsystems. Optical properties data and contaminant gage data will be displayed on the panel in real time and will also be recorded on magnetic tape for later relay to the ground.

The component parts of the IRTCM system are conceptually shown in Figure 1-9. The optical module is installed in the integrating housing such that the axis of the sample table is concentric with the centerline of the vertical cylinder. With the upper housing section in the "open" position, a sample located in the exposure position (shown in Figure 1-8) is then exposed to incoming contaminants from almost a complete hemisphere. Auxillary apertures may be installed within the housing to selectively expose the material samples and contaminant gages.

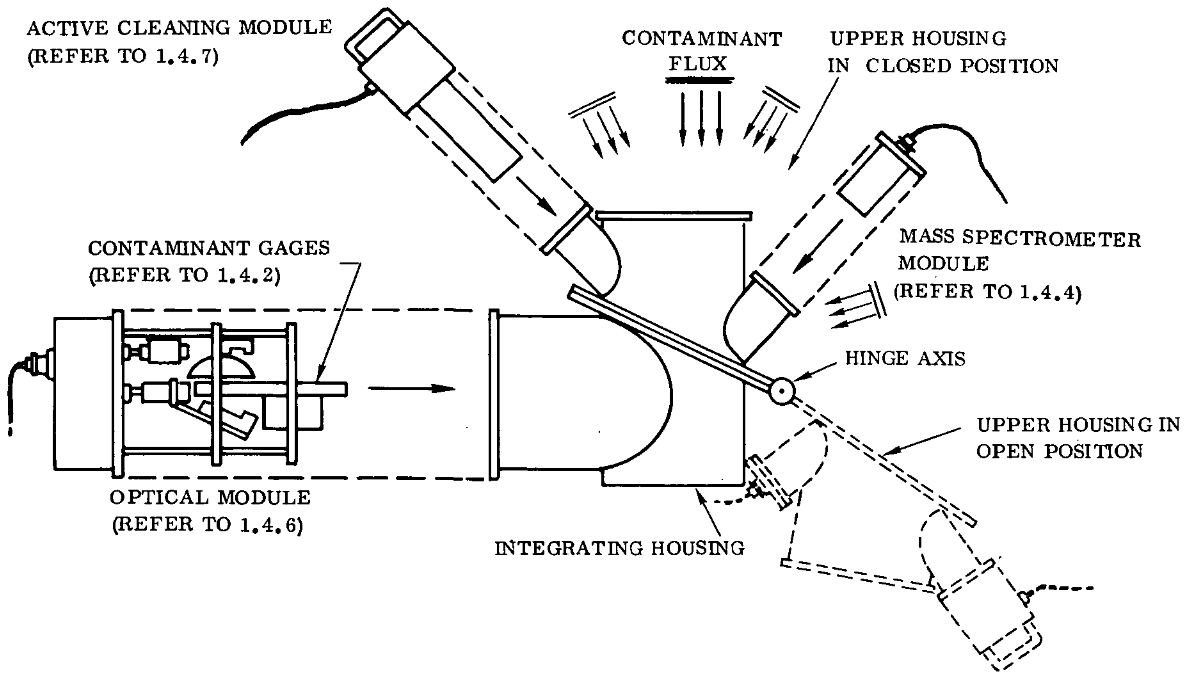


Figure 1-9. IRTCM Concept

Figure 1-9 also illustrates the locations of the mass spectrometer and contaminant gages, and the active cleaning device employed for Experiment 1.4.7.

The IRTCM system concept shown in Figure 1-9 is only one of several configurations which could be employed, and is considered to be representative of the interfacing and support requirements for any of the probable configurations. The optical module could be employed with a variety of IRTCM configurations by virtue of a standardized interface with the integrating housing.

The optical properties evaluation module, installed in an integrating housing, may be deployed from an airlock for short-term exposure periods; for long-term exposure, the module may be deployed by an astronaut via EVA, and hard-mounted to the space craft external structure. Mounting pads and electrical feedthroughs must be provided by the spacecraft for the latter case.

1.4.6.3 Observation/Measurement Program. The Optical Properties Evaluation Module of the IRTCM will normally be operated by remote control per a programmed sequence. Mechanical controls on the instrument will allow the astronaut, if desired, to select the source, sample, and detector positions manually. Samples will include reflecting and transmitting optics typical for optical experiments, such as gold, platinum, and magnesium fluoride overcoated aluminum mirrors and quartz windows and typical thermal control materials (e.g. white paints and surface mirrors). The module will be continuously exposed to the contamination environment, although measurements on the affected optics will be taken only at programmed intervals, or manual override periods. The OPEM operates through a measurement sequence for a period of about four minutes and is then automatically turned off until the beginning of the next programmed sequence.

1.4.6.4 Interface, Support and Performance Requirements

Crew

a. Preparation. The astronaut will install the samples and deploy the IRTCM either through an airlock or via EVA. All utilities will be attached at the time of mounting the IRTCM.

b. Use. The experiment will be operated using the controls in a spacecraft console in the cabin environment. Direct astronaut contact with the instrument is not required although manual controls will be available on the instrument if events suggest such contact may be desirable. A crewman will periodically monitor the data returned from the instrument and may modify the exposure or measurement sequence.

c. Termination. A crewman will retrieve the IRTCM, remove the sample trays, and store them in transit cases for later evaluation.

d. Special Skills. Assembly, deployment, and operation of the experiment requires skills equivalent to an Electromechanical Technician. Interpretation of test results requires a Physicist.

Subsystems Support

a. Storage. The OPEM displaces a volume of 0.03 m^3 (1 ft^3), and weighs 10 kg (22 lb). Space must be provided in a spacecraft console to house the operating and readout panel. Size: 25 × 35 × 15 cm (10 × 14 × 6 in.), Weight: 9 kg (15 lb).

b. Power. 100 watts average

c. Data. Photomultiplier tube: 19.6 kbps; contaminant gages: 0.6 kbps; sequencing position indicator; 0.2 kbps. Spacecraft orientation and event-sequence time-line are required for evaluation.

Constraints. The OPEM may be operated at any spacecraft operational altitude; however, when it is integrated with other experiment equipment, pressure constraints dictated by the other equipment may be applicable.

1.4.6.5 Potential Role of Man. A crew member will deploy and retrieve the instruments, control the instruments from the cabin control panel, observe the data readout during active phases, and, if desired, manually operate the experiment.

1.4.6.6 Available Background Data. There is considerable experience in the laboratory in monitoring the optical properties of contraminated optics and evaluating the results.

A Proposal for Modules for Real-Time Contamination Monitoring, General Dynamics/Convair Report No. GDC-PIN70-143, in response to RFQ No. 1-0-80-00056; General Dynamics/Convair is now building the OPEM under Contract NAS8-26132.

1.4.7 ACTIVE CLEANING TECHNIQUE EVALUATION. Degradation of optical flight instruments and thermal control surfaces by contamination from rocket engine exhausts, waste dumps, and outgassing of materials poses a serious threat to successful utilization of these instruments and to spacecraft thermal control system performance. Contamination of optical surfaces can alter the spectral sensitivity of the instrument, thereby preventing absolute radiometric studies, and can blur an image by diffraction and scattered light to such a degree as to jeopardize visual observation. Changes in the optical properties of thermal control surfaces in the solar region of the spectrum are of primary importance since they affect the equilibrium temperature of the surface.

Much effort is underway to control contamination by eliminating the sources of contamination or at least to minimize their output. From a practical viewpoint, in the foreseeable future, it will be impossible to eliminate all contamination sources on a spacecraft or to completely prevent them from reaching optical surfaces. Therefore, an Active

Cleaning Technique (ACT) device will be required to provide a method to restore the original optical properties of contaminated optical and thermal control surfaces during long duration space missions. Naturally, before such a device is incorporated into operational flight hardware to perform the cleaning function, the ACT must be proven in an actual space flight environment.

1.4.7.1 Objective. The objective of this experiment is to evaluate the effectiveness of one or more types of devices which employ active cleaning techniques to remove contaminants from optical surfaces in a true space flight environment. Data will be obtained to support the development of operational cleaning devices for optical instruments and for spacecraft thermal control surfaces.

1.4.7.2 Description. The evaluation of a typical active cleaning device is described herein. Over a period of years, devices which employ several different operating principles may be evaluated. These experimental devices will all be configured, if possible, as illustrated in Figure 1-10, so that common experiment equipment (IRTCM) and controllable test conditions can be employed.

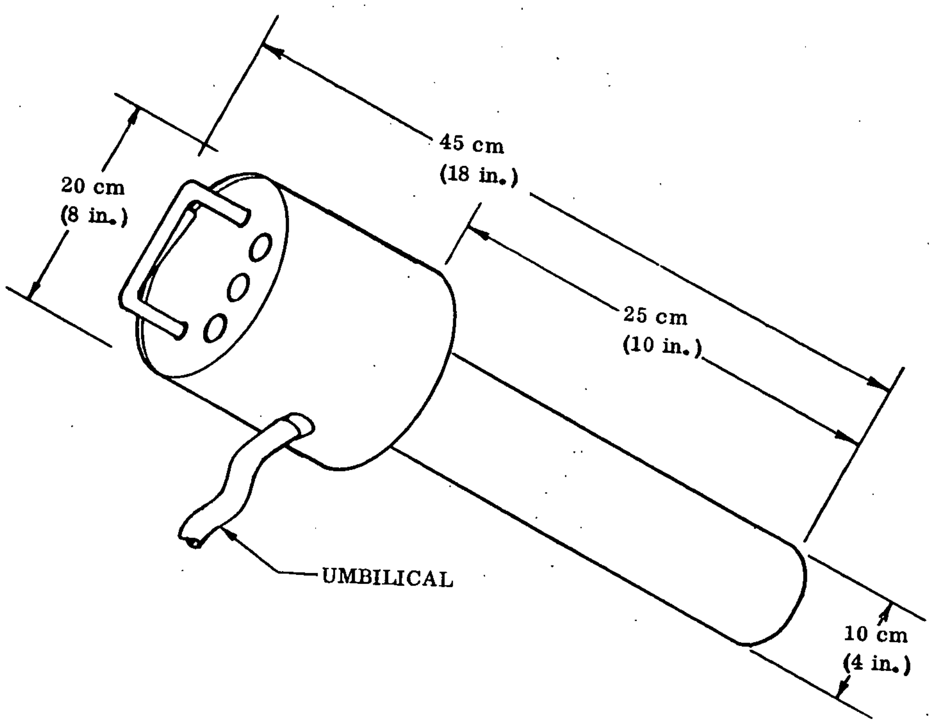


Figure 1-10. Active Cleaning Device

The device will be designed for two different modes of operation.

Mode A - IRTCM. This operating mode is illustrated in Figure 1-9. In this operating mode the cleaning device is installed in the IRTCM integrating housing such that optics in the IRTCM exposed position will be in direct line of sight with the ACT, thereby enabling cleaning of contaminated optics while monitoring with the mass spectrometer and contaminant gages. Remote operation is anticipated with the exposure device mounted flush with the spacecraft surface or on an extended structure. This type operation will simulate actual use of the ACT mounted remotely in an optical instrument such as a large telescope.

Mode B - EVA. In this mode of operation an astronaut on EVA can use the ACT to clean various critical areas located outside the spacecraft, such as thermal control radiator surfaces, windows, and objective lenses of optical instruments. In this mode of operation the portable spectroreflectometer (Section 1.4.3) aids in identifying when cleaning is necessary and when the surfaces are cleaned sufficiently.

1.4.7.3 Observation/Measurement Program

Mode A - IRTCM. The IRTCM will be loaded with a series of samples with typical optical coatings such as gold, platinum, iridium, and magnesium fluoride over aluminum, and with typical thermal control materials.

These samples will be exposed to the space environment including any spacecraft contamination. After collection of a sufficient layer of contaminants, as monitored by the optical and contaminant gage modules of the IRTCM, the ACT device will be turned on until the contaminant gage indicates contaminants have been removed. Then the optical module will be used to determine to what extent the original optical properties have been restored. During cleaning the mass spectrometer will be used to monitor the mass species being removed from the samples. All data will be recorded and then the unit will be put on standby until contamination builds up again because of outgassing, waste dumps or thruster firings.

Mode B - EVA. In this mode of operation the test will be carried out during EVA operations. The astronaut using the portable spectroreflectometer will check an exposed sample tray for degradation of the samples (optical and thermal control coatings). When these indicate degradation, the ACT device will be used to clean the samples. After exposure to the ACT the samples will be rechecked with the portable spectroreflectometer to determine extent of recovery; all data will be recorded such as exposure times to space environment, spectroreflectometer readings, exposure time to ACT and ACT readouts.

1.4.7.4 Interface, Support and Performance Requirements

Crew

a. Preparation. Mode A - The ACT must be installed in the IRTCM housing (see Figure 1-9). The astronaut will turn on the IRTCM per its requirements; at the same time, the ACT will be turned on and permitted to warm up. At time of actual use, the ACT will be adjusted as required. All utilities will have been attached at the time of mounting of the IRTCM, and the ACT will require only direct astronaut contact if difficulties arise.

Mode B - Outside sample holders will be mounted and samples installed by the astronaut on EVA, exposing them to the space environment. Both the portable spectroreflectometer and ACT shall be employed during EVA.

b. Use. Mode A - As implied, the remote configuration shall be operated with the astronaut inside the spacecraft in the cabin environment while the ACT and IRTCM are located in the space environment.

   Mode B - During EVA operations the astronaut shall carry the ACT to the various surfaces to be cleaned along with the portable spectroreflectometer.

c. Termination. Mode A - The sample tray in the IRTCM shall be recovered to check optical measurements. Also, if malfunctions occur in the ACT module, it shall be removed from the IRTCM and returned.

   Mode B - The sample tray shall be removed and returned, to check in detail for degree of cleaning success. Also, the ACT shall be returned if malfunctions occur.

d. Special Skills. Skill equivalent to an Electromechanical Technician is required. Three to four hours will be required for special training in use of the ACT device.

Subsystems Support. EVA proficiency is required.

a. Volume of the ACT module during storage will be approximately 0.03 cu. meter (1 cu.ft).

   It will be mounted on the IRTCM during operation in Mode A.

b. Data. Data requirements include reflectance, mass analysis, and contaminant gage readouts of IRTCM, portable spectroreflectometer output data, spacecraft orientation and operation timeline, critical temperatures, and operational parameter readouts for the ACT.

Constraints. The experiment will be attempted at all spacecraft operational altitudes. However, the effectiveness of surface cleaning is presently unknown at pressures higher than 1.3×10^{-3} N/m^2 (10^{-5} torr).

1.4.7.5 Potential Role of Man. The role of man is two-fold. First, he is required to recognize when cleaning is necessary either by direct reading with instrumentation or by visual identification of contamination degraded surfaces (color, texture change). Second, he is required to initiate the cleaning sequence either remotely or manually by physically locating the ACT device over the surface to be cleaned. Obviously, man's ability to select particular areas requiring cleaning and to accomplish the cleaning with only one device would be most difficult and impractical to automate.

1.4.7.6 Available Background Data. There is considerable experience in the MSFC SSL laboratory in cleaning optical surfaces *in situ*.

1.4.8 CONTAMINATION CONTROL EVALUATION

1.4.8.1 Objective. The objective of this experiment is to determine the extent to which contaminant materials can be controlled in the transport phase through electromagnetic, electrostatic, and/or mechanical devices.

The experimental devices and operating conditions will lead to the development of advanced contamination control systems which will be employed as operational components for future space missions.

1.4.8.2 Description. The experiment is based on the concept of controlling contaminant material prior to its deposition upon critical surfaces by diverting the material or causing it to deposit on sacrificial surfaces.

The control techniques to be used in the experiment include:

a. Generation of an electrostatic field to divert ions, charged particles, and polarizable material away from critical surfaces, either repulsing them completely or allowing them to deposit on sacrificial surfaces.

b. Use of a magnetic field to alter the trajectories of incoming charged material so that a superposed electric field will cause the material to drift out of the critical region.

c. Creation of a gas cushion very close to the critical surface.

Test exposures will be made in which sample surfaces installed on test panels will be exposed to the contaminant environment as shown in Figure 1-11. Two control samples on the panel are "unprotected" while others are "protected" by the control techniques being investigated. The differential deposition of material on protected and unprotected surfaces will be determined and related to the control system operating parameters.

A calibration panel will be exposed without any active control device in order to determine any inhomogeneities in the local contaminant environment. Such inhomogeneities could be caused by geometric factors involving the location of contaminant sources in relation to the experiment location and the configuration of local spacecraft surfaces.

Test panels will be deployed through the airlock for most tests but may be hard-mounted on the external spacecraft surface.

The contamination environment during the test run will be monitored at the test panel location by a mass spectrometer and a contaminant gage. These instruments are described in Experiment 1.4.4 and Experiments 1.4.2, respectively.

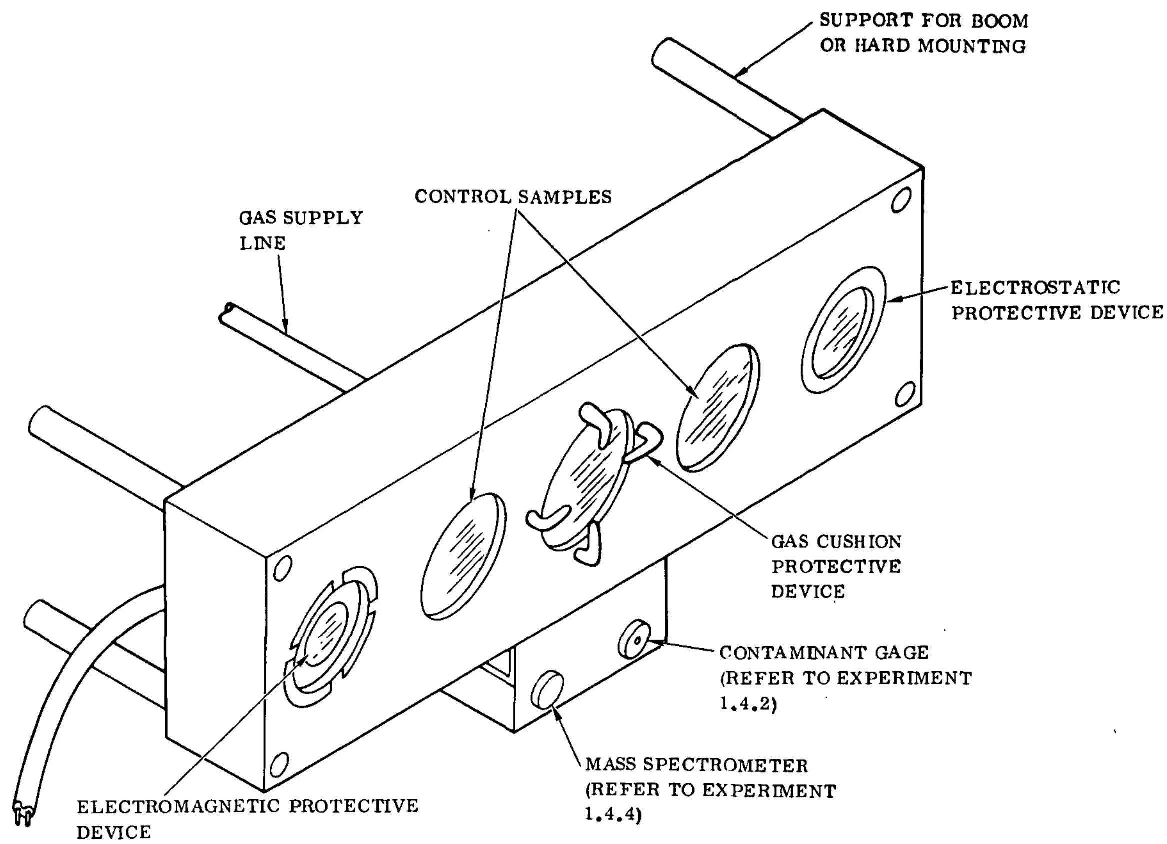


Figure 1-11. Contamination Control Test Panel

After exposure, the test panel will be retrieved, and the deposition will be analyzed to determine types and quantities of contaminants, and their effects on optical properties. During the exposure, real-time measurements of contaminant levels and composition, current drawn in the electrostatic and electromagnetic control devices, and gas flow in the gas cushion device will be recorded.

1.4.8.3 Observation/Measurement Program. Panels will be deployed preferably during times of high contaminant concentration, as determined through real-time contamination monitoring. The deployment sequence will be arranged so that the geometric factors in contaminant transport will be the same from run to run. This implies that the contaminant sources are the same for all related runs.

After exposure the test panels will be withdrawn from the contamination environment, the samples removed, and the deposition analyzed optically. Differential deposition will be tabulated according to the values of the control system parameters.

The exposure will be timed so that the deposition on an unprotected sample will be several times the threshold value of the measuring instrument.

1.4.8.4 Interface Support and Performance Requirements

Crew Support. One crewman is required to deploy the panels, set the instrument controls, retrieve the panels, measure the deposition, and record the data. A skill level equivalent to an electromechanical technician is required. The crewman determines when to begin an exposure, selects the panel of samples to be exposed, mounts the panel in its housing, and deploys the instrument through the airlock. He sets the test parameters, determines the level of contamination present (through the real-time contamination monitors), calculates the minimum acceptable exposure time, and times the experiment. At the end of the exposure he records the pertinent data, zero-sets the controls, retrieves the deployed instrument, stows the housing, measures the deposition and records the data. Preflight training of 80 hours is required.

Subsystem Support

a. Volume and Weight - Deployable part of instrument: 0.02 cu. meter (0.75 cu ft), 9 kg (20 lb). Storage for panels: 0.06 cu. meter (2 cu ft). Console: 0.06 cu. meter (2 cu ft), 11 kg (25 lb).

b. Power - During use of electrostatic device: 100 watts.
 - Other times during use: 35 watts.

c. Gas - Several moles of N_2.

d. Data - Contamination control system operating parameters and IRTCM system data shall be automatically recorded at intervals set by the crewman, or at his command.

e. Deployment System - An airlock and extendable boom must be provided if EVA is to be avoided. Alternatively, the panels may be hardmounted externally on the spacecraft via EVA.

Constraints. The experiment will be attempted at all spacecraft operational altitudes; however, special precautions may be required at altitudes below 280 km (150 n. mi.)

1.4.8.5 Potential Role of Man. A crew member is required to prepare, deploy, and retrieve the test panels. In addition, he is required to determine the minimum exposure duration by using a set formula and readings of the real-time contamination monitoring system. He is required to time the exposure and to subject the retrieved panels to simple laboratory measurements. He is required to monitor the data. He must also perform routine maintenance.

1.4.8.6 Available Background Data

Baurer, T., Bortner, M. H., Pikus, I. M., and Cooper, A. M., External Spacecraft Contamination Modeling and Countermeasures, TIS No. 70SD260, General Electric Company, Space Division, June 1970.

1.5 FPE INTERFACE, SUPPORT, AND PERFORMANCE REQUIREMENTS

The summary data presented in Table 1-4 represents, in the best judgment of NASA scientists, the overall facility and experimental requirements to accomplish a realistic experimental program. The rationale for selection of the summary parameters is in some instances arbitrary but has as a basis the total NASA experience and knowledge of prior flight and experiment definition and integration programs.

Table 1-4. Summary Interface, Support and Performance Requirements

Parameter	Value	
Mass	190 kg	(420 lb)
Volume	0.68 m^3	(24 ft^3)
Power	700 watts	
Crew Skills	Physicist	
	Electromechanical Technician	
Data Rate	107 kbps +	10 MHz TV
Logistics Up (30 days)	15 kg	(33 lb)
Logistics Down (30 days)	11 kg	(25 lb)
Pointing and Stability	$\pm 8.7 \times 10^{-3}$ rad	($\pm$0.5 deg)
Orbit Altitude and Inclination	Altitude: Any spacecraft operational altitude.	
	Inclination: Any	
Unique Environmental Requirements	Experiment Peculiar	

Most of the experiments described in this FPE require external placement for exposure and/or measurements. Many will require the support of scientific airlocks equipped with extendable booms and two-axis pointing heads if EVA is to be avoided. For those experiments that are hardmounted to the spacecraft exterior, a mounting structure designed for EVA installation and removal must be provided. With the exception of passive samples, all of the experiment equipment will require some type of utility support from the spacecraft. Therefore, a variety of electrical and fluid feedthroughs will be required. These hull penetrations should be located close to the instrument mounting point to minimize the length of electrical cable exposed to the space environment. For maximum flexibility in accommodating a variety of experiments, the spacecraft should be initially designed with standardized instrumentation ports located adjacent to all potential external instrument mounting points or viewing vantage points.

Standardized feedthrough plates with bulkhead electrical connectors or fluid fittings installed would then be employed as experiment-peculiar support equipment. A universal port design should be developed which allows the standard instrumentation ports to be alternately outfitted for other uses, such as view ports and small airlocks.

In order to minimize the need for EVA support of the experiment program, the spacecraft should be initially designed with scientific airlocks which are large enough to accommodate any of the experiment equipment plus a deployment boom system. One meter diameter is the minimum airlock size that should be considered.

1.6 POTENTIAL MODES OF OPERATION

The potential modes of operation to be considered are:

Mode A. Limited on-orbit stay time attached to the Space Shuttle.

Mode B. Extended on-orbit stay time free flying, periodically revisited by a Space Shuttle.

Mode C. Extended on-orbit stay time, either attached to the Space Station or in a free flying mode supported by the Space Station.

All of these potential modes of operation are applicable for this FPE. The operating modes applicable to each experiment are shown in Table 1-5.

Table 1-5. Potential Operating Modes

Number	Experiment Title	Applicable Modes A	B	C
1.4.1	Sky Background Brightness Measurement	X		X
1.4.2	Real-Time Contamination Measurement	X	X	X
1.4.3	Surface Degradation Measurement		X	X
1.4.4	Contaminant Cloud Composition Measurement	X		X
1.4.5	Contaminant Dispersal Measurement	X		X
1.4.6	IRTCM: Optical Module Evaluation	X	X	X
1.4.7	Active Cleaning Technique Evaluation	X		X
1.4.8	Contamination Control Evaluation	X	X	X

1.7 ROLE OF MAN

An astronaut is required to:

a. Prepare scientific air locks.

b. Assemble and checkout experiment equipment.

c. Deploy and retrieve instruments, test samples, and sample collectors.

d. Operate controls, make routine and special measurements.

e. Perform preliminary data analysis.

f. Perform maintenance and servicing.

EVA will be required for deployment and retrieval of long-term exposure samples, for in situ measurements of contamination effects, and for active cleaning experiments.

1.8 SCHEDULES

The development and flight schedule for this FPE is shown in Table 1-6. Following the two year experiment mission period described in the FPE, some of the instruments will continue in use for operational support of other experiments. Others will continue to evaluate new materials and contamination countermeasures techniques.

1.9 PRELAUNCH SUPPORT REQUIREMENTS AND GSE

Prelaunch checkout of the instruments for Contamination Cloud Composition Measurement (Section 1.4.4), IRTCM Optical Module Evaluation (Section 1.4.6) and the Active Cleaning Techniques Evaluation (Section 1.4.7) will require a vacuum chamber. and associated support equipment for interfacing the instruments with the chamber.

1.10 SAFETY ANALYSIS

There are no unusual hazards associated with these experiments, although EVA is required for long term exposure sample deployment and retrieval, for in situ contamination measurements, and for countermeasures experiments.

1.11 AVAILABLE BACKGROUND DATA

Pertinent background data is listed for each experiment, where applicable.

Table 1-6. FPE Development and Flight Schedule

FPE/Experiments	n-5	n-4	n-3	n-2	n-1	n	n+1	n+2	- - -
1. Sky Background Brightness Meas.		A B	C	D					Note 1
2. Real-Time Contamination Meas.			A	B C	D				Note 1
3. Surface Degradation Meas.			A	B C	D				Note 2
4. Contaminant Cloud Composition Meas.		A B	C	D					Note 1
5. Contaminant Dispersal Meas.			A	B C	D				Note 1
6. IRTCM: Optical Module			A B	C	D				Note 1
7. Active Cleaning Technique Eval.		A B	C	D					Note 3
8. Contamination Control Eval.		A B	C	D					Note 3

Schedule (Years) re. Launch Date

A, B, C, D = PHASE

Notes:
1. Continue operation support
2. Continue with additional samples
3. Continue to evaluate other techniques

VOLUME VII

SECTION 2

FLUID MANAGEMENT

SECTION 2

FLUID MANAGEMENT

2.1 GOALS AND OBJECTIVES

The basic fluid physics phenomena to be studied are those which are greatly affected by gravity level. Earth-bound experimental studies of most of these gravity effects are restricted due to short low-g test times available when employing drop towers and aircraft and to the difficulty of scaling small model test results to real space vehicle operating conditions. Data to be obtained from the experiments will not only provide a better basic understanding of fluid physical behavior, but will provide information required for the design of the next generation life support, space propulsion and other fluid systems.

The experiments described in this FPE are designed to yield parametric data over the entire range of flows, temperatures, acceleration levels, and heat transfer rates which will be encountered in future vehicle design. The information derived from these experiments will be documented in handbook form for application to future vehicle design.

2.2 PHYSICAL DESCRIPTION

The Fluid Management FPE consists of a group of containers, pressure vessels, fluid loops, storage tanks, fluid transfer equipment, and instrumentation. As many as nine liquids and three gases must be stored (and/or resupplied) until the astronauts have concluded the particular experiment. Several experiments require that the container and flow loops be transparent in order that the astronaut witness and photograph the results. Essential data to be collected during the various experiments are accelerations, pressures, temperatures and flows. TV coverage is required in some experiments to provide timely readjustments. Photographic records are essential to analyze the experimental results. High-speed movie cameras will obtain the most significant data in some experiments.

The orbital vehicle carrying the experiments must provide data storage and transmission of experimental results and sustained acceleration at various levels, as well as power, and cooling for the heat generated during some experiments.

2.3 EXPERIMENT REQUIREMENTS SUMMARY

The major requirements of the fluid management experiment program are summarized in Tables 2-1, 2-2, 2-3, and 2-4. These data identify each experiment weight,

Table 2-1. Experiment Requirements Summary

EXP	MASS (WEIGHT) ITEM	kg	(lb)	VOLUME m^3 (ft^3)	ENVELOPE m (ft)	POWER REQUIREMENTS	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS	hours	DATA REQUIREMENTS
2.4.1 Interface Stability	Fluid Tanks Structure Instr	204 136 68 16 424	(450) (300) (150) (35) (935)	1.4 (50)	$1.5 \times 1.5 \times 0.6$ ($5 \times 5 \times 2$)	Nominal: 100 W Peak: 500 W for 10 sec	Electromechanical Technician 72 hr Thermodynamicist 20 hr	Controlled g level.	Set-up 10^{-3} g 10^{-4} g 10^{-5} g	48.0 9.1 9.1 9.1	Data generation rate = 760 bits/sec; Total data sampled = 7×10^6 bits; Film storage = 1200 m (4000 ft); Film Wt: 4.5 kg (10 lb) TV = 5.8 MHz
2.4.2 Boiling Heat Transfer	Tanks Structure Propellant Trans Sys Vent Sys Press. Instr	27 27 77 55 45 18 23 272	(60) (60) (170) (120) (100) (40) (50) (600)	1.5 (54)	$0.9 \times 0.9 \times 1.8$ ($3 \times 3 \times 6$)	Nominal: 27 W Peak: 500 W for 1 hour	Electromechanical Technician 18 hr Thermodynamicist 100 hr	Pressure $\leq 1.3 \times 10^{-4} N/m^2$ ($\leq 10^{-6}$ Torr.) Controlled g level.	Set-up 10^{-3} g 10^{-4} g 10^{-5} g	12.0 10.4 17.8 70.3	Data generation rate = 192 bits/sec; Total data sampled = 2×10^6 bits; Film storage = 1900 m (6400 ft); Film Wt: 7.2 kg (16 lb) TV = 5.8 MHz
2.4.3 Capillary Studies	Chambers Tanks Fluids Methanol Ethanol Pentane Support Sys	105 89 255 86 410 73 1018	(230) (195) (560) (190) (900) (160) (2235)	1.8 (65)	$0.9 \times 0.9 \times 0.9$ ($3 \times 3 \times 3$) (Plus Storage Tanks)	Nominal: 115 W Peak: 165 W for 4 min.	Thermodynamicist 18 hr	Temperature nominally 294.15°K (70°F). Controlled g level.	10^{-3} g 10^{-4} g 10^{-5} g	6.0 6.0 6.0	Data generation rate = 25 bits/sec; Total data sampled = 1.62×10^6; Film storage = 0 TV = 2.9 MHz
2.4.4 Condensing Heat Transfer	Cond Pkg Support Eqpt Fluids Cameras Heat Sink Power Supply Instr Controls Misc	44 18 2 52 27 30 9 16 18 216	(97) (39) (5) (115) (60) (65) (20) (35) (40) (476)	2.1 (75)	$1.8 \times 1.5 \times 0.75$ ($6 \times 5 \times 2.5$)	Nominal: 1.21 kW Peak: 1.65 kW for 12 sec 25 times	Electromechanical Technician 1 hr Thermodynamicist 3.35 hr	Controlled g level.	Set-up 10^{-3} g 10^{-4} g	1.0 2.1 1.25	Data generation rate = 5780 bits/sec; Total data sampled = 17×10^6; Film storage = 1800 m (6,000 ft); Film Wt: 6.8 kg (15 lb) TV = 2.9 MHz
2.4.5 Two-Phase Flow Regimes	Structure Fluid	45 163 208	(100) (360) (460)	0.34 (12)	$0.6 \times 0.6 \times 0.9$ ($2 \times 2 \times 3$)	Nominal: 167 W Peak: 300 W for 15 sec.	Electromechanical Technician 24 hr Thermodynamicist 20 hr	Constant thermal environment 294.15°K (70°F). Controlled g level.	Set-up 10^{-3} g 10^{-5} g	16.0 6.0 6.0	Data generation rate = 160 bits/sec; Total data sampled = 1×10^5 bits; Film storage = 1300 m (4400 ft); Film Wt: 5 kg (11 lb) TV = 2.9 MHz

Table 2-1. Experiment Requirements Summary, Contd

EXP	MASS (WEIGHT) ITEM	kg	(lb)	VOLUME m^3	(ft^3)	ENVELOPE m	(ft)	POWER REQUIREMENTS	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS	hours	DATA REQUIREMENTS
2.4.6 Propellant Transfer	Tanks & Structure LH$_2$ GHe Fill & Vent Sys Instr Insul. Test Eqpt TV Press. 	227 390 9 114 23 18 41 41 41 904	(500) (850) (20) (250) (50) (40) (90) (90) (90) (1980)	51	(1800)	2.4 × 3.6 × 5.4	(8 × 12 × 18)	Nominal: 1.3 kW Peak: 4 kW for 6 hr	Electromechanical Technician 12 hr Thermodynamicist 56 hr	Pressure: $\leq 1.3 \times 10^{-4}$ N/m^2 (10^{-6} Torr.) Controlled g level.	Set-up 10^{-3} g 10^{-4} g 10^{-5} g Coast	8.0 7.0 1.0 7.0 33.0	Data generation rate = 160 bits/sec; Total data sampled = 8×10^6 bits; Film storage = 0 TV = 5.8 MHz
2.4.7 Long Term Storage of Cryogenics	Tank Shroud LH$_2$ Fill & Vent Sys Instr Insul Test Eqpt TV Press. 	454 365 1140 114 91 130 14 18 68 2394	(1000) (800) (2500) (250) (200) (280) (30) (40) (150) (5250)	59	(2100)	3.2 × 3.2 × 5.7	(10.5 × 10.5 × 19)	Nominal: 250 W Peak: 1200 W for 17 hr	Electromechanical Technician 32 hr Thermodynamicist 400 hr	Pressure: $\leq 1.3 \times 10^{-4}$ N/m^2 (10^{-6} Torr.) Controlled g level.	Set-up 10^{-3} g 10^{-4} g 10^{-5} g Coast	24 17 200 475 4200	Data generation rate = 160 bits/sec; Total data sampled = 5×10^7 bits; Film storage = 0 TV = 5.8 MHz
2.4.8 Slush Propellant	Tank & Insul Heaters Structure Press. Sys Test Eqpt Slush Fill & Vent Sys Instr 	236 11 55 41 55 80 114 68 660	(520) (25) (120) (90) (120) (175) (250) (150) (1430)	24	(840)	2.1 × 3.6 × 3	(7 × 12 × 10)	Nominal: 40 W Peak: 1200 W for 2 min	Electromechanical Technician 12 hr Thermodynamicist 68 hr	Pressure: $\leq 1.3 \times 10^{-4}$ N/m^2 (10^{-6} Torr.) Controlled g level.	Set-up 10^{-3} g 10^{-4} g 10^{-5} g	8.0 3.6 42.0 152.0	Data generation rate = 160 bits/sec; Total data sampled = 5×10^6 bits; Film storage = 0
2.4.9 Two-Phase Dynamics	Test Section Support Instr 	9 65 21 95	(20) (145) (45) (210)	0.28	(10)	0.6 × 0.6 × 0.75	(2 × 2 × 2.5)	Nominal: 400 W Peak: 1000 W for 180 sec	Electromechanical Technician 120 hr	Controlled g levels	Set-up 10^{-3} g 10^{-5} g Coast	24.0 4.2 4.2 4.2	Data generation rate = 160 bits/sec. Film = 750 m (2500 ft)
2.4.10 Channel Flow Systems	Test Section Support Instr 	23 91 34 148	(50) (200) (75) (325)	0.59	(21)	0.6 × 0.8 × 1.2	(2 × 2.7 × 4)	Nominal: 750 W Peak: 1800 W for 180 sec	Electromechanical Technician 140 hr	Controlled g levels	Set-up 10^{-3} g 10^{-5} g Coast	48 12 12 12	Data generation rate = 1000 bits/sec. Film = 1200 m (4000 ft)
2.4.11 Conical Flow Systems	Test Section Support Instr 	9 34 21 64	(20) (75) (45) (140)	0.62	(22)	0.6 × 0.9 × 1.1	(2 × 3 × 3.5)	Nominal: 200 W Peak: 750 W for 180 sec	Electromechanical Technician 123 hr	Controlled g levels	Set-up 10^{-3} g 10^{-5} g Coast	48 6 6 6	Data generation rate = 100 bits/sec. Film = 600 m (2000 ft)

Table 2-2. Experiment Characteristics - 2.4.1, 2.4.2, 2.4.3, 2.4.4

	2.4.1 Interface Stability	2.4.2 Boiling Heat Transfer	2.4.3 Capillary Studies	2.4.4 Condensing Heat Transfer
Experiments	a. Outflow fluid transfer With baffles - 12 Without baffles - 12 b. Inflow fluid transfer With baffles - 30 Without baffles - 20 c. Large amplitude slosh - 16 d. Reorientation - 30 e. Interface break-up & entrainment - 10 f. Bubble cluster - 20	Heater / Fluid Vert Sat (VS-1) Hor Sat (HS-2) Vert Subcool (VSC-3) Hor Subcool (HSC-4) Vert Sat (VS-5) Hor Sat (HS-6) Vert Sat (VS-7) Hor Sat (HS-8) Vert Subcool (VSC-9) Hor Subcool (HSC-10) Boilover (BO-11) Boilover (BO-12) Boilover (BO-13)	4 Wicks 3 Heights/wick 3 Fluids 3 g levels Total = 108 tests	Mode I - 5 tests Mode II - 5 tests Mode III - 5 tests Mode IV - 5 tests Mode V - 5 tests
Acceleration Levels (g ± 10%) /Duration	a. 10^{-3}/1.1 hr 10^{-4}/1.1 hr 10^{-5}/1.1 hr b. 10^{-3}/2.4 hr 10^{-4}/2.4 hr 10^{-5}/2.4 hr c. 10^{-3}/1.4 hr 10^{-4}/1.4 hr 10^{-5}/1.4 hr d. 10^{-3}/1.4 hr 10^{-4}/1.4 hr 10^{-5}/1.4 hr e. 10^{-3}/0.7 hr 10^{-4}/0.7 hr 10^{-5}/0.7 hr f. 10^{-3}/1.4 hr 10^{-4}/1.4 hr 10^{-5}/1.4 hr	VS-1 10^{-3}/3.0 hr HS-2 10^{-3}/2.4 hr VSC-3 10^{-3}/2.0 hr HSC-4 10^{-3}/2.0 hr VS-5 10^{-4}/9.4 hr HS-6 10^{-4}/7.4 hr VS-7 10^{-5}/26.1 hr HS-8 10^{-5}/21.4 hr VSC-9 10^{-5}/11.8 hr HSC-10 10^{-5}/10.0 hr BO-11 10^{-3} - 1.0 hr BO-12 10^{-4} - 1.0 hr BO-13 10^{-5} - 1.0 hr	10^{-5} - 10 min each test 10^{-4} - 10 min each test 10^{-3} - 10 min each test	Mode I - 10^{-3}/7.5 min/test Mode II - 10^{-4}/7.5 min/test, 10^{-3}/5 sec/test Mode III - 10^{-3}/7.5 min/test Mode IV - 10^{-4}/7.5 min/test, 10^{-3}/5 sec/test Mode V - 10^{-3}/10 min/test
Orientation Requirement	Axial acceleration	Parallel and perpendicular to acceleration vector.	Parallel to wick.	Parallel and perpendicular to acceleration vector.
Contamination Limits	None	No contact with condensable gases when LH_2 in tanks	None	No contaminant interference with visual control and recording

Table 2-2. Experiment Characteristics - 2.4.1, 2.4.2, 2.4.3, 2.4.4, Contd

	2.4.1 Interface Stability	2.4.2 Boiling Heat Transfer	2.4.3 Capillary Studies	2.4.4 Condensing Heat Transfer
Potential Experiment Contamination	None	Gaseous H_2 venting will occur	Venting of methanol, ethanol or pentane may be necessary	None
Instrumentation	Temp 17 Press 14 Accel 11 Flow 5 Vibration 6 Force 12 Events 25	Temp 8; 0 to 444°K ΔT 2; 0 to 0.55°K ΔT 10; 18.9 to 22.3°K 2; 19 to 423°K Press 2; 69×10^3 to 207×10^3 N/m^2 (10 to 30 psia) Accel 3; 10^{-3} to 10^{-6} g Voltage 2; 0 to 28 v Current 2; 0 to 110 a	Temp Platinum 1; 284 to 306°K Thermometer 1; 284 to 306°K Press 1; 0 to 138×10^3 N/m^2 (0 to 20 psia) Accel 1; 10^{-3} to 10^{-6} g	Temp 13; 250 to 328°K 8; 189 to 311°K 4; 211 to 328°K 10; 189 to 328°K Press 10; 1.38×10^3 to 138×10^3 N/m^2 (0.2 to 20 psia) 4; 0 to 13.8×10^3 N/m^2 (0 to 2 psia) 2; 6.9×10^3 to 138×10^3 N/m^2 (1 to 20 psia) 1; 0 to 2070×10^3 N/m^2 (0 to 300 psia) Flow 4; 22.7×10^{-5} to 181.6×10^{-5} kg/sec (0.0005 to 0.004 lb/sec) 1; 517.6×10^{-5} to 6129×10^{-5} kg/sec (0.0114 to 0.135 lb/sec) 1; 172.5×10^{-5} to 2043×10^{-5} kg/sec (0.0038 to 0.045 lb/sec) Voltage 1; 0 to 28 volts Current 1; 200 to 900 W Accel - TBD Velocity - TBD Events - TBD
Cameras	TV - 2 Movie - 1 at 400 fps	TV - 3 (Exp. Monitoring) Movie - 3 at 24 fps - 3 at 400 fps - 1 at 4000 fps	TV - 1	TV - 1 Movie - 1 at 24 fps - 1 at 400 fps
Remote Data Monitoring	12 hr	100 hr	18 hr	3.35 hr
Set-up and Shutdown Time	72 hr	18 hr	None	1 hr
Fluids Required	Hexane, Methanol Pentane or Freon	Liquid Hydrogen	Methanol, Ethanol, Pentane	Freon 114B2, Gaseous Nitrogen, Freon 21, LN_2

Table 2-2. Experiment Characteristics - 2.4.1, 2.4.2, 2.4.3, 2.4.4, Contd

<table>
<tr><th></th><th>2.4.1
Interface Stability</th><th>2.4.2
Boiling Heat Transfer</th><th>2.4.3
Capillary Studies</th><th>2.4.4
Condensing Heat Transfer</th></tr>
<tr><td>Resupply Requirements</td><td>None</td><td>None</td><td>Required if small fluid supply tanks are used as an alternative.</td><td>None</td></tr>
<tr><td>Safety Requirements</td><td>Potentially toxic and flammable fluids. Tanks and lines must be purged prior to disassembly.</td><td>Cryogenic flammable fluid</td><td>Potentially toxic and flammable fluids</td><td>Potentially toxic fluids</td></tr>
<tr><td>Special Test Conditions</td><td></td><td>
<table>
<tr><th>Test</th><th>Heat Flux W/m^2 (Btu/ft^2 hr)</th><th>Heater Power (W-hr)</th><th>Movie Time (sec)</th><th>TV Time (sec)</th></tr>
<tr><td>VS-1</td><td>0.0315 to 15,760
(0.01 to 5000)</td><td>680</td><td>20</td><td>130</td></tr>
<tr><td>HS-2</td><td>0.0315 to 15,760
(0.01 to 5000)</td><td>600</td><td>20</td><td>100</td></tr>
<tr><td>VCS-3</td><td>0.0315 to 15,760
(0.01 to 5000)</td><td>400</td><td>15</td><td>90</td></tr>
<tr><td>HCS-4</td><td>0.0315 to 15,760
(0.01 to 5000)</td><td>400</td><td>15</td><td>90</td></tr>
<tr><td>VS-5</td><td>0.0315 to 9475
(0.01 to 3000)</td><td>730</td><td>40</td><td>350</td></tr>
<tr><td>HS-6</td><td>0.0315 to 9475
(0.01 to 3000)</td><td>100</td><td>30</td><td>350</td></tr>
<tr><td>VS-7</td><td>0.0315 to 4730
(0.01 to 1500)</td><td>320</td><td>120</td><td>700</td></tr>
<tr><td>HS-8</td><td>0.0315 to 4730
(0.01 to 1500)</td><td>100</td><td>30</td><td>390</td></tr>
<tr><td>NCS-9</td><td>0.0315 to 3150
(0.01 to 1000)</td><td>100</td><td>10</td><td>60</td></tr>
<tr><td>HCS-10</td><td>0.0315 to 3150
(0.01 to 1000)</td><td>100</td><td>10</td><td>60</td></tr>
<tr><td>BO-11</td><td></td><td></td><td>10</td><td>180</td></tr>
<tr><td>BO-12</td><td></td><td></td><td>10</td><td>180</td></tr>
<tr><td>BO-13</td><td></td><td></td><td>10</td><td>180</td></tr>
</table>
</td><td>Test Sequence
1. Position screen.
2. Set chamber pressure.
3. Fill reservoir with test fluid.
4. Reach equilibrium P and T conditions.
5. Raise heater power until vapor is evident at top of wick.
6. Record liquid height, P, T and power.</td><td>Mode I - 3 straight condensing tubes.
Mode II - 3 straight condensing tubes and g bursts.
Mode III - straight tube and tapered tube in parallel.
Mode IV - straight tube and tapered tube in parallel and g bursts.
Mode V - single heavily instrumented straight tube
Pressure and flow rate to vary for each mode.</td></tr>
</table>

Table 2-3. Experiment Characteristics - 2.4.5, 2.4.6, 2.4.7, 2.4.8

	2.4.5 Two-Phase Flow Regimes	2.4.6 Propellant Transfer	2.4.7 Long Term Storage of Cryogenics	2.4.8 Slush Propellant
Experiments	a. Porous beds 1. gravity-direction of flow 2. gravity-counter to flow 3. gravity perpendicular to flow b. Cylindrical Ducts 1. gravity-direction of flow 2. gravity-counter to flow 3. gravity perpendicular to flow Total 12 tests, one hour each	a. Low-g Transfer 12 b. Moderate-g Transfer 3 c. High-g Transfer 12	a. Vent System 10 b. Insulation (290°K Shroud) 1 c. Insulation (266°K Shroud) 1 d. Stratification/ destratification 1. 3 heat flux 3 2. 3 heat flux 3 3. 3 heat flux 3 e. Reliquefaction 1 f. Insulation (290°K Shroud) 1 g. Insulation (266°K Shroud) 1	a. 1. Stratification 2. Mixer speed 1 3. Transfer } 3 b. 1. Stratification 2. Mixer speed 2 3. Transfer } 3 c. 1. Stratification 2. Mixer speed 1 3. Transfer } 3 d. 1. Stratification 2. Mixer speed 2 3. Transfer } 3 e. 1. Stratification 2. Mixer speed 1 3. Transfer } 3 f. 1. Stratification 2. Mixer speed 2 3. Transfer } 3
Acceleration Levels (g ± 10%) /Duration	a. 1. 10^{-3}, 10^{-5}/1 hr each 2. 10^{-3}, 10^{-5}/1 hr each 3. 10^{-3}, 10^{-5}/1 hr each b. 1. 10^{-3}, 10^{-5}/1 hr each 2. 10^{-3}, 10^{-5}/1 hr each 3. 10^{-3}, 10^{-5}/1 hr each	a. 10^{-5}/7 hr b. 10^{-4}/1 hr c. 10^{-3}/7 hr Orbital coast 33 hr total for heat-up between tests	a. Coast/100 hr b. Coast/1000 hr 10^{-3} - 3 min every 20 hr c. Coast/1000 hr 10^{-3} - 3 min every 20 hr d. 1. 10^{-3}/4, 2, 1 hr/test 2. 10^{-4}/150, 45, 5 hr/test 3. 10^{-5}/350, 120, 5 hr/test e. Coast/100 hr f. Same as B g. Same as C	a. 10^{-3}/1.8 hr b. 10^{-3}/1.8 hr c. 10^{-4}/21.0 hr d. 10^{-4}/21.0 hr e. 10^{-5}/76.0 hr f. 10^{-5}/76.0 hr
Orientation Requirement	Gravity parallel and perpendicular to flow direction.	Acceleration to be axially directed.	Acceleration to be axially directed.	Acceleration to be axially directed.
Contamination Limits	None	No contact with condensable gases with LH_2 in tanks.	No contact with condensable gases with LH_2 in tanks.	No contact with condensable gases with slush in tanks.
Potential Experiment Contamination	Venting of test fluids may be necessary.	Gaseous H_2 will be vented.	Gaseous H_2 will be vented.	Gaseous H_2 will be vented.

Table 2-3. Experiment Characteristics - 2.4.5, 2.4.6, 2.4.7, 2.4.8, Contd

	2.4.5 Two-Phase Flow Regimes	2.4.6 Propellant Transport	2.4.7 Long Term Storage of Cryogenics	2.4.8 Slush Propellant
Instrumentation	Temp 9; 278 to 375°K Accel 3; 10^{-3} to 10^{-6} g Quality 1; 0.0 to 1.0 Pressure 3; 0 to 207 x 10^3 N/m^2 (0 to 30 psia) ΔPress 1; 0 to 13.8 x 10^3 N/m^2 (0 to 2 psig) Not Def. 3;	Temp 137; 11 to 223°K Press 15; 0 to 414 x 10^3 N/m^2 (0 to 60 psia) Flow 6; 0 to 2.7 kg/sec (0 to 6 lb/sec) Liq/Vap Sen. 60 TV Camera 6 (*) Mass Gage 3 Accel 17; 10^{-3} to 10^{-6} g Current 6 Voltage 6 Velocity 3 Quality 4; 0 to 1.0 3; 0.5 to 1.0 Events 62 (*) Intermittent operation only; all six cameras will not be operated at the same time.	<u>Insulation & Stratification</u> Temp 150; 19.5 to 27.7°K 70; 19.5 to 167°K 50; 167 to 305°K 11; 111 to 223°K 6; 19.5 to 223°K ΔT 15; 0 to 18.2°K Press 4; 69 x 10^3 to 345 x 10^3 N/m^2 (10 - 50 psia) Liq/Vap 80; Ins. Th. 10; (0.5 - 4 in) 30; (0.1 - 4 in) Mass Gage 1; Liq Level 2; Cont Leak Det 5; 10^{-3} - 10^{-10} cc/sec Elec. Pwr. 14; Flow 1; 28 x 10^{-2} m^3/min (0 - 10 f^3/min) Accel 17; Velocity 3; <u>Reliquefaction:</u> Temp 4; 16.7 to 27.7°K 3; 27.7 to 41.6°K 1; 69 to 83°K 1; 83 to 97°K Press 1; 103.5 x 10^3 to 207 x 10^3 N/m^2 (15 - 30 psia) 1; 1897.5 x 10^3 to 2242.5 x 10^3 N/m^2 (275 - 325 psia) 1; 0 to 34.5 x 10^3 N/m^2 (0 - 5 psia) Flow (GH_2) 1; 0.454 to 1.36 kg/hr (1 - 3 lb/hr) Flow (LH_2) 1; 0.454 to 1.36 kg/hr (1 - 3 lb/hr) Power 1; 150 - 250 W <u>Zero-g Vent:</u> Temp 6; 15.6 to 27.7°K Press 1; 103.5 x 10^3 to 207 x 10^3 N/m^2 (15 to 30 psia) 1; 0 to 69 x 10^3 N/m^2 (0 to 10 psia) 1; 0 to 3.45 x 10^3 N/m^2 (0 to 0.5 psid) 1; 0 to 1.7 x 10^3 N/m^2 (0 to 0.25 psid) Flow (GH_2) 1; 0.9 to 1.8 kg/hr (2 to 4 lb/hr) 1; 1.8 to 5.45 kg/hr (4 to 12 lb/hr) Quality 1; 0.5 to 1.0 Power 1; 0 to 10 W Events 40	Temp 103; 11 to 27.7°K 40; 11 to 167°K 65; 11 to 223°K 4; 33.4 to 144°K 4; 111 to 228°K 4; 182 to 295°K 8; 56 to 250°K 4; 8.3 to 69°K 16; 223 to 334°K Press 12; 0 to 414 x 10^3 N/m^2 (0 to 60 psia) 2; 0 to 151.8 x 10^5 N/m^2 (0 to 2200 psia) Flow 2; 0 to 2.7 kg/sec (0 to 6 lb/sec) Slush/ Vapor Sen. 30 Mass Gage 4 Accel 17; 10^{-3} to 10^{-6} g Current 6 Voltage 6 Power 2; 0-30 W 2; 0-130 W Velocity 3 Quality 4 Vapor Sen. 2 Liq Level 4; Cont.

Table 2-3. Experiment Characteristics - 2.4.5, 2.4.6, 2.4.7, 2.4.8, Contd

	2.4.5 Two-Phase Flow Regimes	2.4.6 Propellant Transport	2.4.7 Long Term Storage of Cryogenics	2.4.8 Slush Propellant
Cameras	TV-1 Movie-1, 400 fps	TV-6, Two for each tank. No more than 2 operate at any time.	TV-2	None
Remote Data Monitoring	4 hr	48 hr	100 hr	24 hr
Set-up and Shutdown Time	24 hr	12 hr	36 hr	12 hr
Fluids Required	Pentane and/or Hexane	Liquid Hydrogen, Gaseous Helium	Liquid Hydrogen	Slush Hydrogen
Resupply Requirements	None	250 kg (550 lb) of LH_2.	1600 kg (3500 lb) of LH_2 to complete full sequence of tests	None
Safety Considerations	Toxic and flammable fluids. Tanks and lines must be purged prior to disassembly.	Cryogenic flammable fluid	Cryogenic flammable fluid	Cryogenic flammable fluid
Special Test Conditions	Vary vapor and liquid flow rates over complete quality range. 15 points during each test will define map using movie coverage.			

Table 2-4. Experiment Characteristics - 2.4.9, 2.4.10, 2.4.11

	2.4.9 Two-Phase Dynamics	2.4.10 Channel Flow Systems	2.4.11 Conical Flow Systems
Experiments	a. Bubble Evolution (six times) b. Two-Phase Flow Regimes (six times)	a. Diffusion/convention (5 times) b. Flat Plate Film Stability & Transport (5 times) c. Screen Inertial Separation (9 times) d. Convection Heat Transport (5 times)	a. Conical Film stability and transport (12 times) b. Vortex Inertial separation (12 times)
Acceleration Levels (g ± 10%)/ Duration	a. 10^{-3}/2.1 hr; 10^{-5}/2.1 hr; Coast/2.1 hr b. 10^{-3}/2.1 hr; 10^{-5}/2.1 hr; Coast/2.1 hr	a. 10^{-3}/2.5 hr; 10^{-5}/2.5 hr; Coast/2.5 hr b. 10^{-3}/2.5 hr; 10^{-5}/2.5 hr; Coast/2.5 hr c. 10^{-3}/4.5 hr; 10^{-5}/4.5 hr; Coast/4.5 hr d. 10^{-3}/2.5 hr; 10^{-5}/2.5 hr; Coast/2.5 h4	a. 10^{-3}/3 hr; 10^{-5}/3 hr; Coast/3 hr b. 10^{-3}/3 hr; 10^{-5}/3 hr; Coast/3 hr
Orientation Requirements	Parallel and perpendicular to acceleration vector	Parallel and perpendicular to acceleration vector	Parallel and perpendicular to acceleration vector
Contamination Limits	None	None	None
Potential Experiment Contamination	None	None	None
Instrumentation	Temp Press. Flow Accel Events	Temp Press. Flow Accel Humidity Events	Temp Press. Flow Accel Events
Cameras	Movie - 1, 120 fps	Movie - 1, 400 fps 1, 24 fps	Movie - 1, 24 fps
Remote Data Monitoring	None	None	None
Set-up & Shutdown	2 hr	8 hr	2 hr
Fluids Required	Air, water, glycol	Air, water, glycol	Air, water, glycol
Resupply Req.	None	None	None
Safety Considerations	Potentially toxic fluid	Potentially toxic fluid	-

volume and envelope, electrical power, physical environment, data requirements, crew skills, and other support necessary to accomplish the objectives of the experiments.

2.4 EXPERIMENT PROGRAM

The experiments included in the Fluid Management FPE, along with categorization of the experiments according to class, are tabulated in Table 2-5. A detailed description of each experiment is given in the sections which follow.

2.4.1 LIQUID/VAPOR INTERFACE STABILITY

2.4.1.1 Objectives. The primary objective of this experiment is to observe the behavior of fluid interfaces in tanks under extended low gravity environments. A secondary objective is to define bubble/ullage behavior in low-g environments in large tanks.

2.4.1.2 Description. The fluid dynamics tests in this experiment investigate fluid behavior phenomena which are encountered in spacecraft operation. The series of tests involve: (1) fluid transfer; (2) large amplitude sloshing; (3) liquid reorientation; (4) interface breakup; and (5) growth, motion and interaction of large bubbles in low-g. Tests are required to evaluate the effectiveness of various geometric shapes including baffles, conical surfaces, and screens for propellant control during various disturbances. Evaluation of the effects of these geometric shapes on fluid motion during

Table 2-5. Summary of Fluid Management Experiments

Experiment Number and Title	Classifications					
	Scientific	Engineering	Cryogenic	Non-Cryogenic	Heat Transfer	Fluid Dynamics
1. Interface Stability	X	X		X		X
2. Boiling Heat Transfer	X	X	X		X	
3. Capillary Studies		X		X		X
4. Condensing Heat Transfer		X		X	X	
5. Two-Phase Flow Regimes	X	X		X	X	X
6. Propellant Transfer		X	X		X	
7. Long-Term Storage of Cryogenics		X	X		X	
8. Slush Hydrogen		X	X		X	X
9. Two-Phase Dynamics	X	X		X	X	X
10. Channel Flow Systems		X		X	X	X
11. Conical Flow Systems		X		X	X	X

settling is also required. These tests will provide design data for low gravity baffle damping and settling paths for fluids under various g-levels. Additional tests will be performed to define the effects of gravity level on bubble motion and agglomeration, including interactions with the above geometric configurations. Rapid vent down from a settled saturated liquid condition will indicate mechanisms, velocities, and trajectories of liquid globules torn from the interface or entrained during venting. Freon 11 will be used for the latter runs at or near ambient laboratory temperatures.

These tests will be performed in three interconnected transparent tanks as shown by the conceptual drawing of Figure 2-1. The first tank will be spherical with outlets located on the centerline at the tank top and bottom. A screen channel reservoir will be located in this tank for zero-g fluid acquisition. The other two tanks will be cylindrical with similar outlets. The two cylindrical tanks will afford scaling evaluations. All three tanks will have gas pressurant inlets at the tank top. Plumbing and valving shall be designed to permit liquid transfer from any one tank to any other tank with the tanks serving as storage tanks for each other. The tanks will be designed to permit in-orbit installation and reconfiguration of internal baffles and screen retention devices for liquid-vapor interface inflow-outflow control. The tanks will be movable and will have oscillatory mechanisms to induce liquid sloshing. Additional equipment

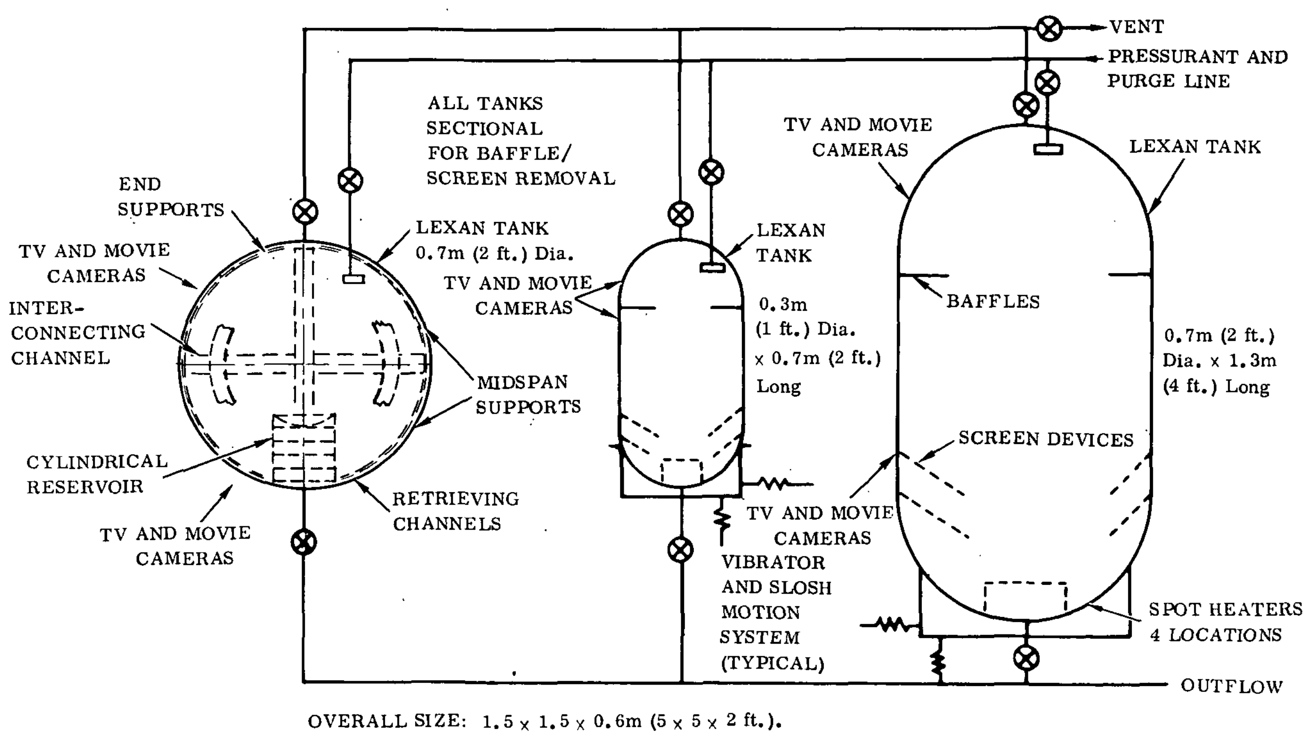


Figure 2-1. Interface Stability and Bubble Growth Experimental Setup

data are contained in Tables 2-1 and 2-2. The tanks and lines will be emptied and purged of test fluids prior to disassembly for changing the configuration of internal devices.

The low-g fluid transfer and interface stability problems are typified by the sketches shown on Figures 2-2 and 2-3, where the fluid phenomena associated with low-g fluid inflow and outflow are depicted.

2.4.1.3 Observation/Measurement Program. The flight test program will consist of a series of tests which require some hardware changes, refilling, pressure regulation, etc. Test setups, when completed, will allow a series of tests to be remotely controlled by manipulating console settings. The fluid transfer program, for example, will be conducted in two phases - one investigating the outflow process and the second studying the inflow phenomenon. The primary form of data will be the television record of observed phenomena. Two TV and two motion picture cameras are required for each of the three tanks. The details of the experiment measurements program are contained in Table 2-2.

2.4.1.4 Interface, Support, and Performance Requirements. The interface, support, and performance requirements for this experiment are contained in Table 2-6. Additional details are listed in Table 2-2.

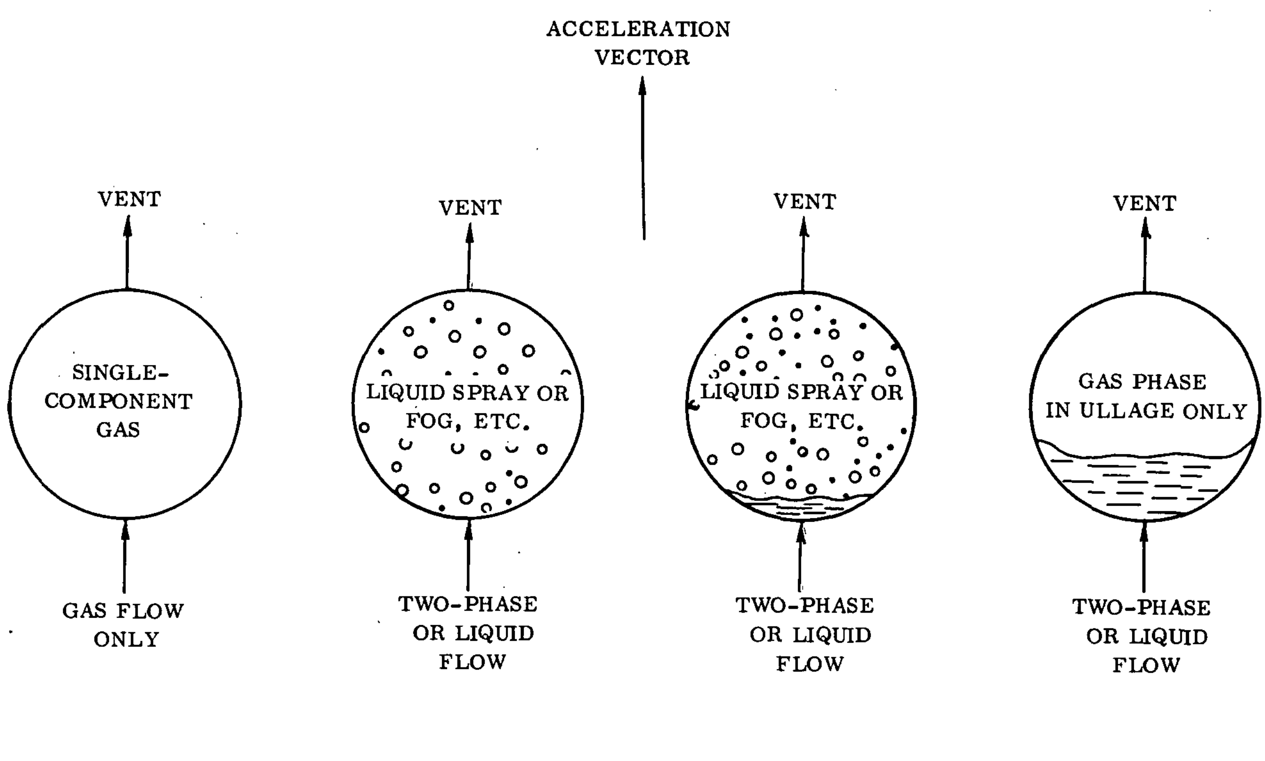


Figure 2-2. Sequence of Receiver Tank Fill Conditions Under Microgravity

2.4.1.5 Potential Role of Man. The experiment will require TV monitoring during the tests, and critical observation and comments from the astronaut remotely monitoring the experiment. Each test series is anticipated to require one astronaut's attention for a period of four hours. This includes hardware changes, test setup, test operation, and system shutdown time. Only a brief training period would be required for these tasks. Installation of baffles and capillary surfaces requires active participation. Each test run should be on the order of ten minutes or less, during which time up to ten observations may be obtained.

2.4.1.6 Available Background Data. A definite need exists for longer duration testing of interface dynamics. Project THERMO (References 2-1, 2-2, and 2-3) defined this as a primary experiment and major descriptive data have been taken from that source. Drop tower studies indicated the importance of this type of data in vehicle design (References 2-4 and 2-5). Analytical models have been developed for sloshing, but low-g verification data are required. Capillary devices for propellant outflow and control require orbital verification (Reference 2-6). The problem of liquid level rise has been treated analytically, but entrainment of liquid due to interface break-up remains unsolved (Reference 2-7). Bubble motion is being investigated in one-g and an analytical model has been developed (Reference 2-8). An alternate method to the use of spot heaters for vapor bubble generation would be to inject gas bubbles of the

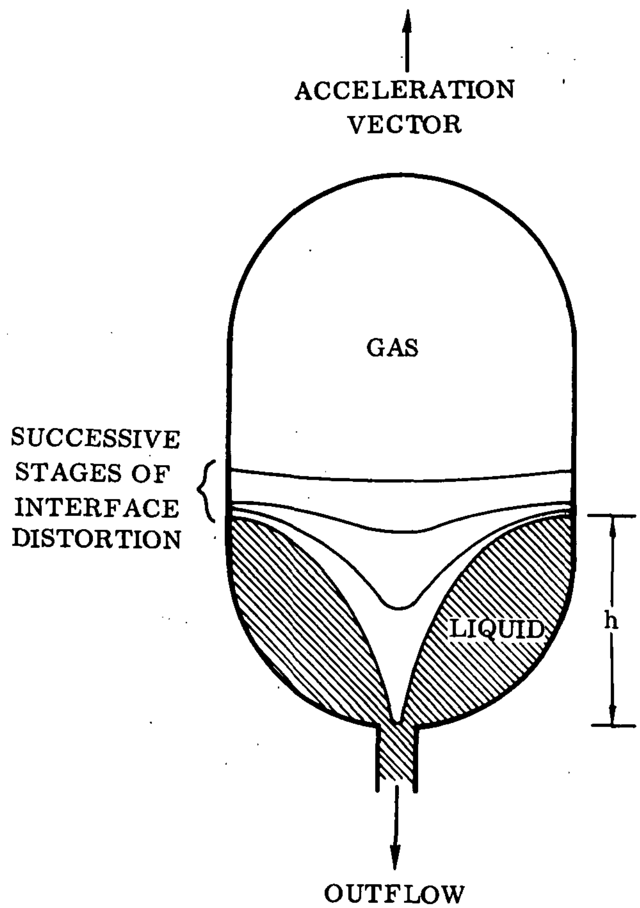


Figure 2-3. Gas Ingestion Due to Flow Into Outlet

evaporated propellant. However, heater gas bubble generators have been used successfully in the experimental portion of the gravity sensitivity study (Reference 2-8), and appear to be the better approach to bubble generation. Sufficient data exists for design of this experiment.

References

2-1 Thermo and Hydrodynamic Experiment Research Module in Orbit, Final Report, Contract NAS8-18053, Douglas Report DAC-60594, March 1967.

2-2 Project THERMO - Phase B Prime, Final Report, Contract NAS8-21129, Douglas Report DAC-60799, September 1967.

2-3 Results of a Preliminary Design & System Integration Study of Flying Several Cryogenic and Fluid Mechanics Experiments on an Unmanned Saturn IB for Long-Term Low-g Investigations, Contract SVD-3-67-002, LMSC/HREC A791322, March 1968.

2-4 L. Hastings, Experimental Study of the Behavior of a Sloshing Liquid Subjected to a Sudden Reduction in Acceleration, TM-X-53755, August 1968.

2-5 J. A. Salzman, An Experimental Investigation of Frequency and Viscous Damping of Liquids During Weightlessness, NASA TN D-4132, August 1967.

2-6 Low-Gravity Propellant Control Using Capillary Devices in Large Scale Cryogenic Vehicles, Contract NAS8-21465, Convair Division of General Dynamics Corporation, October 1968.

2-7 Evaluation & Application of Data from Low-Gravity Orbital Experiment, Contract NAS8-21291, Convair Division of General Dynamics Corporation, Report GDC-DDB-70-003, April 1970.

2-8 Gravity-Sensitivity Assessment Criteria Study, Contract NAS1-8494, NASA CR-66945, Convair Division of General Dynamics Corporation, June 1970.

2.4.2 BOILING HEAT TRANSFER

2.4.2.1 Objectives. The objectives of this experiment are:

a. To obtain data to provide a fundamental understanding of boiling phenomena and thermal stratifications in low-g.

b. To obtain boiling curves $q = f(\Delta T)$ for LH_2 for a range of g-levels from 10^{-3} to 10^{-5} g for characteristic surfaces and a heat flux range of 0.0315 to 15,760 W/m^2 (0.01 to 5000 Btu/ft^2hr).

c. To obtain data on interface dynamics of liquid hydrogen during the venting process.

2.4.2.2 Description. The equipment to be used in conducting the boiling heat transfer experiments is shown in schematic form in Figure 2-4. A 1 m dia. x 2 m long (3 x 6 ft) cylindrical tank with hemispherical ends is to be used. Three TV and four movie cameras and necessary lamps for lighting are to be used to obtain visual data. The tank will have vent and pressurization capability to maintain the desired saturation level in the tank. The tank will be insulated with HPI to minimize external heat leaks. Two heater orientations are to be used: horizontal and vertical flat plates.

During the boiling process, bubble formation will be photographed using a 4000 frame per second (fps) camera, and bubble motion away from the plate will be observed with TV and photographed with 400 fps cameras. Container walls should be sufficiently distant from the boiling plate to allow bubble travel normal to the gravity vector until buoyancy forces are dominant and cause the bubbles to move parallel to the wall. Figure 2-5 presents the results of a typical bubble dynamics profile generated from a

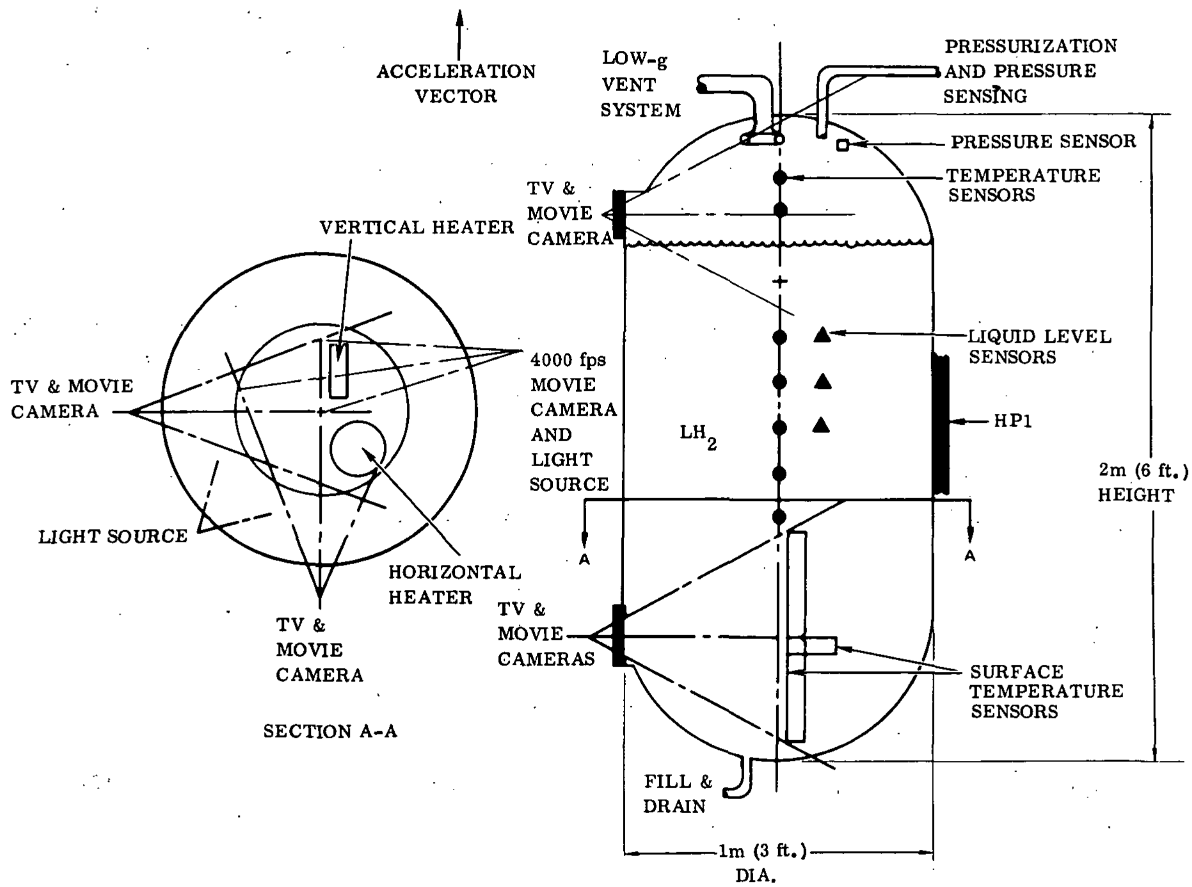


Figure 2-4. Boiling Heat Transfer Experiment

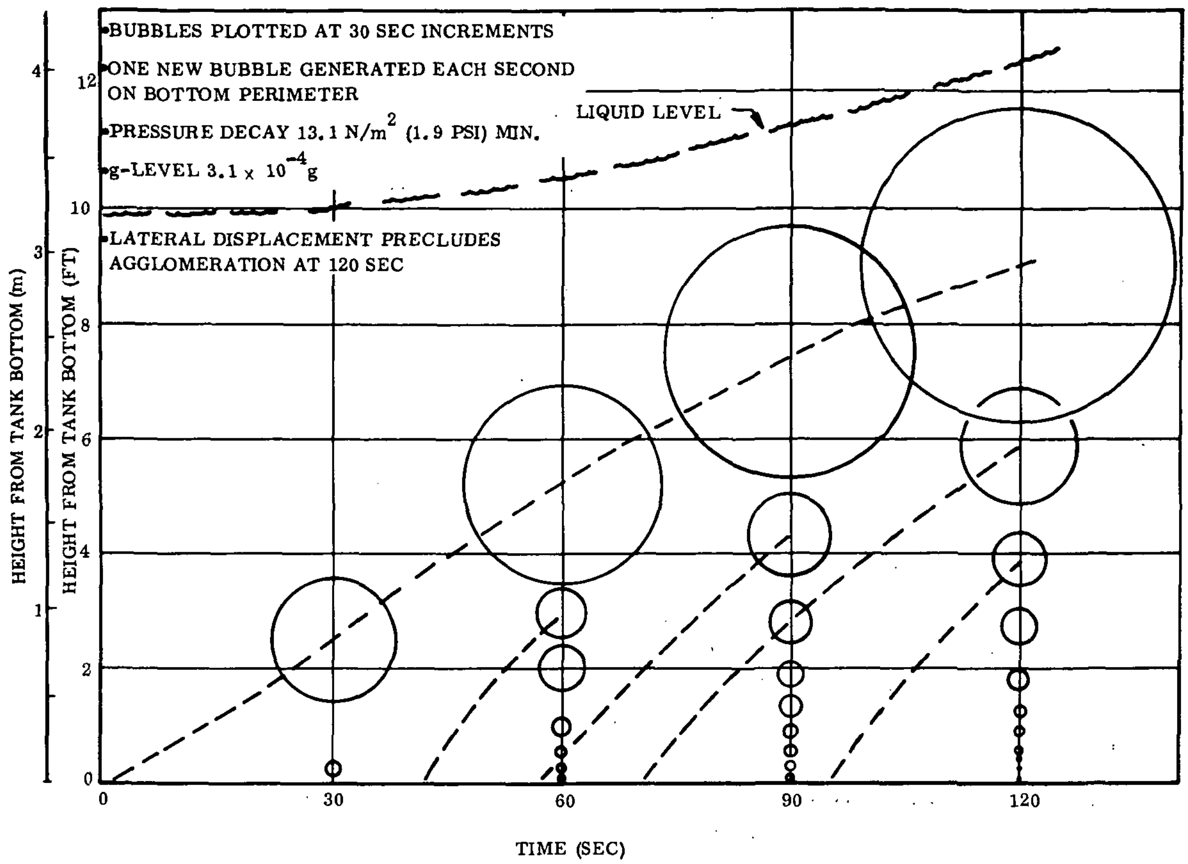


Figure 2-5. Bubble Dynamics Simulation Result

computer simulation of hydrogen bubble rise during the vent down of the hydrogen tank of the Saturn AS-203 orbital vehicle. This experiment will provide data to evaluate the accuracy of such bubble motion prediction programs.

Experiments will be run at both saturated and slightly subcooled conditions. From the boiling curves (heat flux versus ΔT, the difference between the surface temperature and the saturation temperature) the peak heat flux and nucleate boiling regimes will be defined. Typical boiling curves are shown in Figure 2-6. Primary interest lies in the definition of the point of incipient boiling and the region below this point in the natural free convection area. The incipient boiling point will be identified by the sharp change in slope of the experimentally determined boiling curve, as noted in Figure 2-6. The effects of heater surface characteristics, pressure, and the degree of subcooling will also be determined from these experiments.

2.4.2.3 Observation/Measurement Program. A proposed test plan requiring 150 hours is outlined herein. For more extensive specification of test conditions, consult Table 2-2 and Reference 2-9. Each test series is identified as to orientation and liquid condition and is composed of runs at several discrete heat fluxes.

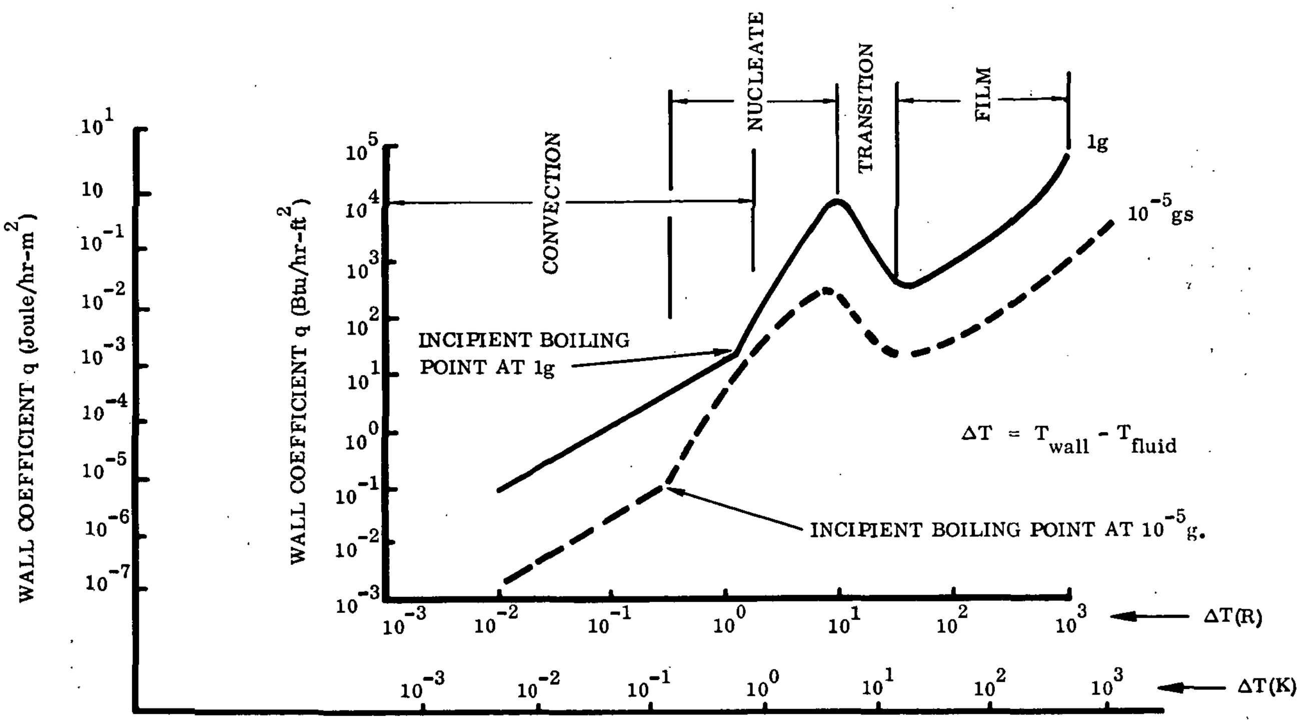


Figure 2-6. Typical Heat Transfer Coefficients and Boiling Regimes

This 1 x 2 m (3 by 6 ft) tank containing liquid hydrogen provides an excellent opportunity to investigate cryogenic fluid interface break-up. The lower cameras will record liquid behavior to indicate bulk boiling during a ventdown, while the upper ullage cameras will indicate the magnitude of entrainment. These tests will supplement the non-cryogenic fluid tests in the interface stability experiment of Section 2.4.1.

Instrumentation for the nucleate boiling test includes temperature and pressure measurements in the liquid hydrogen and ullage volume, heater power, plate temperatures, and acceleration levels.

2.4.2.4 Interface, Support, and Performance Requirements. Coriolis forces are undesirable in the vertical heater tests; any rotational velocity must be limited to some prescribed value. Instrumentation display requirements for the astronaut will consist of TV monitors, a control panel showing boiling test measurements, and a panel showing miscellaneous tank environment data. Additional requirements are contained in Table 2-2.

2.4.2.5 Suggested Role of Man. The astronaut's tasks consist of turning the heater on, monitoring tank pressure, temperature (as well as the heater temperature) and liquid level, determining when a steady state heater temperature has been reached, turning on the lights and cameras, readjusting the heater power, repeating this procedure for a prescribed number of times, and then turning off the heater. Each individual experiment requires active participation only when steady state has been reached. In properly monitoring and controlling the experiment, the astronaut must be assured that the test heaters are functioning properly and must be continually informed of their operation. To determine steady state, the astronaut must periodically observe the heater temperature. Hence, a temperature indicator should be available for each heater or one indicator with a switching device to either heater. Since the steady state condition must be recognized by the astronaut, a strip chart recorder or equivalent display will be necessary. Visual observation is required to control photography. Therefore, the astronaut must periodically observe the TV monitors in addition to controlling the motion picture cameras and lights.

2.4.2.6 Available Background Data. Interest in heat transfer to boiling cryogenic fluids has increased rapidly primarily because of the growing number of space applications. Since cryogenic boiling is characterized by small temperature driving forces and small heat fluxes, cryogens storage and transfer usually involves boiling and the associated problems of vapor removal, tank pressure control, tank boilover, etc. While these conditions may be looked at by a space vehicle designer as undesirable and complicating, other aspects of cryogenic boiling are desirable for heat transfer equipment design. For instance the direct transition of nulceate boiling to stable film boiling without exceeding burnout temperatures for many materials affords the design of high power density evaporators such as may be used in life support and cooling equipment.

However, theory and limited experimentation show dependence of the boiling phenomena on the local acceleration and, thus, detailed studies are required to understand the influence of the gravity forces on the mechanism of boiling. The experiment is considered a high priority fluid management study because of its emphasis on understanding boiling phenomena and its importance in design. Much of the data presented here results from PROJECT THERMO (References 2-9, 2-10, and 2-11). A pilot test program was reported in Reference 2-9. Macroscopic boiling data were also obtained from the orbital flight of the Saturn AS-203 vehicle. These test results are presented in References 2-12, 2-13, and 2-14.

A particularly difficult task during an experiment as described above is obtaining satisfactory motion picture coverage of the boiling phenomena to completely determine the vapor bubble trajectories and agglomeration rates. Studies have been conducted for NASA by Convair Division of General Dynamics as part of the Gravity-Sensitivity Assessment Criteria Study which show that a camera framing rate of 400 frames/second is adequate to record bubble trajectory and agglomeration data in a one-g environment. This framing rate should be more than adequate under the reduced gravity environment of the orbital experiment (Reference 2-15). In addition, a motion picture camera operating for brief periods at 4000 frames/second will be employed for observing bubble formation. Appropriate lighting will be provided as well.

This experiment specifies the use of high-performance insulation (HPI), but also specifies various holes cut in it for cameras and lights. Results of the Project Thermo Study indicate that these specifications can be made compatible, but will require considerable design care.

References

2-9 Thermo and Hydrodynamic Experiment Research Module in Orbit, Final Report, Contract NAS8-18053, Douglas Aircraft Company, DAC-60594, March 1967.

2-10 Project THERMO - Phase B Prime, Final Report, Contract NAS8-21129, Douglas Aircraft Company, DAC-60799, September 1967.

2-11 Results of a Preliminary Design and System Integration Study of Flying Several Cryogenic and Fluid Mechanics Experiments on an Unmanned Saturn-1B for Long-Term Low-G Investigations, Contract SVD-3-67-002, LMSC/HREC A791322, March 1968.

2-12 Saturn S-IVG-203 Stage Flight Evaluation Report, Volume II, Douglas Report SM-46988, March 1967.

2-13 Evaluation of AS-203 Low Gravity Orbital Experiment, Chrysler Report HSM-R-421-67, 13 January 1967.

2-14 Evaluation and Application of Data from Low-Gravity Orbital Experiment, Convair Report GDC-DDB-70-003, 1 April 1970.

2-15 Gravity-Sensitivity Assessment Criteria Study, Convair Division of General Dynamics Corporation, NASA CR-66945, June 1970.

2.4.3 CAPILLARY STUDIES

2.4.3.1 Objective. The objective of these experiments is to obtain basic information on the performance of capillary devices in a low gravity environment. Wicking is of primary interest in low gravity since the high wicking rates present are difficult to simulate under normal gravity conditions. The analytical solution for wicking under the high velocity and acceleration conditions anticipated in low gravity is considerably more complex than the approximate solution which correlates well with earth gravity data.

2.4.3.2 Description. Wicking experiments will be run in a transparent test enclosure as shown in Figure 2-7. Figure 2-8 shows flow schematic of test setup. The wick is connected to a heating element which is insulated in order to direct all the heat generated into the wick being tested. The heating element is calibrated on the ground so that for given power input to the system, the heat input to the wick is known. The wicking material is held in position in the test enclosure by a clamp connected to the heater element outside the enclosure. Depth of wick immersion in the liquid reservoir is varied by sliding the heating element up and then clamping in the desired position by visually noting the position of the bottom of the heater element with respect to the height gage mounted in the test enclosure.

The fluid reservoir feed system is designed to provide a continuous supply of liquid for the wick while maintaining the reservoir full of liquid. This system consists of three large storage tanks containing collapsible bladders, a pressurant tank, an inlet manifold, and individual shutoff valves. A single valve from the manifold is used to shut off the entire feed system. Following the completion of each series of experimental runs with one test fluid, the fluid reservoir and experiment enclosure will be completely purged of residual fluid before the next series of test is begun. Purging can be accomplished by alternately exposing the test article to the space vacuum to boil off residual liquid and then charging with the inert pressurant gas for dilution of any residual gases.

Alternate methods of conducting the capillary studies experiments can be devised if resupply is possible. The fluid storage tanks can be made significantly smaller thus reducing the weight of the experimental hardware if test fluids are resupplied after

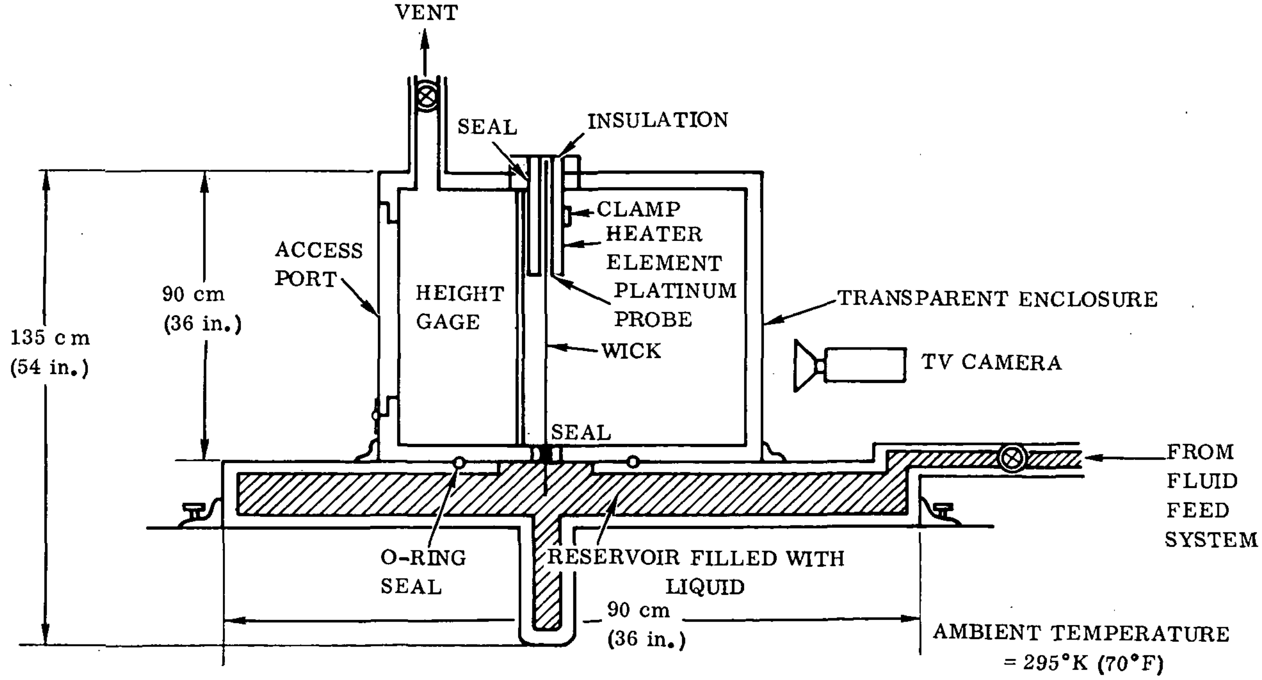


Figure 2-7. Wicking Test Setup

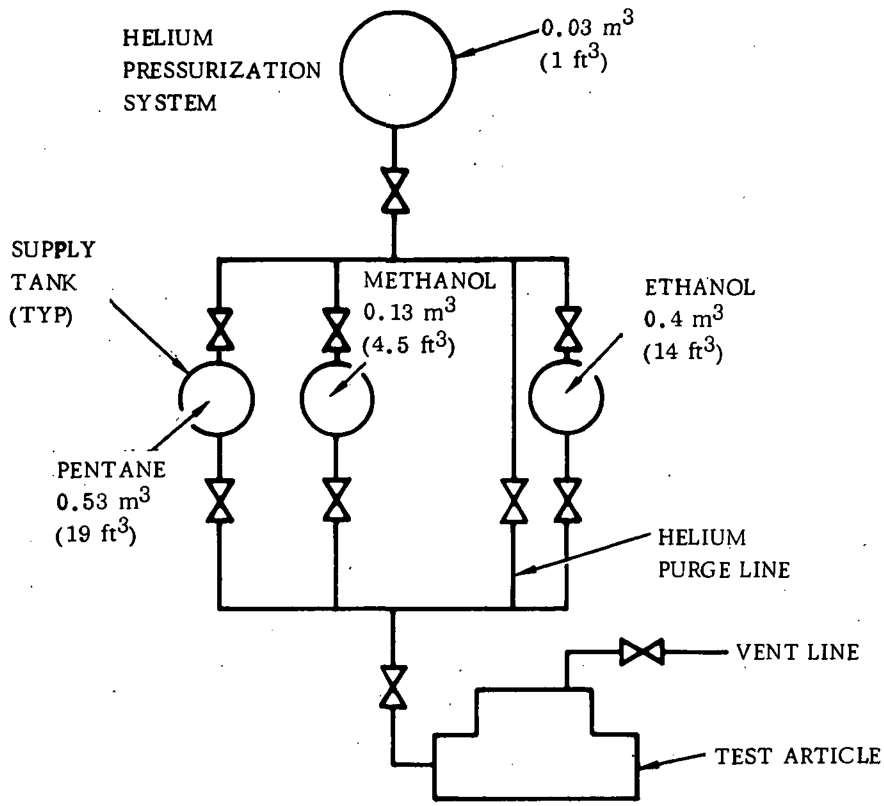


Figure 2-8. Flow Schematic of Wicking Test Setup

each series of experiments. In addition, it is possible to modularize the experiment by utilizing only one test fluid supply tank at a time and completing a full test sequence before replacing the tank with the next fluid container for another test sequence. The alternate methods of test operation can be used where weight or volume limitations exist on the carrier vehicle.

2.4.3.3 Observation/Measurement Program. A detailed description of the measurements program is contained in Table 2-2.

2.4.3.4 Interface, Support and Performance Requirements. The interface, support and performance requirements for this experiment are contained in Table 2-6. Additional requirements are contained in Table 2-2.

2.4.3.5 Potential Role of Man. An astronaut will monitor specimen temperature, adjust enclosure pressure, change wick sample, control heater power, adjust wick heights, fill and maintain uniform liquid level in reservoir, turn on TV camera and lights and observe when vapor is formed at the top of the screen. The TV image and other test parameters will be recorded for later analysis. The astronaut will monitor and control g level during test runs.

2.4.3.6 Available Background Data. Tests by Ligenza and Bernstein (Reference 2-16) have indicated that several terms in the generalized capillary flow equation can be neglected at low wicking velocities. This enables a closed form solution to be obtained by dropping out momentum change and end drag terms. In low gravity, anticipated wicking velocities will be high enough to cause these terms to be significant. This complicates the solution considerably. Efforts are being made (Reference 2-17) to numerically obtain a solution to these equations.

Normal gravity tests are to be run to simulate the high velocities occurring in low gravity. This will provide concrete background material for an orbital experiment. Information obtained will provide basic scientific knowledge of capillary flow, and will be useful in engineering design and analysis of heat pipes and surface tension propellant control systems.

References

2-16 Joseph R. Ligenza and Richard B. Bernstein, "The Rate of Rise of Liquids in Fine Vertical Capillaries," Journal of the American Chemical Society, Volume 73, October 1951.

2-17 M. H. Blatt, et al. "Low Gravity Propellant Control Using Capillary Devices in Large Scale Cryogenic Vehicles," Third Quarterly Progress Report, NAS8-21465, 584-4-288, April 20, 1969.

2.4.4 CONDENSING HEAT TRANSFER

2.4.4.1 Objectives. The objectives of the condensing heat transfer experiment are to investigate condenser fluid dynamics and heat transfer under conditions of zero gravity, and to study the perturbations caused when a condenser is subjected to a sudden axial acceleration field in a zero-gravity environment.

2.4.4.2 Description. The experiment package is self-contained to permit detached, remote operation in order to achieve the required g-level control. The package includes the fluid system for providing the desired phenomena and a remote positioning camera package for visual control and recording. The package is shown in Figure 2-9.

The fluid system is composed of three loops employing Freon 114B2 as the test fluid. A schematic diagram of the system is shown in Figure 2-10. In the test fluid loop, the Freon 114B2 is vaporized in an electric boiler and is condensed in a four-tube transparent condenser. The accumulator in the test fluid loop uses GN_2 at a regulated pressure to change the condenser loop pressure level. The test condenser consists of three constant diameter tubes and one tapered tube. On each of the four condenser tubes there is a valve so that the tube may be turned on or off. One of the constant

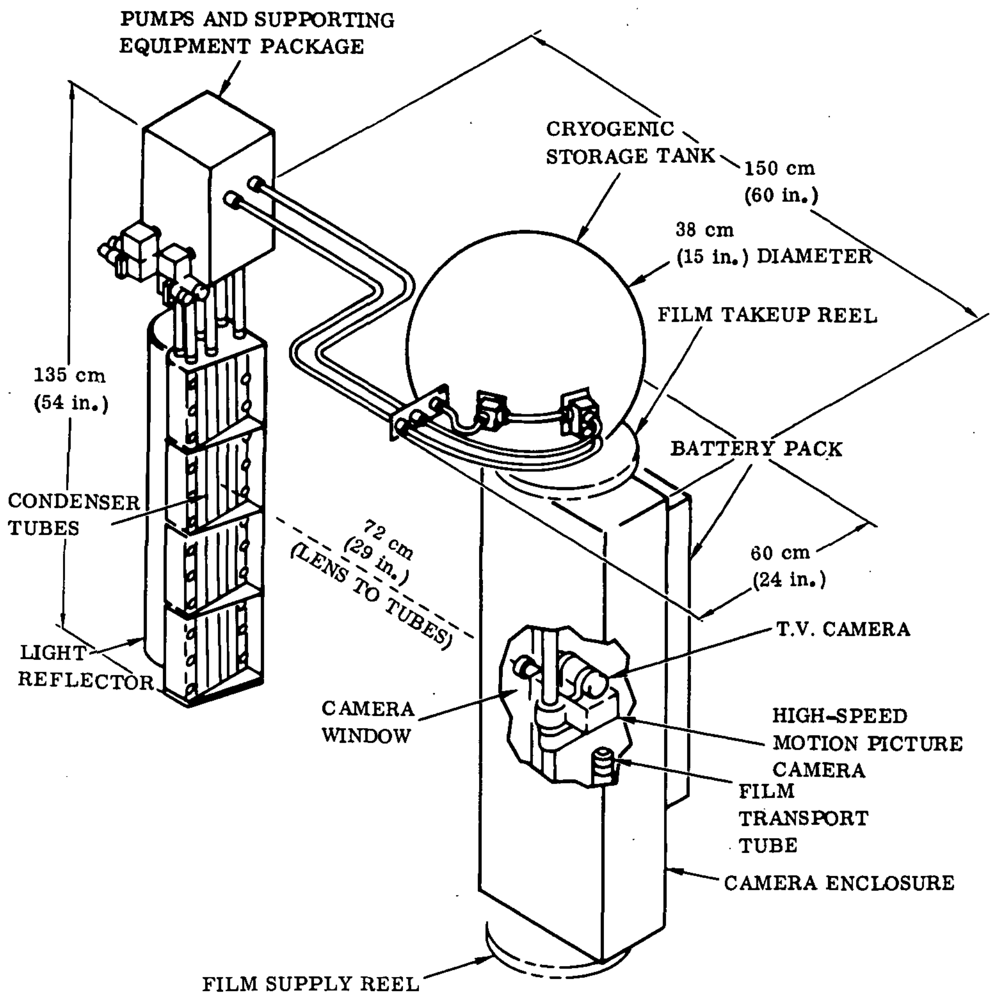


Figure 2-9. Experimental Condensing System

diameter tubes is provided with temperature and pressure sensors along its length to obtain local heat transfer and pressure drop data. A schematic diagram of the test condenser and its instrumentation is shown in Figure 2-11.

The heat of condensation is picked up by a Freon 21 heat transport loop, which couples the test condenser to an expendable cryogenic heat sink system. In the coolant heat exchanger, which consists of two concentric stainless steel tubes, the cryogen flows in the inner tube parallel to the flow of Freon 21 in the annulus. The Freon 21 rejects the heat which it absorbs in the test condenser to the cryogen, which is then exhausted to space.

In the cryogenic loop (nitrogen will most likely be used), the pressure in the storage vessel is maintained at a constant value during the period of the experiment. The flow rate in the coolant heat exchanger is controlled to give the desired temperature of Freon 21 at the inlet of the condenser tubes. This is necessary to satisfy the condition of a uniform heat flux along the condenser tubes.

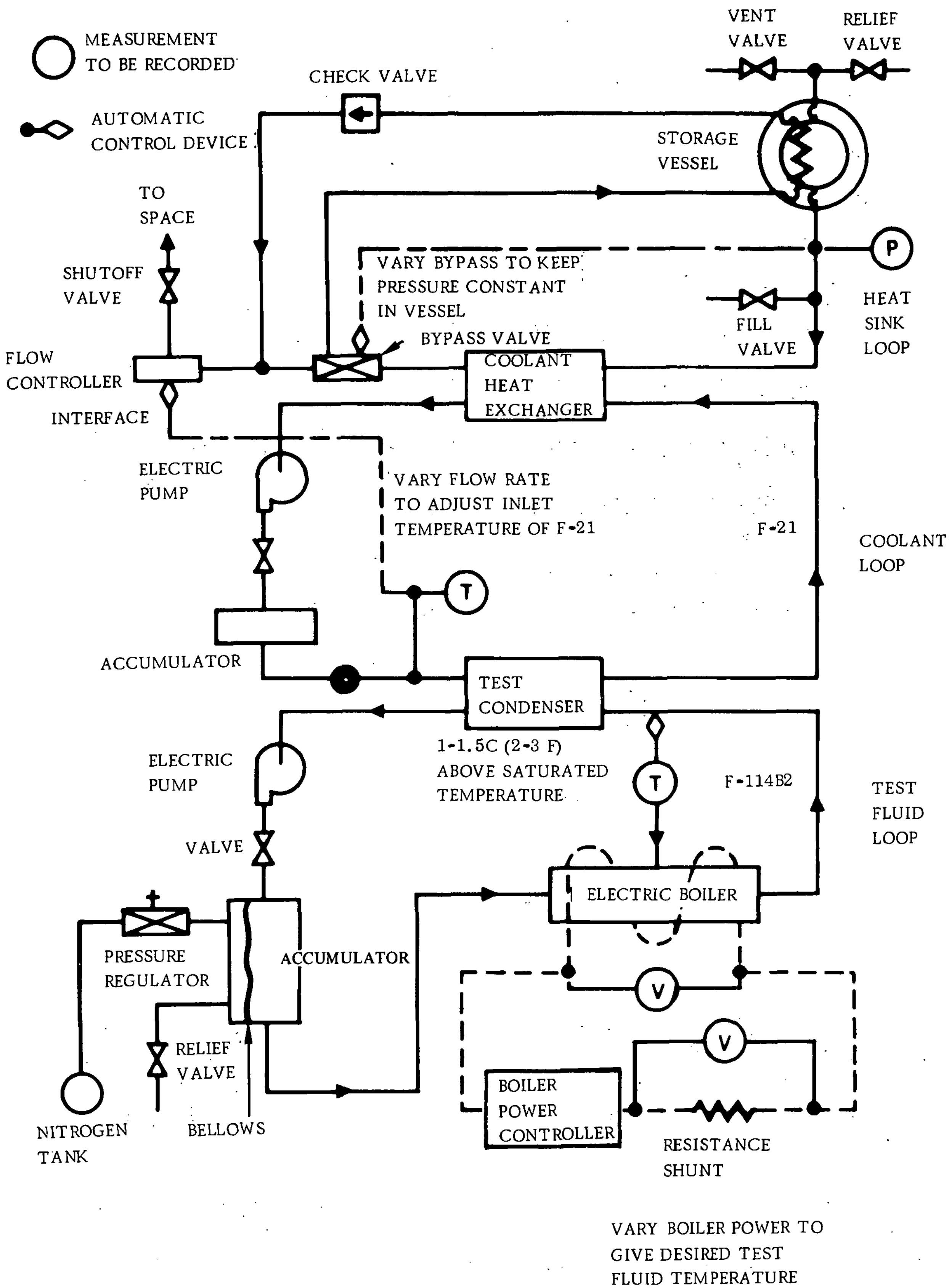


Figure 2-10. Condensing System Schematic

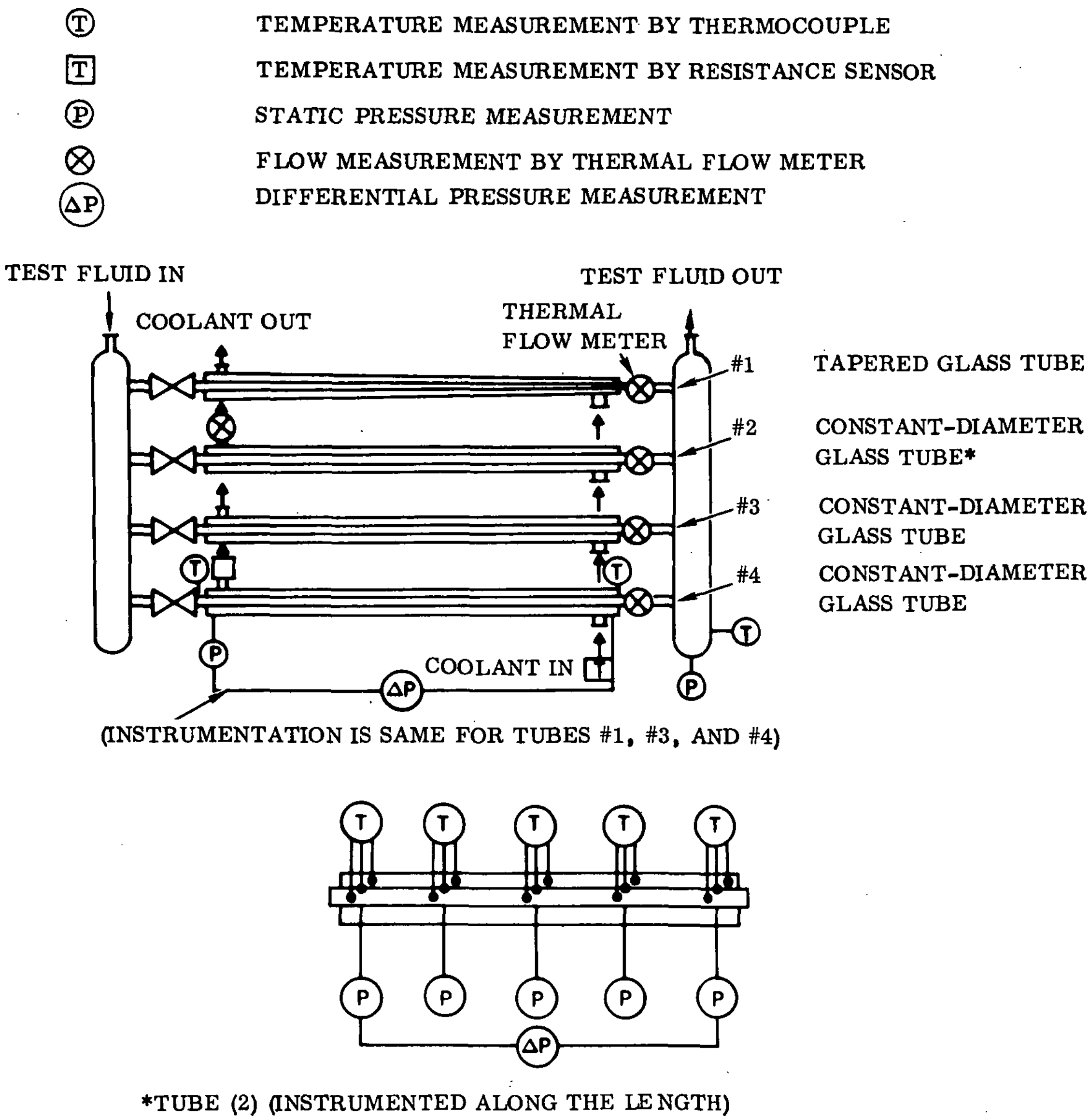


Figure 2-11. Condenser Instrumentation

The TV and motion picture cameras and the mechanism for moving them laterally along the condenser length are contained in a pressurized compartment, which is attached to a vertical structural member opposite the condenser package. The camera movement is accomplished with a motor-driven lead screw and support is provided by a track and bearing arrangement.

2.4.4.3 Observation/Measurement Program. The heat transfer study consists of the measurement of the local as well as the mean condensing heat transfer coefficients. The study of the condenser fluid dynamics consists of measuring local as well as overall pressure drops along the condensing length, investigating condenser flow stability due to runback of the condenser film, and investigating the dynamics of vapor-liquid interface and flow distribution.

The experiment is divided into five operating modes based on commonality of operating conditions and optimum sequencing. Modes I and II are run to investigate multitube condenser flow stability and flow distribution in low-g. Modes III and IV are intended to study the performance of a tapered tube compared to a constant-diameter tube under conditions which are believed to produce run-back and flow instability in the latter tube. Local pressure and heat transfer data will be recorded in all modes, but Mode V will be specifically devoted to these measurements. It will also include a repetition of an earlier run to serve as a check point.

Ground based testing will be run in conjunction with the orbital testing to provide correlation of the ground and orbital results, but over a much broader range.

2.4.4.4 Interface, Support, and Performance Requirements. The experiment, as currently designed, is self-contained and only depends upon the carrying vehicle for structural support and housing volume, g-level control, electrical power, command and control, and data handling (including signal conditioning as required).

In addition, the following support is required by the experiment:

a. Crew Support — One astronaut is required full time during the five-hour test; however, remote operation is currently planned except for film retrieval.

b. Preparation by the astronaut merely includes remote control switching and observation procedures to:

    1. Bring telemetering and data handling equipment on-line.
    2. Assure that electrical power and cryogenic fluid for cooling are available.
    3. Start up the experiment package pumps, instrumentation, lights, TV camera, etc.

c. Experiment execution will typically require the crewman to remotely:

    1. Set flow, pressure and temperature controls for the run being executed.
    2. Observe when system achieves steady-state operation.
    3. Make final trim adjustments.
    4. Switch TV and instrument recorders on.
    5. Adjust camera to look at one-third of length of tubes.
    6. Start high-speed movie camera.
    7. Apply five-second axial acceleration thrust pulse.
    8. Shut off high-speed movie camera.

9. Allow system to return to steady state.

10. Switch off TV and instrument recorders.

d. Post-experiment procedure will require film retrieval. Data will be reduced on the ground.

e. Skills Required — Electromechanical Technician and Thermodynamicist.

2.4.4.5 Potential Role of Man. Man is primarily required to observe and adjust flow, pressure, and temperature conditions to produce the desired condensing. He will determine when steady state conditions are satisfied and initiate photographic recording at this time.

2.4.4.6 Available Background Data. The experiment described in this section was formulated under Contract NAS8-21005; Analysis, Criteria Development, and Design of an Orbital Condensing Heat Transfer Experiment, Final Report, Vol. I, Report No. 67-1797-1 AiResearch Mfg., Los Angeles, Calif., March 25, 1967.

2.4.5 TWO-PHASE FLOW REGIMES

2.4.5.1 Objective. The objective of this experiment is to define the effect of gravity on the flow regimes characterizing two-phase flow. Pressure drop, heat transfer, and hydrodynamic stability of two-phase flow depend upon a definition of the regimes, which are gravity sensitive. Additionally, the hold-up characteristics of packed beds are affected by body forces, therefore their performance must be assessed to determine the design data required for future spacecraft life support equipment processes.

2.4.5.2 Description. The experiment apparatus shown in Figure 2-12 consists of a flow loop with a condensible liquid and its vapor. Tests will be conducted with two different, interchangeable test sections, i.e., a cylindrical duct and a porous bed. A mixer section will be provided immediately preceding the test section. The 60 cm (2 ft) long test section will be a 5 cm (2 in.) I.D. plexiglass cylindrical pipe or a 5 cm (2 in.) square section filled with 1 mm glass beads packed and contained between supports at the test section ends. The experiment will be so mounted as to permit tests in three directions corresponding to upflow, downflow, and horizontal in the g-field.

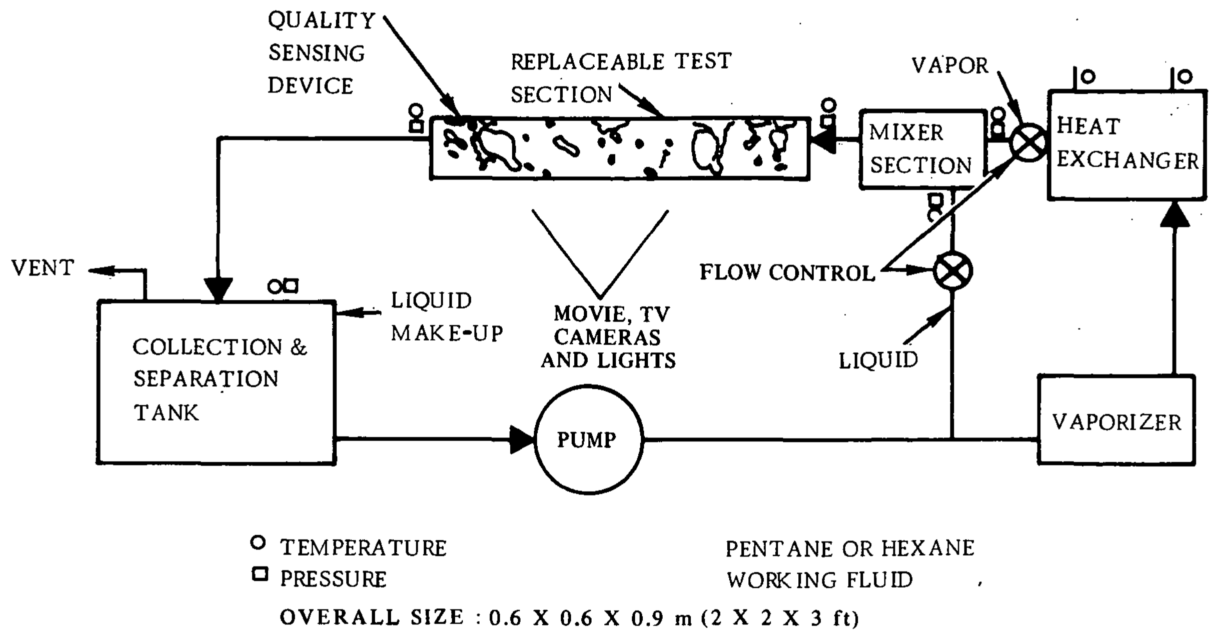


Figure 2-12. Two-Phase Flow in Porous Beds

A variable flow rate pump will provide a range of mass velocities. The heat exchanger will insure control of the vapor temperature to provide saturated vapor at the mixer inlet. Flowmeters and control valves will enable the crewman monitoring the experiment to make adjustments as required to define the transition points in the various flow regimes.

The support requirements for the experiment are summarized in Table 2-1.

2.4.5.3 Observation/Measurement Program. Primary evaluation data from this experiment will be contained in the visual records and in the corresponding temperature and pressure measurements. The visual records will consist of TV tape recordings and brief coverage with a movie camera at 400 fps. Recent investigators have indicated that a wall-mounted pressure transducer with 100 Hz response will provide a definitive evaluation of pressure fluctuations in the flow. The test section pressure transducers must have high frequency response and must be continuously recorded when a test is in progress. The details of the measurement program are contained in Table 2-3.

2.4.5.4 Interface, Support, and Performance Requirements. Continuous recording is required of two pressure measurements, while the remainder of the data can be sampled at one sample/second. Eight minutes of movie coverage at 400 fps is required, which results in 1350 m (4400 feet) of film. TV monitoring is required, with a TV tape for two hours of coverage. Additional requirements data are given in Table 2-3.

2.4.5.5 Potential Role of Man. Man is required in this experiment to establish the various flow regimes where data is to be recorded. The individual must be trained to be proficient in identifying the flow regimes and in adjusting the flow controls to achieve the maximum data possible. He will monitor the system and add make-up fluid as necessary. He may change the apparatus posture to modify the acceleration vector with respect to the test section. The man in the loop will make the decision on when steady state is achieved and when to perform movie coverage.

2.4.5.6 Available Background Data. The characterization of flow fields in two-phase flow is yet an art. Current design of major items of space hardware necessarily involves assumptions relative to two-phase flow. Designers of life support hardware have a major interest in data on two-phase fluids in low-g. The application of data pertaining to flow in porous beds extends to water treatment and reclamation, semipermeable membranes, porous plate fuel cells and nuclear reactor design. An analytical and experimental study was recently completed at the University of Alabama investigating two-phase flow in porous beds to define gravity sensitivity (Reference 2-18). Another NASA-funded study is currently in progress at Convair to examine gravity-sensitivity in the definition of two-phase flow regime characteristics (Reference 2-19).

References

2-18 H. Henry, Two-Phase Flow and Heat Transfer in Porous Beds Under Variable Body Forces, Contract NAS8-21143, University of Alabama, September 1969.

2-19 J. Burnett, Gravity Sensitivity Assessment Criteria Study, NASA CR-66945, Contract NAS1-8494, Convair Division of General Dynamics Corporation, June 1970.

2.4.6 PROPELLANT TRANSFER IN SPACE

2.4.6.1 Objectives. The primary objective of this experiment is to obtain fundamental data on the fluid mechanics, fluid dynamics and thermodynamics associated with propellant transfer under low-gravity conditions. The data obtained will be used to develop design criteria for orbital transfer systems as well as to advance the general understanding of low-g fluid behavior.

The design criteria and operational procedures necessary to reliably effect the transfer of propellant from a source tank to a receiver tank in a reduced gravity environment are essential to a NASA integrated space program. There are several interrelated hydrodynamic and thermodynamic disciplines and/or parameters which must be isolated and assessed to determine the relative influence of potential configuration design drivers. The interrelationship of the parameters is illustrated by the application of technical disciplines to either the source or receiver tanks. This arrangement also denotes disciplines as primarily hydrodynamic or thermodynamic. The hydrodynamic and thermodynamic disciplines of source and receiver tanks must be integrated into a system capable of effecting fluid transfer in orbit.

A detailed model of the propellant transfer process will be developed to evaluate overall system performance. Individual problems for which data will be provided are: line and tank chilldown efficiency, fluid control in receiver and supply tanks, and overall performance of an integrated system. A measure can be made of the surface tension system capability to acquire vapor-free liquid in a low-gravity environment. This information will enable an optimization to be made of various transfer techniques.

2.4.6.2 Description. The test system and operating procedures are designed to provide data on chilldown efficiency, inlet inertia control, propellant acquisition, suction dip and integrated system performance. The test system configuration is shown in Figure 2-13. A total of 27 transfers between the three tanks is planned. Use of cylindrical tanks with hemispherical ends will provide data applicable to most anticipated vehicles. The larger tank will be used to investigate the effect of size. Analysis shows that tank size should have a significant effect on receiver tank thermodynamics. The larger tank is approximately twice the volume of each of the smaller tanks.

In general, the experiment will use pumps and pressure to transfer LH_2 alternately between the three superinsulated tanks under varying g loads with both vented and nonvented receiver tanks. Tests will be accomplished with various inlet configurations as indicated in Figure 2-13 at different flow rates and with several different initial wall temperatures.

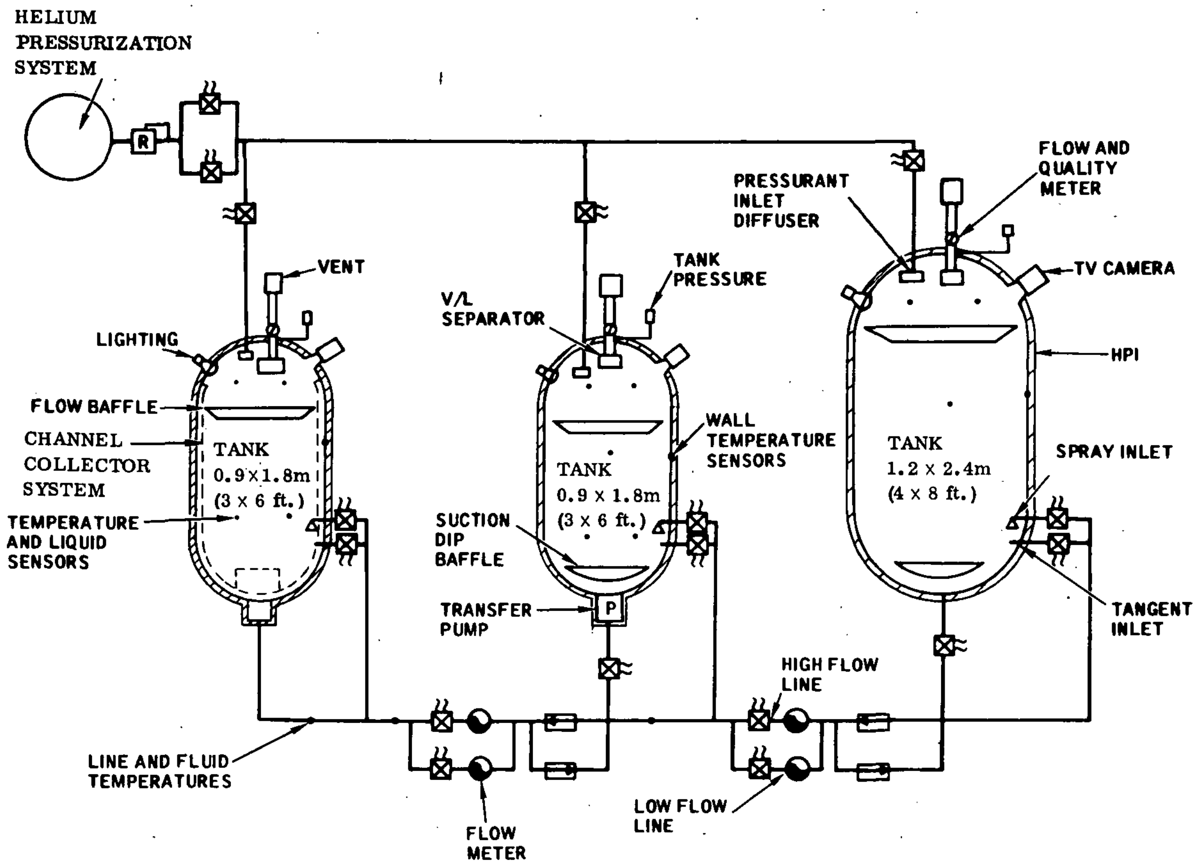


Figure 2-13. Propellant Transfer Test Schematic

The following steps comprise the basic transfer sequence and are applicable to every run:

a. Heatup – The tank walls are heated so that a chilldown test may be performed. The astronaut should be provided with capability for manual override, based on skin temperature readings, in case of malfunction of the automatic controls.

b. Settling – Prior to the start of the transfer, it is necessary to ensure that propellant is settled in the supply tank because control will not be maintained during the heat-up sequence. Cameras and instrumentation are turned on automatically at this time. The settling sequence is terminated by the astronaut, based on TV observations.

c. Slosh Reduction – Because settling should be carried out at a relatively low g level to minimize ullaging propellant use, a significant slosh wave may persist at the conclusion of the settling sequence. If this is the case, the astronaut may elect to use the slosh-reduction sequence, which involves manual firing of highest level of thrusters available at minimum slosh wave amplitude, followed by a switch to experiment level thrusters at maximum wave amplitude.

d. Chilldown – This sequence is initiated manually at the conclusion of the settling or the slosh-reduction sequence. On initiation of chilldown by the astronaut, the appropriate pressurization, vent, and transfer systems are activated automatically. Completion of chilldown is determined automatically by temperature-sensing devices. The astronaut should have the capability to override the automatic controllers, based on his readings of wall temperatures.

e. Bulk Transfer – On indication that chilldown has been completed, the appropriate changes to the pressurization and transfer systems are made automatically to provide the flow rate desired for bulk transfer. The bulk transfer sequence is terminated by the astronaut when he observes (on TV or transfer flow meter reading) the ullage pull-through.

f. Suction Dip Residual Reduction – This sequence is to be initiated by the astronaut if the observed residual is larger than about 1%. This observation will be based on whether visual reference markers at the bottom of the tank are covered with liquid. Transfer at the lowest flow rate would be initiated and would be terminated manually on observation of ullage pull-through.

Experiment run times are presented in Table 2-1 showing a total time for this experiment of approximately 48 hours. Experiment time parameters are summarized below:

Test Durations and Acceleration Requirements

Event	Acceleration Level (g)	Total Time (hours)
Maximum-g testing	10^{-3}	7
Medium-g testing	10^{-4}	1
Low-g testing	10^{-5}	7
Tank Heating and Vent Down Between Tests	Orbital Drag (i.e., 10^{-6} to 10^{-9})	33

2.4.6.3 Observation/Measurement Program. A list of measurements required for the test program is presented in Table 2-3. Chilldown efficiency will be determined from measurements of flow rate into and out of the receiver tank. Vent exit temperature will also be monitored to obtain heat transfer rates and vent quality will be monitored to indicate the amount of liquid entrainment. Ullage temperature, liquid sensing and visual data will be taken to help follow the chilldown process. Line chilldown will also be monitored through temperature probes and flow measurements.

Flow meter data will be used to determine when pullthrough occurs and integration of flow rates will yield percent residual. Liquid surface shape, needed for analytical model verification, will be obtained from visual data and from temperature probes and liquid sensors suspended inside the tanks.

Visual data will be used primarily to study the inlet inertia of the propellant.

Essentially continuous data recording will be accomplished during actual transfer testing. This time is estimated to be approximately 15 hours. During tank warm up between tests, only intermittent temperature data (approximately every five minutes) will be taken over a total period of 33 hours.

Instrumentation items needing further development are the low-gravity vapor/liquid sensors, quality meter and low gravity mass gage. Also, further ground test development is needed on the camera and lighting requirements to obtain good visual coverage of the testing.

2.4.6.4 Interface, Support and Performance Requirements. Estimated weights of the experiment package are shown in Table 2-1. These weights do not include power supplies, recording equipment or other support systems which are assumed to be available from the experiment carrier vehicle. It should be noted that propellant weights shown include resupply and chilldown losses and that no more than 300 lb of LH_2 will actually be aboard the experiment at any one time.

Estimated power requirements are presented in Table 2-1 and acceleration requirements in Table 2-3. Accelerations are to be in the tank longitudinal direction in a manner to settle the propellant away from the vent.

2.4.6.5 Potential Role of Man. It is anticipated that astronaut monitoring will be essentially continuous throughout the 48 hours of this experiment. Throughout the experiment, the astronaut should monitor the vent flowmeter and TV coverage of the receiver vent area to determine if excessive venting of liquid is occurring. Because determination of the amount of entrainment is one of the objectives of the tests, nearly every test will start without the mechanical separator. The astronaut can switch to the vent line containing the separator if excessive liquid loss is observed. If the problem persists, it would be necessary for the astronaut to terminate the test. Astronaut duties are summarized as follows:

a. Heat-up sequence – Manual override of automatic termination.

b. Settling sequence – Manual termination.

c. Slosh-reduction sequence (optional) – High-level thrusters on manually (at minimum-wave amplitude). Switch to experiment-level thrusters (at maximum-wave amplitude).

d. Chilldown sequence – Manual override of automatic termination. Switch to separator if entrainment is excessive. Terminate if entrainment problem persists.

e. Bulk-transfer sequence – Manual termination.

f. Suction dip residual reduction sequence (optional) – Manual initiation and termination.

2.4.6.6 Available Background Data. The complex super-position of heat transfer and fluid motion occurring during orbital propellant transfer cannot be simulated on the ground; therefore, the basic principles and concepts have been partially established on a purely analytical basis. Good low-gravity experiment data are required to correlate theories and substantiate dimensionless parameters currently believed to be capable of describing the propellant transfer process.

This experiment specifies the use of high-performance insulation (HPI) but also specifies various holes cut in it for cameras and lights. Results of the Project Thermo study indicate that these specifications will require considerable design care.

A comprehensive study (Project Thermo) was initiated in 1966 by NASA/MSFC to define an orbital experiment capable of obtaining the required data. Results of this study are contained in the following references:

2-20 Thermo and Hydrodynamic Experiment Research Module in Orbit, Final Report, DAC-60594, March 1967, NAS8-1053.

2-21 Project Thermo - Phase B Prime, DAC-60799, September 1967, NAS8-21129.

Further work was also accomplished to broaden the scope of the Project Thermo data. These results are presented in the following references:

2-22 Results of a Preliminary Design and System Integration Study of Flying Several Cryogenic and Fluid Mechanics Experiments on an Unmanned Saturn IB for Long-Term, Low-G Investigations, LMSC/HREC A791322, March 1968, Contract SVD-3-67-002.

2-23 "Fluid Mechanics and Thermodynamics Flight Experiments Program," P&VE Internal Note No. P-68-7, NASA/MSFC, 13 September 1968.

The experiment described herein is based on the above data. It is essentially the same as that described in the initial Project Thermo study (DAC-60594) except for the addition of a larger transfer tank and an associated increase in testing. The use of larger tanks was recommended by the Project Thermo study. This was primarily in order to obtain further data on the size dependence of receiver tank chilldown thermodynamics.

2.4.7 LONG TERM CRYOGENIC STORAGE

2.4.7.1 Objectives. The objectives of this experiment are to obtain basic fluid dynamic and thermodynamic data required to optimize the design of vessels for the long term storage of cryogenic propellants in space and to evaluate various hardware systems required for such storage. Data are to be obtained on high performance insulation, stratification/destratification, zero-gravity venting and propellant reliquefaction.

2.4.7.2 Description. The proposed test configuration is illustrated in Figure 2-14. The superinsulated test tank is 2.4 m (8 ft) in diameter by 4.8 m (16 ft) long (internal dimensions) with hemispherical ends. The choice of this diameter is based on a

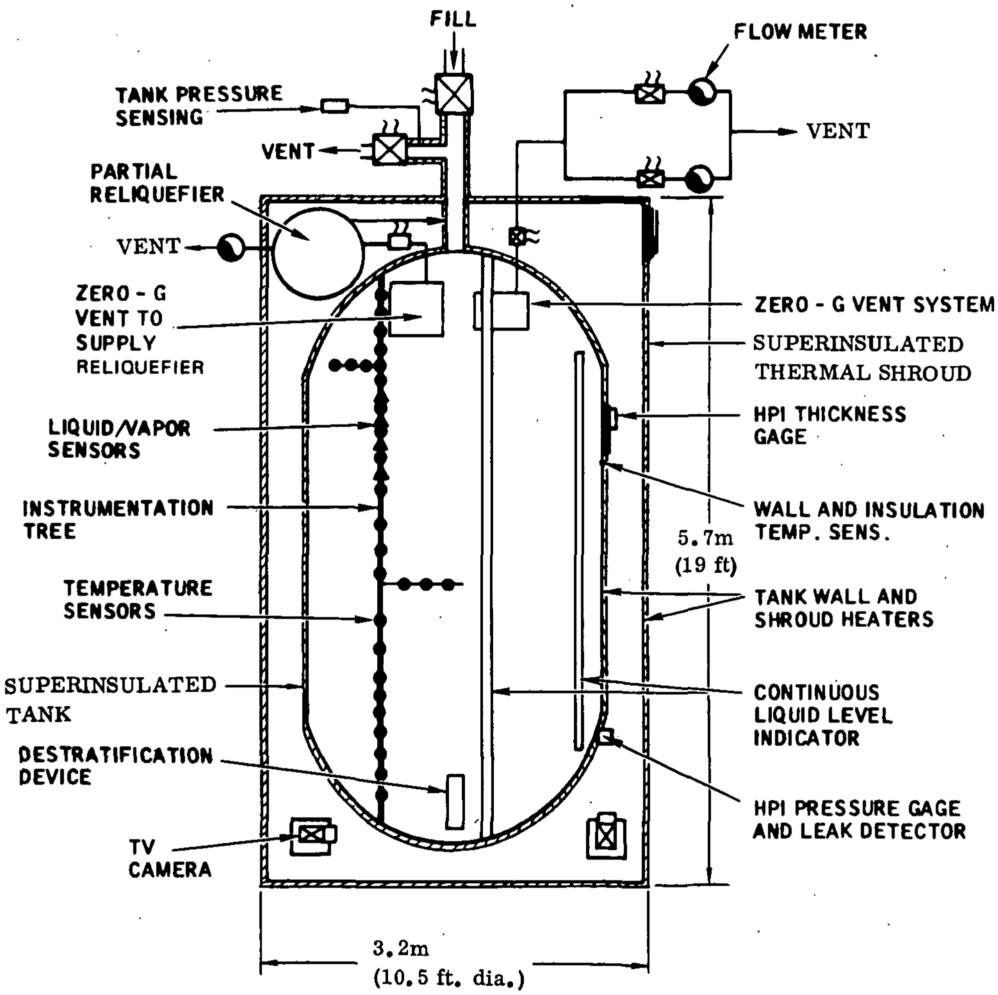


Figure 2-14. Long-Term Propellant Storage Test Article

consideration of instrumentation and scaling requirements as discussed in Reference 2-27. Tank sizes smaller than this create a sharp rise in the potential inaccuracy of the measured superinsulation thermal conductivity. Small tank sizes also affect the allowable insulation batten size, structural loading, evacuation characteristics, and anisotropic thermal characteristics. A length-to-diameter ratio of 2/1 was chosen as being representative of existing and planned cryogenic vehicles.

The test tank is surrounded with a superinsulated thermal shroud, used to control the test tank's local thermal environment.

Testing is divided into the following areas:

a. High-Performance Insulation

b. Stratification/Destratification

c. Zero-Gravity Venting

d. Reliquefaction

Based on previous studies it was determined that test conditions are compatible for combined testing of the above systems. A general discussion of testing for each of these systems is presented below.

2.4.7.2.1 High-Performance Insulation. Performance of the insulation will be evaluated in a series of four tests, each lasting approximately 1,000 hr. During these tests, the thermal shroud will be used to maintain a constant insulation surface temperature. An insulation test will consist of allowing the tank pressure to rise in the tank without venting, from 110 x 10^3 N/m^2 (16 psia) to approximately 310 x 10^3 N/m^2 (45 psia). Temperatures, pressures and liquid level measurements will be made at various times throughout the test in order to obtain thermal performance data, by first settling the liquid (to obtain liquid level) and then mixing the fluid to obtain temperature homogeneity. The final two tests of the series will be performed following the stratification/destratification tests in order to determine the effect of long term space exposure on insulation performance. Refilling of the hydrogen tank will be accomplished prior to these final tests.

2.4.7.2.2 Stratification/Destratification. Testing will consist of allowing a buildup of temperature stratification over a period of time and then destroying this stratification using the destratification device located in the bottom of the test tank as shown in Figure 2-14. A schematic of the device is presented in Figure 2-15. The overall envelope for this device is 15 cm (6 in.) dia. x 45 cm (18 in.) long. A tank wall heater is provided to obtain stratification data at various heat inputs. Testing will be accomplished at two heating rates in addition to the normal insulation heat leak. Also, three different controlled g-levels will be used. A series of nine tests are planned, with a total test time of approximately 682 hours.

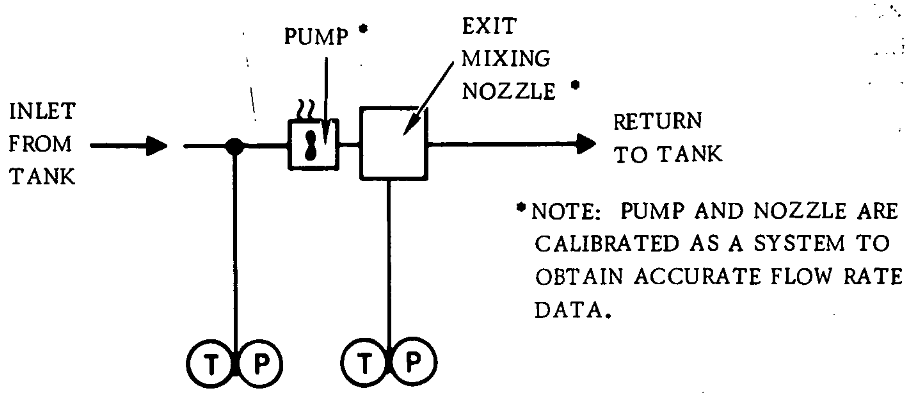


Figure 2-15. Destratification Device Schematic

This device will also be used to periodically mix the tank fluid during insulation testing.

2.4.7.2.3 Zero-Gravity Venting. The zero-gravity vent system consists of a heat exchanger and associated components as shown in Figure 2-16. The system is designed to operate with either gas or liquid and is, therefore, independent of the local fluid quality. Basically, the vent fluid is throttled to low pressure and low temperature and allowed to exchange heat with the tank fluid before being vented overboard. Assuming a sufficient amount of heat transfer to evaporate all of the liquid originally present in the vent fluid and sufficient heat transfer on the tank side to condense the equivalent quantity of gas, the net effect on the tank pressure is the same as for all-gas venting. The overall envelope of this system is 30 x 30 x 45 cm (12 x 12 x 18 in.).

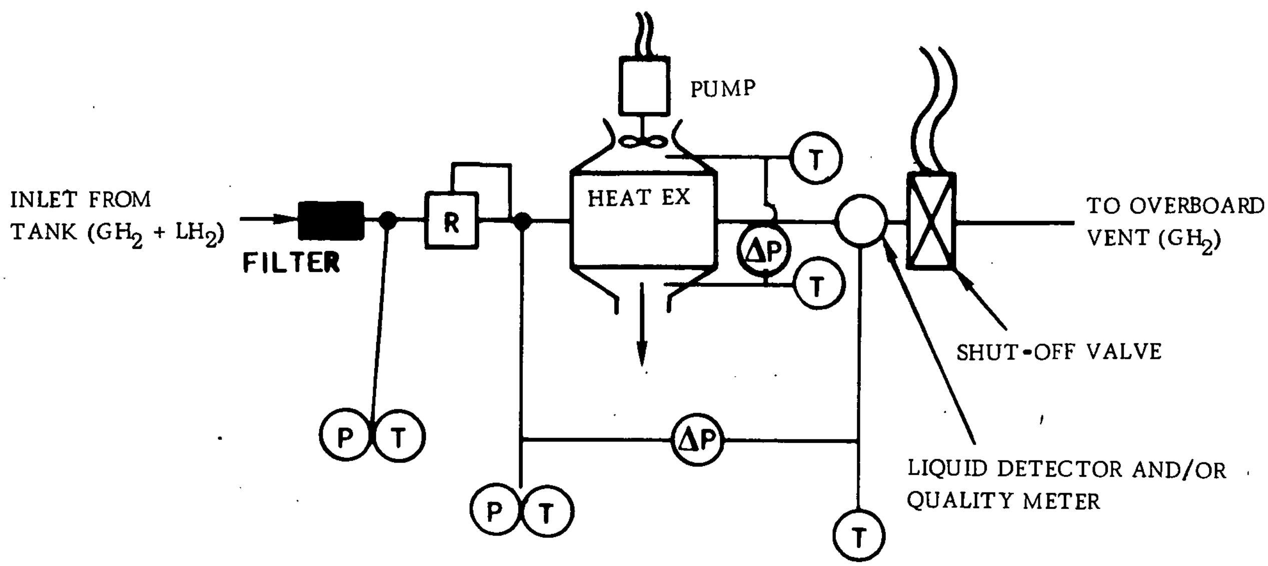


Figure 2-16. Zero-Gravity Vent System

Venting will occur on an intermittent basis with a tank pressure switch controlling actuation and deactuation. A total test time of 100 hours is planned with temperatures, pressures, exit quality and flow rate being measured. The wall heaters will be used to control the test times. This system is also used to vent down the test tank following each insulation and stratification/destratification test.

2.4.7.2.4 Reliquefaction. This system is designed to liquefy approximately 50% of the vent gas. This liquid is then introduced back into the propellant tank to increase the overall efficiency of the propellant storage process. A schematic of this system along with anticipated operation conditions is presented in Figure 2-17. The overall envelope is 75 cm (30 in.) dia. x 120 cm (48 in.) long.

A zero-gravity vent system is required at the reliquefier inlet, as shown in Figure 2-14 in order to assure an all-gas reliquefier inlet. This vent system is basically the same as shown in Figure 2-16 except for an increase in exchanger size due to lower pressure drop requirements imposed by the reliquefier. The envelope for this vent system is 45 x 45 x 75 cm (18 x 18 x 30 in.).

Operation of the reliquefaction system will be intermittent, with a tank pressure switch controlling actuation and deactuation. A total test time of 100 hours is planned with temperatures, pressures, exit quality and flow rate being measured. The tank wall heaters will be used to control the test times.

The requirements imposed by these experiments upon the carrying vehicle are summarized in Table 2-1.

2.4.7.3 Observation/Measurement Program. A list of measurements required for the overall test program is presented in Table 2-3.

HPI thermal conductivity will be determined from tank, insulation and fluid temperature and pressure measurements. Heat shorts into the tank through the struts, wire bundle, etc., will be kept to a minimum and monitored so that these may be deducted in determining the heat flow through the HPI. Liquid level and total liquid mass will also be monitored for thermal performance evaluation. Structural response will be monitored using the two TV cameras. Pressure will be monitored inside the HPI layers to study evacuation efficiency. Also, a H_e - H_2 detector will be utilized to monitor for any H_2 leakage which would alter the apparent evacuation rates. Energy input to the tank from mixing will be determined from power measurements of pump motor input.

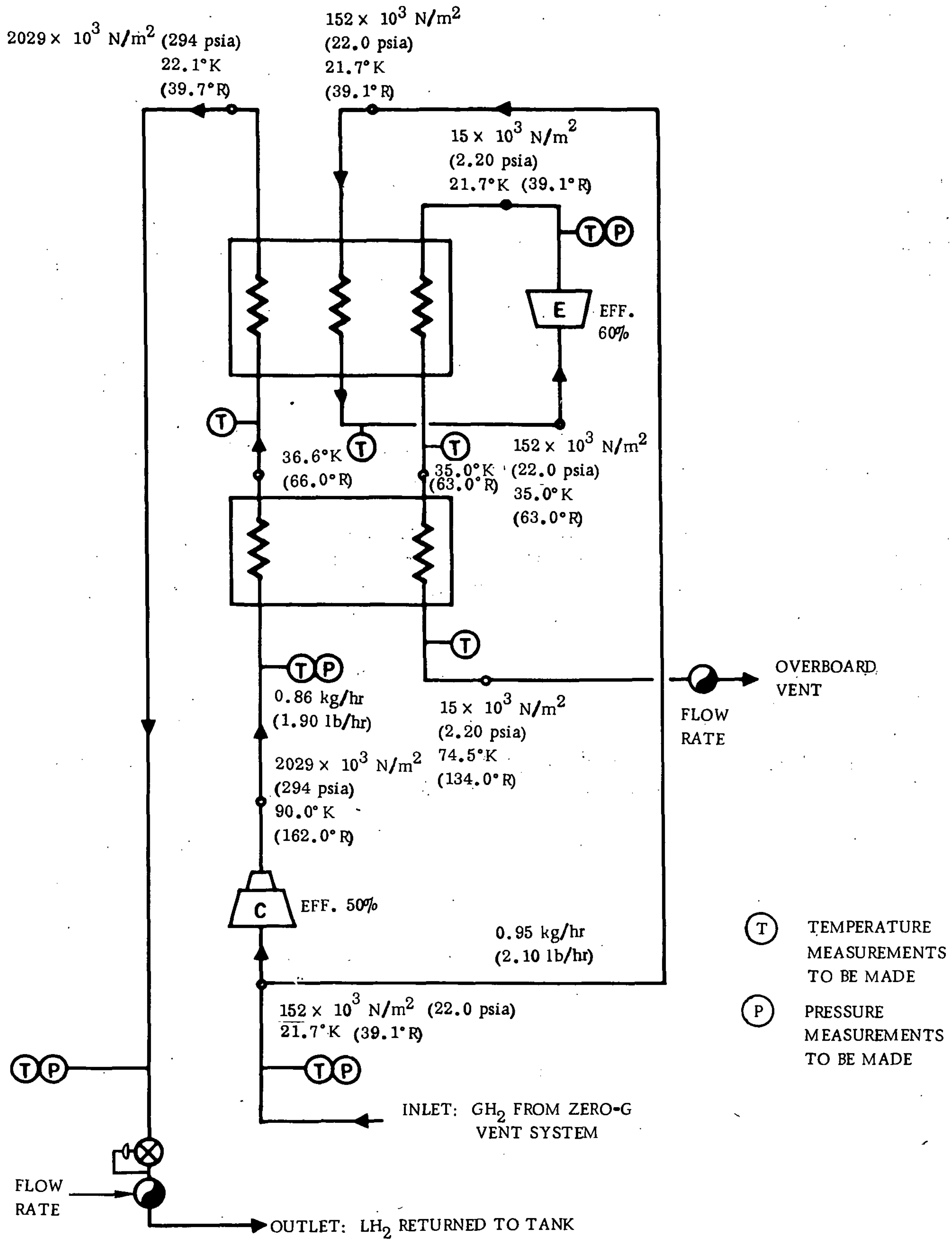


Figure 2-17. Reliquefier Operating Schematic

For stratification/destratification testing the tank will be instrumented with a set of temperature sensors capable of measuring a complete axial temperature profile in the tank and various off-axis temperatures. Ullage pressure in the tank will also be measured. Liquid height will be measured when the liquid is settled, using the continuous capacitor probes. Liquid/vapor sensors will provide an indication of the fluid configuration during ullage break-up mixing tests. The power input to tank wall heaters and mixing devices will be monitored when they are in operation.

From the stratification portion of the experiments the following effects will be determined:

a. Effects of ullage volume on stratification at a constant, low Bond number.

b. Effect of modified Rayleigh number on stratification at constant Bond number.

c. Effect of Bond number on stratification at nearly constant modified Rayleigh number.

d. Pressure rise in tank for initially completely mixed and completely stratified cases.

From the destratification portion of the experiments the following effects will be obtained:

a. Effect of mixer Weber number on ullage distribution for various initial liquid levels.

b. Effect of mixer Weber number on destratification at a constant heating rate.

During test tank refilling operations, temperatures, flow rates, and pressures will be recorded to obtain information on receiver tank thermodynamics applicable to orbital propellant transfer.

Data sampling for the insulation and stratification/destratification tests is assumed to occur, on the average, every 20 hours for a continuous period of approximately 15 minutes each time. For the zero-gravity venting and reliquefaction experiments this sampling is every 10 hours for one hour each time.

Instrumentation which needs further development or testing includes the liquid level/mass indicator, the low range (10^{-3} to 10^{-6} torr) pressure gage, the leak detector, the quality meter, the low-gravity liquid/vapor sensor, the low-gravity mass gage, and the high-performance insulation thickness gage. The arrangement of the cameras and mirrors, the camera lighting, and the temperature sensor locations on the heat shorts also need to be further considered.

2.4.7.4 Interface, Support and Performance Requirements. The experiment interface, support and performance requirements are listed in Table 2-3.

2.4.7.5 Potential Role of Man. An astronaut will be required to monitor the experiments only on an intermittent basis to assure that testing is proceeding as planned. During data sampling periods when the propellant is to be settled the astronaut will be required to monitor the position of the liquid within the tank to assure that the liquid is indeed settled and that acceleration levels used are adequate for this purpose.

During venting, periodic checks of the quality and flow through the vent lines will be required to assure that excessive liquid loss is not occurring. It is estimated that during the high-performance insulation and stratification/destratification testing, monitoring of the experiment will be required at 20-hour intervals. During the zero-gravity venting and reliquefaction experiments, monitoring will be required every 10 hours. It is estimated that the total Astronaut time required for these experiments will be on the order of 400 hours.

2.4.7.6 Available Background Data. An orbital High Performance Insulation (HPI) experiment is needed because all important environments cannot simultaneously be duplicated with ground test facilities. Considerable thermal and structural testing has been done on several HPI systems. The effect, however, of an actual spacecraft operating environment on the thermal and structural performance of an HPI system is not known. It is not possible to obtain, in ground-based testing, an extended time duration in a zero-g environment, and it is not feasible to simulate, simultaneously, all of the structural loadings and the thermal environments which occur in an actual flight. A one-g environment causes the HPI to be self-compressing and the HPI on the bottom bulkhead tends to sag. As a result, the installed layer density tends to change. Calorimeter studies show that slight bearing pressures, either from an external source or from self-compressing effects can have a significant effect on the HPI thermal conductivity values. As a result, exposure of a HPI system to a sustained low-g environment would permit thermal evaluation of the installed HPI under essentially a no-load condition.

Further, to acquire adequate technology for designing propellant systems for long term storage of cryogenics, it is necessary to perform an inflight orbital experiment to define the fluid phenomena under low-g environment. Ground test data is not adequate due to the buoyancy effect on stratification and mixer performance. For example, the power required to mix an LH_2 propellant system at 10^{-3} g is increased by 2 orders of magnitude at 1 g.

The destratification system is of major importance for design of any vehicle requiring long term storage in that a mixer system is required in any event for accomplishing low "g" venting and for use with subcooled propellants to utilize the increased sensible energy available. Testing performed at General Dynamics Convair under

Contract NAS 8-20146 illustrated the importance of mixing on zero-gravity vent performance. The major scaling parameters affected by the mixer system are acceleration levels, tank diameter, and mixer jet diameter.

A comprehensive study (Project Thermo) was initiated in 1966 by NASA-MSFC to define an orbital experiment capable of obtaining the required data on long term propellant storage at low gravity. Results of this study are contained in the following references:

2-24 Thermo and Hydrodynamic Experiment Research Module in Orbit, Final Report, DAC-60594, March 1967, NAS 8-1053.

2-25 Project Thermo-Phase B Prime, DAC-60799, September 1967, NAS 8-21129.

Further work was also accomplished to broaden the scope of the Project Thermo data. These results are presented in the following references:

2-26 Results of a Preliminary Design and System Integration Study of Flying Several Cryogenic and Fluid Mechanics Experiments on an Unmanned Saturn IB for Long-Term, Low-G Investigations, LMSC/HREC A791322, March 1968, Contract SVD-3-67-002.

2-27 Fluid Mechanics and Thermodynamics Flight Experiments Program, P&VE Internal Note No. P-68-7, NASA-MSFC, 13 September 1968.

The experiment described herein is based on the above data. It is essentially the same as that described in the initial Project Thermo study (DAC-60594) except for the use of a larger test tank. Also, the reliquefaction system was added to evaluate its performance under actual space flight conditions. The use of larger tanks was recommended by the Project Thermo study. The data presented is scaled from the Project Thermo results.

2.4.8 SLUSH PROPELLANT BEHAVIOR

2.4.8.1 Objective. The objective of this experiment is to determine the thermodynamic behavior of slush propellant in a reduced gravity environment. Ground testing of stratification, destratification, mixing, and tank draining must be supplemented with low-gravity orbital testing to properly design a vehicle for a long term mission.

2.4.8.2 Description. Two nearly identical, superinsulated tanks (Figure 2-18) will be used to perform the desired experiment. One tank will be filled before launch while the other will be launched empty and serve as the receiver tank during the initial propellant transfer test.

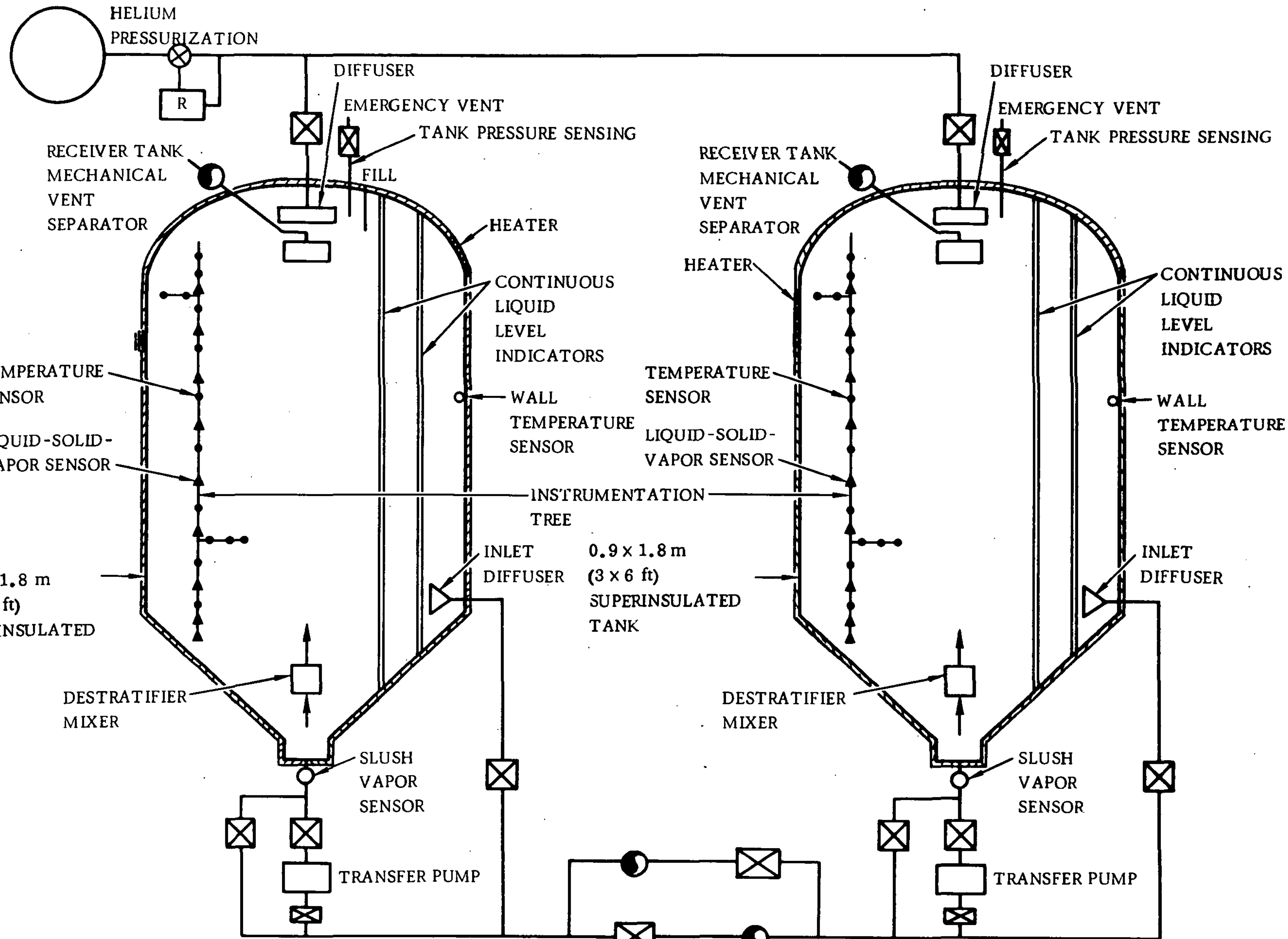


Figure 2-18. Slush Hydrogen Test Schematic

The experiment consists of alternately conducting a series of stratification/destratification tests and propellant transfer tests.

The propellant transfer equipment consists of: a vapor sensor at the outlet in order to determine when pull-through occurs in the supply tank, wall temperature sensors in the receiver tank to monitor chilldown, helium pressurization and hydrogen transfer pumps and a centrifugal separator for venting the receiver tank. Tank outlets are designed with appropriate slope and baffling, using the results of References 2-28 and 2-29 to minimize sliding friction effects with solid hydrogen and to delay vapor pull-through.

In general, the propellant transfer tests will use pumps and pressure to transfer slush hydrogen alternately between the two superinsulated tanks for different g loads, propellant transfer rates, and initial wall temperatures.

The following steps comprise a basic transfer test:

a. Heatup — Receiver tank walls will be brought up to the desired initial temperature automatically. Manual override will be provided for astronaut control.

b. Chilldown — This sequence is initiated manually by the astronaut. The chilldown sequence automatically activates pressurization, vent and transfer systems. Termination of chilldown is determined automatically by temperature sensing devices. The astronaut can override all automatic chilldown events.

c. Bulk Transfer — After chilldown has occurred, the astronaut selects the appropriate transfer rate and initiates automatic transfer. When the vapor sensor downstream of the outlet of the tank indicates vapor is present, the transfer is terminated.

Transfer tests will be run between stratification tests. Time between tests will be varied to determine the influence of slush settling on propellant transfer.

Stratification-destratification testing requires a period of low heat flux input from the wall heaters for self-pressurization and stratification development. Platinum resistance probes will be used to monitor the stratification. After pressure has risen to the desired level, the destratification device is turned on until fluid temperatures reach a steady-state condition.

Stratification-destratification testing would be initiated prior to each propellant transfer test. Stratification-destratification would proceed as follows:

a. Pressure Rise — Manually turn on mixer which will automatically turn off when temperatures are homogeneous. With mixer off, tank pressure will rise to desired level. Heater will assist pressure rise as required.

b. Destratification — When pressure reaches desired level, mixer automatically actuates. Mixer deactuates when tank contents are homogeneous.

2.4.8.3 Observation/Measurement Program. A list of measurements required for the slush tests is presented in Table 2-3. Childown efficiency and tank residuals will be determined using vent and transfer line flow meters. Vent exit temperature and quality will be measured.

Continuous data recording will be required during propellant transfer tests. This time will be approximately seven hours. During stratification testing data recording will be required only every 5 to 30 minutes.

A complete axial temperature profile plus off-axis temperatures will be obtained for measuring stratification. Liquid level will be measured at three locations for stratification purposes and for estimating interface shape at pull-through and during mixing.

Power input to heaters and mixers will be monitored and recorded as will tank and line pressures.

Instrumentation needing further development includes the low-gravity slush/vapor sensors, quality meters and mass gages.

2.4.8.4 Interface, Support and Performance Requirements. The interface, support and performance requirements for this experiment are contained in Table 2-3.

2.4.8.5 Potential Role of Man. The astronaut will monitor all tests for temperature and flow oscillations which may require manual override of automatic operation. The astronaut will initiate automatic sequences after selecting appropriate test variables such as gravity level, flow rates, wall temperatures, mixer speeds, heater power and mode of transfer. The astronaut will monitor fluid quantities and temperatures to assure that sufficient slush is available to complete testing.

2.4.8.6 Available Background Data.

References:

2-28 J. L. Vaniman, A. L. Worlund, and T. W. Winstead, "Slush and Subcooled Propellants for Lunar and Interplanetary Missions," Volume 14, Advances in Cryogenic Engineering.

2-29 C. F. Sindt, R. P. Ludtke, and D. E. Daney, Slush Hydrogen Fluid Characterization and Instrumentation, NBS TN 377, February 1969.

2-30 M. H. Blatt, K. R. Burton, F. Merino, and C. K. Perkins, Low Gravity Propellant Control Using Capillary Devices in Large Scale Cryogenic Vehicles, Third Quarterly Progress Report, Contract NAS8-21465, April 20, 1969.

2-31 L. J. Poth, Study of Cryogenic Propellant Stratification Reduction Techniques, Fort Worth Division of General Dynamics Corporation FZA-419-1, September 1967.

2.4.9 TWO-PHASE DYNAMICS

2.4.9.1 Objectives. The objectives of this experiment are to determine the spatial and temporal evolution of a bubble population in a nucleate boiling process and to determine the various regions of two-phase flow in a pipe as a function of gravity orientation and magnitude.

2.4.9.2 Description. The experimental package depicted in Figure 2-19 is designed to integrate two separate experiments using common support hardware and separate individual test sections for a bubble dynamics experiment and a pipe flow regime characteristics experiment.

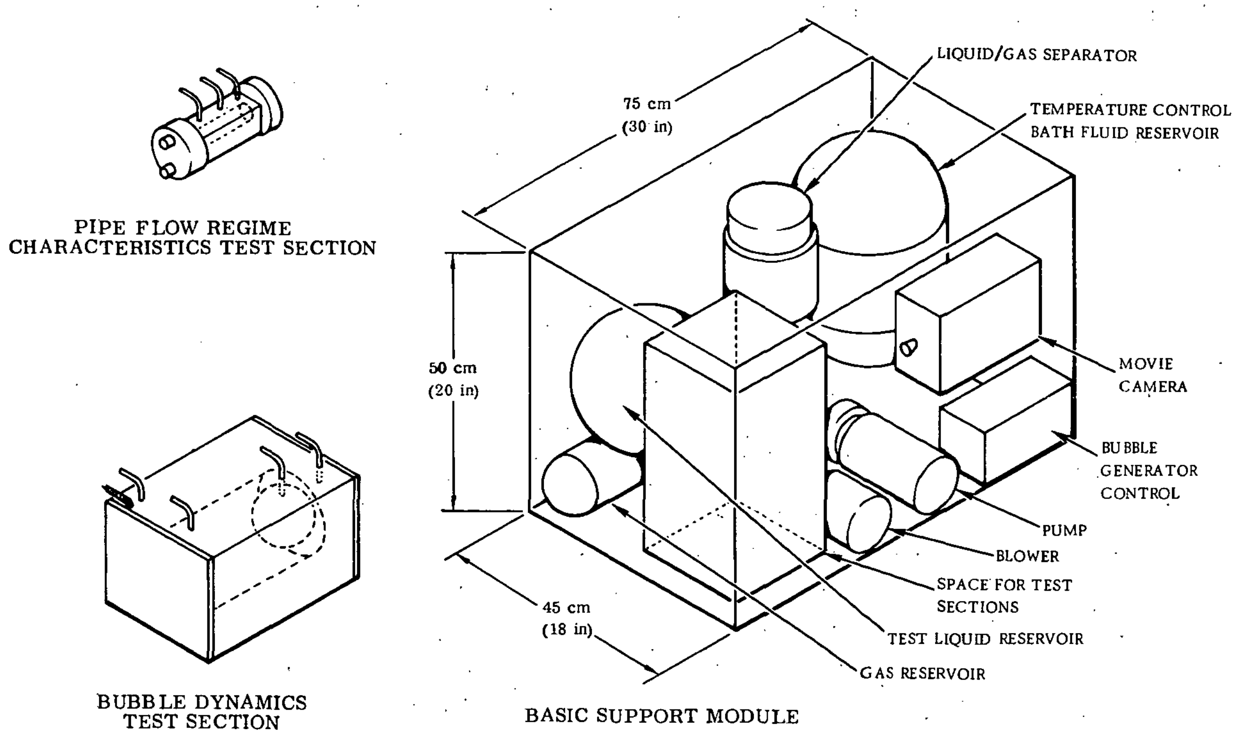


Figure 2-19. Two-Phase Dynamics Experiment Equipment

The basic support module consists of a liquid pump, a gas blower, gas and liquid reservoir tanks, a liquid/gas separator, flow loop ducting, bubble generation control package, and a motion picture camera. The two test sections will be sequentially installed in the flow loop. The test sections are transparent so that motion pictures can be made of the subject phenomena under low-gravity conditions.

The cylindrical bubble dynamics test chamber is surrounded by a rectangular transparent box which provides a thermal bath to maintain precise temperature control over the test section environment. The temperature bath fluid is continuously circulated through the container during the testing operation. The temperature bath fluid flow will be established sufficiently ahead of the start of testing to assure that the test section has reached thermal equilibrium. Bubble generation will be accomplished using either an electrical heater for evaporation of the test liquid or by the introduction of gas bubbles into the test section. Motion picture coverage of the bubble motion under a controlled low-g environment will provide data for correlation of experimental results with analytical models.

The pipe flow regime characteristics test section consists of a transparent flow path fed by a liquid/gas mixing chamber. The motion picture camera provided by the basic support package will record the two-phase flow patterns as the test parameters are varied.

Figures 2-20 and 2-21 illustrate the two-phase flow regimes as they are manifested under normal gravitational forces for vertical and horizontal orientations, respectively. The flow, when vertically oriented and directed upward, progressively moves through the following flow regimes as the mass velocity of the liquid is held constant and the gas mass velocity is increased: bubble, slug, foam, semi-annular, annular,

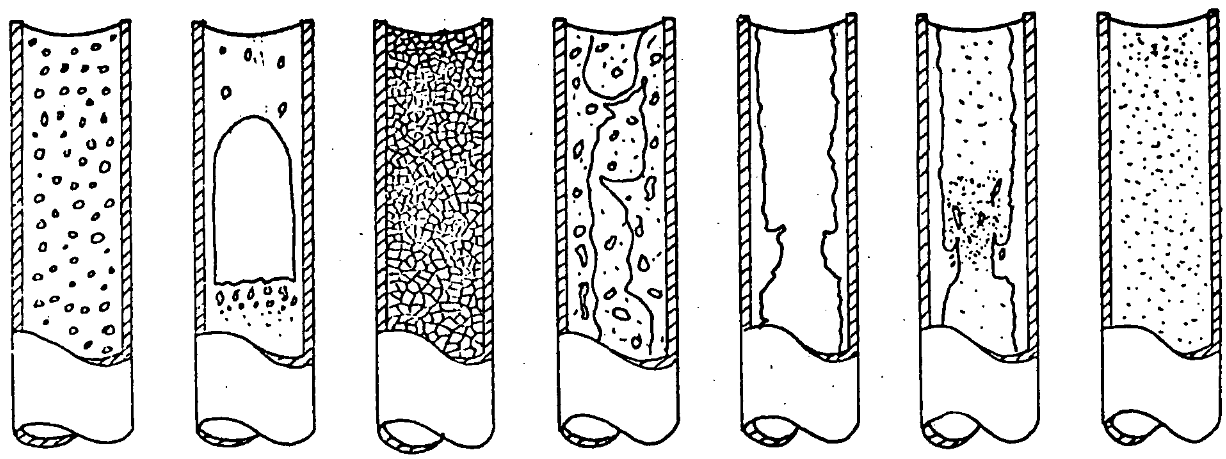


Figure 2-20. Two-Phase Flow Patterns - Vertical Orientation

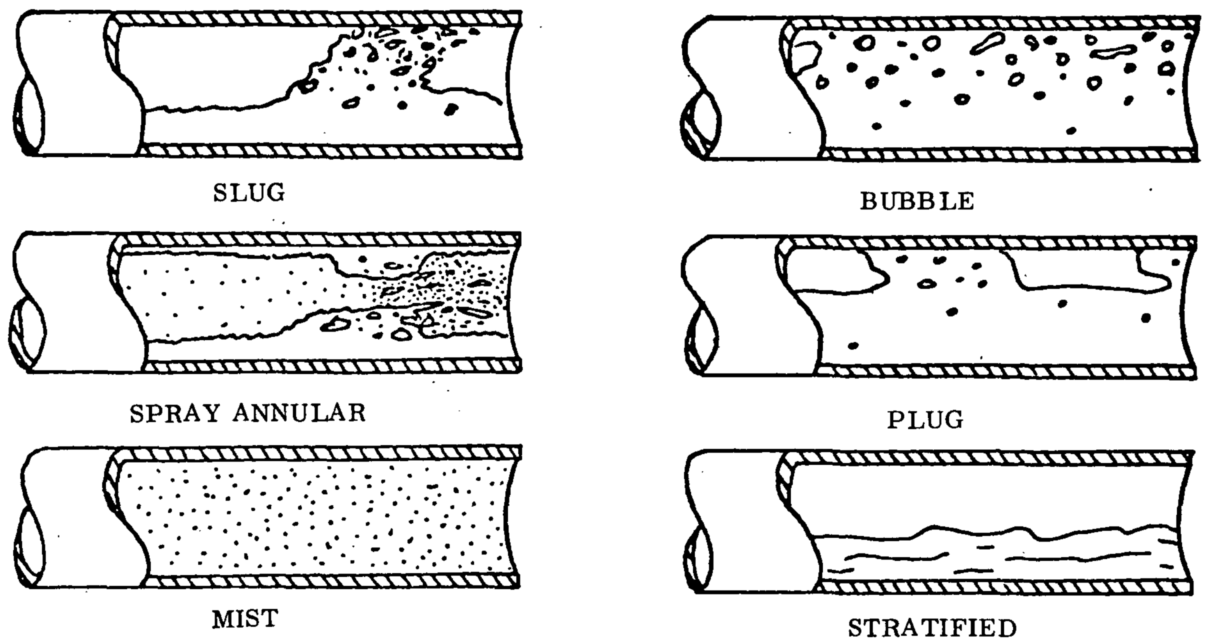


Figure 2-21. Two-Phase Flow Patterns - Horizontal Orientation

dispersed annular, and mist. For horizontal flow, which is selectively gravity-sensitive to stratification, the regimes are: bubble, plug, stratified, slug, spray annular, and mist. In the traditional Baker plots as shown by Figure 2-22 the flow regimes are defined for horizontal flow in the air/water system. The low-gravity experiment program will obtain data to define the two-phase flow patterns under two controlled, low-g acceleration levels, and under near zero-g coast conditions. The experiment will be conducted using either air and water or air and glycol as the test fluids. The mass flow and velocity of the two fluids will be varied to provide a complete flow regime map.

For both the bubble dynamics and flow regime tests described above, the low-g acceleration vector will be oriented with, against, and across the flow direction. The experiment requirements are summarized in Table 2-1.

2.4.9.3 Observation/Measurement Program. The primary source of data for the two-phase dynamics experiment program will be motion pictures. The pictures will be utilized both to identify bubble trajectories and to define the low-g, two-phase flow regimes. Other measurements will include pressures, temperatures, and flows. Additional experiment requirements are given in Table 2-1.

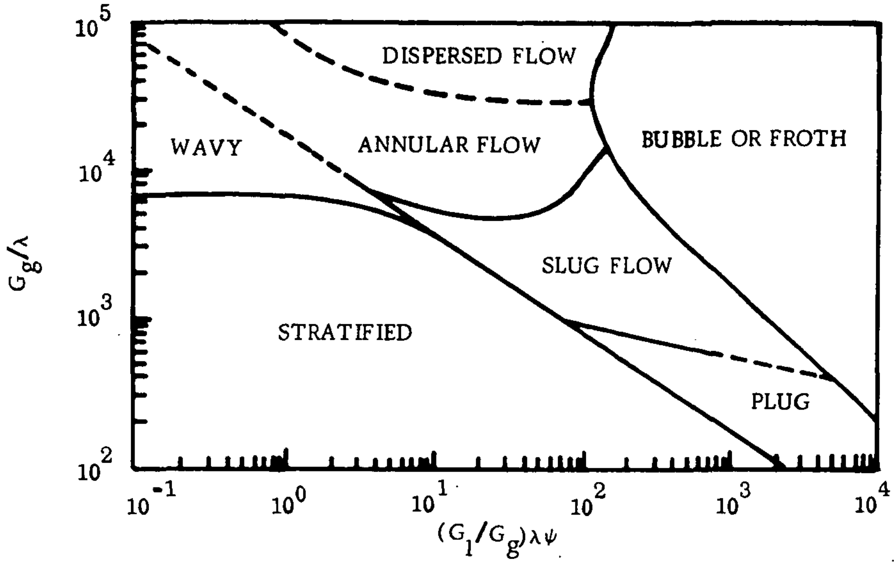


Figure 2-22. Baker Flow Correlation - Horizontal Orientation

2.4.9.4 Interface, Support and Performance Requirements. The experiment package will be designed to operate completely automated. However, interchanging test sections and retrieving film from the high-speed camera will be necessary. Specific details of the experiment weight, volume, power, etc. are contained in Table 2-4.

2.4.9.5 Potential Role of Man. It is anticipated that this experiment can be completely automated with man required only to exchange test sections, retrieve motion picture film, and service the experiment equipment.

2.4.9.6 Available Background Data. Many of the fluid transport processes which occur in a spacecraft life support system are greatly gravity dependent. To better understand these gravity phenomena, a study has been conducted to develop mathematical models for definition of those life support system fluid behavior processes which are influenced by the magnitude or direction of the ambient gravity vector. This study (Contract NAS1-8494) has developed analytical models to define the fluids phenomena described by this experiment and the two which follow. The models have been partially verified by the conduct of one-g laboratory tests. Low-gravity experiments, however, are required to provide adequate model correlation. The results of the analytical model development and one-g experimentation are contained in Reference 2-32.

Reference

2-32 Final Report, Gravity-Sensitivity Assessment Criteria Study, The Life Support System Zero-g Study, NASA CR-66945 prepared by Convair Division of General Dynamics Corporation, June 1970.

2.4.10 CHANNEL FLOW SYSTEMS

2.4.10.1 Objectives. The objectives of this experiment are: (1) describe the behavior of the humidification/dehumidification process in which diffusive and convective mechanisms dominate; (2) examine the behavior of body forces between liquid and gas during film transport along a flat surface; (3) describe the behavior of a liquid and a transporting gas stream with regard to the separation process; (4) define the conditions under which heat transfer between two plates changes from thermal diffusion to natural convection with forced convection superimposed on both processes.

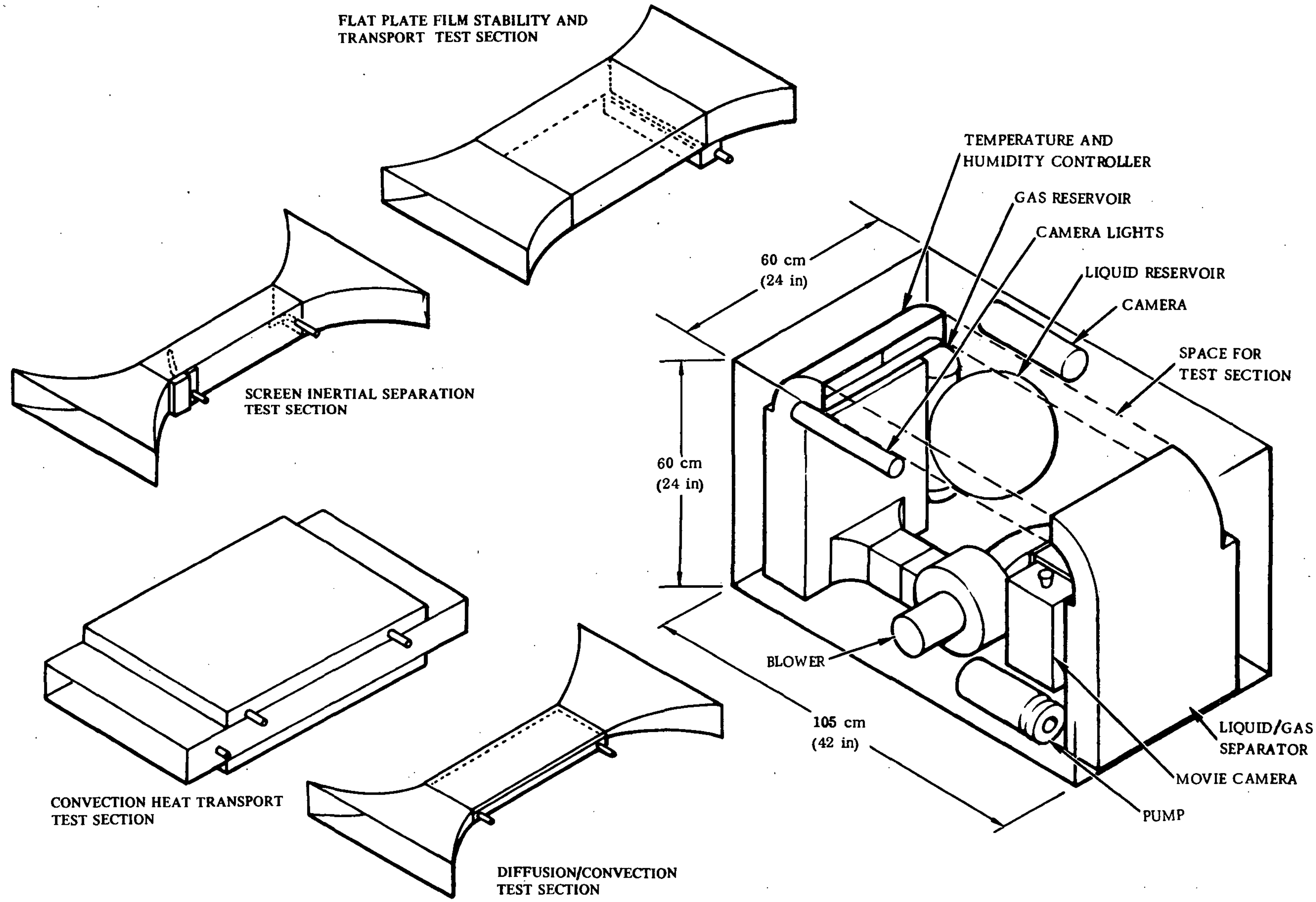
2.4.10.2 Description. The channel flow systems experiment package is designed to integrate four separate experiments using common support hardware and separate individual test sections for a diffusion/convection experiment, a flat plate film stability and transport experiment, a screen inertial separation experiment, and a convective heat transport experiment.

The basic support module shown in Figure 2-23 consists of a gas blower, liquid pump, temperature and humidity control, flow loop ducting, liquid/gas separator, liquid and gas reservoirs, liquid temperature control, lights and motion picture cameras. The four test sections illustrated in Figure 2-23 will be sequentially installed in the flow loop. The test sections are transparent to permit motion picture coverage of the experimental phenomena. The four tests which will be conducted are described in the following paragraphs.

2.4.10.2.1 Diffusion/Convection Experiment. This consists of a porous condenser-evaporator plate which is supplied with water at a temperature above the gas circuit air temperature for the evaporation-diffusion tests and below the air temperature for the condensation convection test. Air and liquid temperature and flow rate will be varied during the testing as well as the inlet relative humidity to the test section. Diffusion and convection efficiency will be determined by the difference in air relative humidity before and after passing through the test section.

2.4.10.2.2 Film Stability and Transport Experiment (Flat Plate). Film stability and transport experiments will be accomplished using a test section which directs a controlled air flow across a continuously replenished liquid film formed on a flat plate. Liquid motion leading to film instability is created by viscous shear forces at the gas/liquid interface. Controlled variables will include input air flow, replenished liquid flow, liquid viscosity, gas/liquid surface tension, g level, and orientation to the gravity vector. Observations will be keyed to the gas/liquid interface characteristics and the film transport through a range of value of the controlled variables.

Water will be injected into the air duct in a smooth stable stream at the upstream end of the test plate. The liquid film will extend over the width of the channel and will be adjusted with no air flow so that a smooth stable film exists. An automatic system for visualizing the liquid flow will be in operation. This will consist of a grid of thin



A. TEST SECTIONS B. BASIC SUPPORT MODULE

Figure 2-23. Channel Flow Systems

wires in the upstream end of the liquid film. A small DC current periodically energized will produce very small hydrogen bubbles in the water by electrolysis. These bubbles are convected with the liquid and are easily photographed.

High-speed (400 fps) photography will be used to record the liquid/gas interface near the point of instability. As the air flow rate is raised from zero, the camera, placed to view the edge of the film, will begin to run.

Adjustments of the inlet geometry for production of the liquid film will provide five different film thicknesses which are stable at zero air velocity. Five tests will result.

2.4.10.2.3 Screen Inertial Separation Experiment. The screen inertial separation experiment will investigate the behavior of the liquid/gas components of mixed phase transport and separation processes. The experiment involves liquid dispersoid separation from the transport gas stream by means of a droplet barrier in the form of a hydrophobic screen. Water drops will be injected into the air stream from the flow loop water storage tank through an injector nozzle(s).

The screen separation test section will provide for installing a hydrophobic screen in the duct at three different angles to the flow direction, i.e., 0.52, 0.8 and 1.2 rad (30, 45, and 60 deg). Three different screens will be sequentially installed, each with different porosity and weave characteristics. Material for construction of the test section will be transparent plastic suitable for photographic coverage.

Water will be sprayed onto the screen from a nozzle projecting into the duct at the upstream end. Cameras will be installed to view the impinging drops and the screen surface. One camera operating at 24 fps film speed will continuously photograph the screen through the large duct side. The camera line of sight will be normal to the screen surface, adjustable for the three screen angles. A high-speed camera (400 fps) will view the screen through the small side of the duct. This camera will view the edge of the screen and will be perpendicular to the air and droplet velocity vector. Operation of the high-speed camera is necessary only for 10 to 15 seconds during each test to observe dispersoid activity.

The air flow rate and water droplet spray rate will be varied to provide a complete screen separation performance map.

2.4.10.2.4 Convection Heat Transport Experiment. The convection heat transport experiment is designed to record the various flow patterns which develop in a ducted air stream due to an imposed temperature differential acting along the vertical axis of a horizontally oriented channel. The data collected by these observations will be employed for the evaluation and possible modification of an analytical model which has been developed to predict the stream characteristics operating in response to imposed heat loads.

Evaluation of the accuracy of the predictive aspects of the analytical model will require the following observations against each condition in a set of steady-state conditions; flow rate (mean velocity), temperature profile, velocity profile, locus of instability onset.

The selection of experiment parameters will be such that they make possible an examination of the potential effect on the model parameters of various values of the local inertial acceleration vector, especially with respect to the effects on transitions from laminar to turbulent flow. Analysis of the experimental data may lead to altering and/or augmenting the analytical model in this area, especially with regard to arbitrarily chosen parameters in the marginal stability analysis.

The experiment will be conducted by maintaining various controlled temperature differences across the hot and cold plates of the test section and also varying the air flow rate at each temperature difference to provide a low-g convective heat transport performance map. The temperature distribution in the flow stream will be measured. These data will be augmented with motion picture coverage of the convection currents taken through the walls of the transparent test section. An optical recording system such as a laser interferometer will be used to provide visualization to the motion pictures.

2.4.10.3 Observation and Measurement Program. The major source of data for the channel flow systems experiments will be motion pictures. Additional data will be obtained for flow rates, temperatures, and pressures. Additional experiment requirements are given in Table 2-1.

2.4.10.4 Interface, Support and Performance Requirements. Design of the experiment package for complete automation will be a goal of this experiment; however, it appears that astronaut support will be necessary for changing test sections and film retrieval. Specific details of experiment weight, volume, power, etc. are contained in Table 2-4.

2.4.10.5 Potential Role of Man. It is anticipated that manned support to this experiment will consist only of exchanging test sections and film retrieval.

2.4.10.6 Available Background Data. Many of the fluid transport processes which occur in a spacecraft life support system are greatly gravity dependent. To better understand these gravity phenomena, a study has been conducted to develop mathematical models for definition of those life support system fluid behavior processes which are influenced by the magnitude or direction of the ambient gravity vector. This study (Contract NAS1-8494) has developed analytical models to define the fluids phenomena described by this experiment. The models have been partially verified by the conduct of one-g laboratory tests. Low-gravity experiments, however, are required to provide adequate model correlation. The results of the analytical model development and one-g experimentation are contained in Reference 2-33.

Reference

2-33 Final Report, Gravity-Sensitivity Assessment Criteria Study, The Life Support System Zero-G Study, NASA CR-66945, prepared by Convair Division of General Dynamics Corporation, June 1970.

2.4.11 CONICAL FLOW SYSTEMS

2.4.11.1 Objectives. The objectives of this experiment are to describe the liquid buildup and transport on a conical surface due to condensing fluid and to describe the behavior of an entrained liquid in a cyclonic separator.

2.4.11.2 Description. The experiment package depicted in Figure 2-24 is designed to integrate two separate experiments using common support hardware and separate individual test sections for a conical film stability and transport experiment and a vortex inertial separation experiment.

The basic support module consists of a gas blower, liquid pump, mixed phase generator, flow loop ducting, liquid/gas separator, liquid reservoir and motion picture

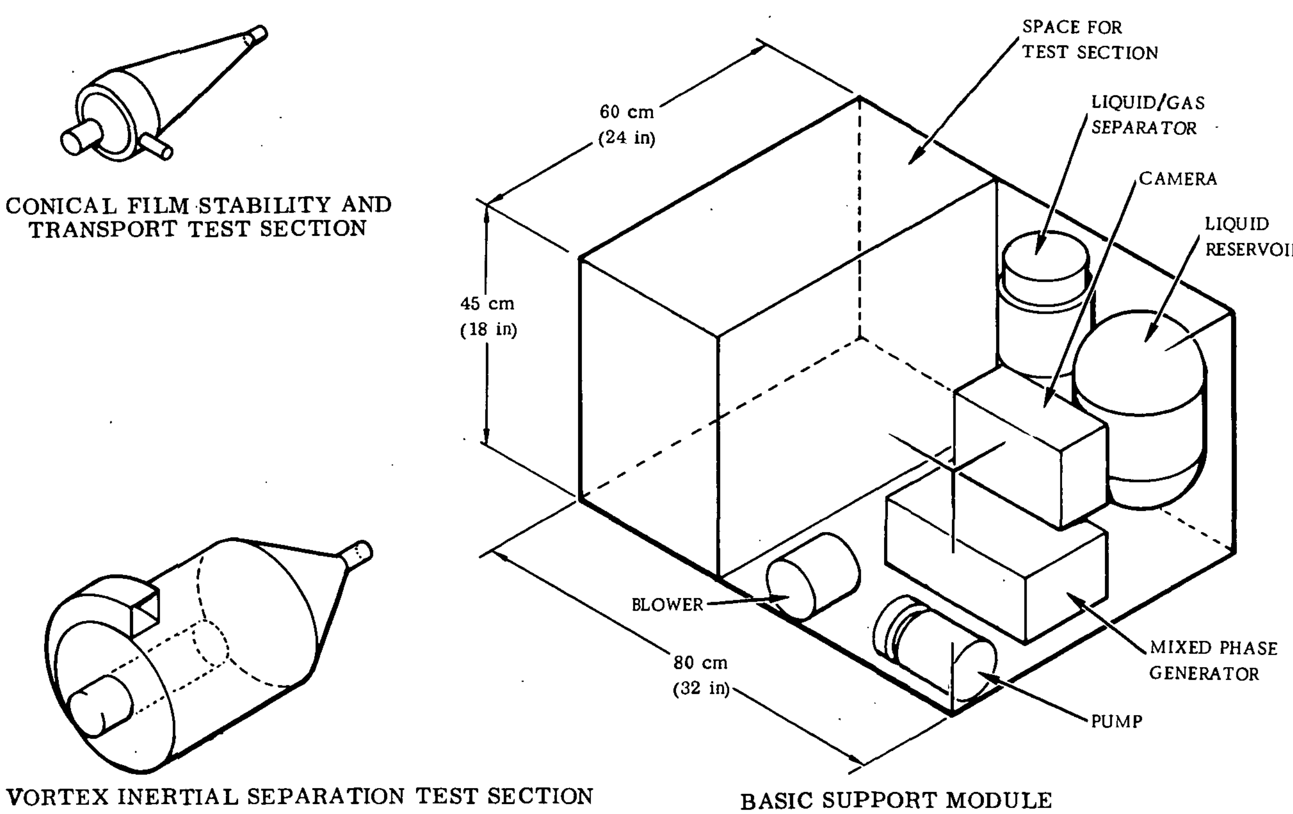


Figure 2-24. Conical Flow System Experiment Equipment

camera. The test sections for the conical film stability and transport experiment and the inertial separation experiment will be sequentially installed in the flow loop. The test sections are transparent so that motion pictures can be made of the phenomena under low-gravity conditions.

The conical film stability test section is designed with separate liquid and gas inlets and one common outlet. The test is designed to verify an analytical model which describes the behavior of thin liquid films which are reacting to the various forces applied in the interfaces between the film and the gaseous environment in which it exists. The analysis addresses itself to transport phenomena involving film transport on conical surfaces where liquid surface effects may provide the major transport force. The model considers the effects on the predicted behavior resulting from variations in such system parameters as: gravitational field strength and orientation; surface temperature gradient; liquid characteristics as influenced by mass density, dynamic viscosity and surface tension; gas stream characteristics as influenced by velocity, density and pressure; and system boundary characteristics as influenced by gas-film interface stability and physical dimensions of the film and the solid surfaces. Special attention is centered on both the conditions producing and the behavior during the transition from a stable to an unstable film/gas interface.

In the test section for the Vortex Inertial Separation experiment, water/air mixture is moved through the system initially as a liquid dispersoid transported in the gas stream, and terminally as separated and independently transported streams - one channel operating to transport an "air-free" liquid stream, the other a "liquid-free" air stream. This experiment is also designed to provide verification data for an analytical model developed to describe vortex inertial separation. In addition to the inertial forces involved in the processes, gas stream interfacial shear and liquid/solid surface effects are treated. The model considers the effects on predicted behavior resulting from variations in a broad range of parameters such as: gravitational field strength and orientation; dispersoid velocity, size and impact angle; gas stream velocity, solid surface physical characteristics; fluid physical characteristics; interfacial shear; droplet adhesion; gas pressure drop; and liquid flow rate. Special emphasis is placed on the behavior of the liquid in its transition from a distribution of impacting dispersoids to the controlled movement of a droplet or liquid film.

The model is designed for use in the development or analysis of LSS equipments where phase separation is required. The case treated herein can be related to a broad spectrum of separation techniques spanning, at least in part, essentially all of those being proposed for the near-term future. The model, when experimentally verified, will help to provide design criteria such as optimum screen configuration, dispersoid impact velocity and angle, vortex centrifugal field strength, and flow field distributions.

2.4.11.3 Observation/Measurement Program. The main observables for the conical film stability and transport experiment are film stability, liquid depth, mean velocity and mass flow rate. The primary experiment variables are cone angle and size, gas velocity and liquid flow rate. The main observables for the vortex inertial separation experiment are suspension density using optical mass and liquid forming and collection rates. The primary experiment variables are cone angle and rotation rate. Motion picture coverage will be required for both experiments. More extensive descriptions of experiment requirements are given in Table 2-1.

2.4.11.4 Interface, Support and Performance Requirements. The experiment package can be designed for automated operation; however, film retrieval from the motion picture camera and test section changes will be necessary. Specific details of the experiment weight, volume, power, etc. are contained in Table 2-4.

2.4.11.5 Potential Role of Man. It is anticipated that this experiment can be completely automated with only test section changes and film retrieval required by man.

2.4.11.6 Available Background Data. Many of the fluid transport processes which occur in a spacecraft life support system are greatly gravity dependent. To better understand these gravity phenomena, a study has been conducted to develop mathematical models for definition of those life support system fluid behavior processes which are influenced by the magnitude or direction of the ambient gravity vector. This study (Contract NAS1-8494) has developed analytical models to define the fluids phenomena described by this experiment. The models have been partially verified by the conduct of one-g laboratory tests. Low-gravity experiments, however, are required to provide adequate model correlation. The results of the analytical model development and one-g experimentation are contained in Reference 2-34.

Reference

2-34 Final Report, Gravity-Sensitivity Assessment Criteria Study, The Life Support System Zero-G Study, NASA CR-66945, prepared by Convair Division of General Dynamics Corporation, June 1970.

2.5 FPE INTERFACE, SUPPORT AND PERFORMANCE REQUIREMENTS

The major interface, support and performance requirements for the experiments of the Fluid Management FPE are presented in Table 2-6. Data is presented for each experiment rather than for the FPE as a whole. This presentation format was employed because the experiments can be accommodated independently or in various combinations, depending upon the capability of the supporting spacecraft to provide the necessary resources and controlled environmental conditions.

Table 2-6. FPE Interface, Support and Performance Requirements Summary

Parameters	Experiments	1	2	3	4	5	6	7	8	9	10	11
Mass, kg (lb)		424 (935)	272 (600)	1,018 (2,235)	216 (476)	208 (460)	904 (1,980)	2,394 (5,250)	660 (1,430)	95 (210)	148 (325)	64 (140)
Volume, m^3 (ft^3)		1.4 (50)	1.5 (54)	1.8 (65)	2.1 (75)	0.34 (12)	51. (1,800)	59. (2,095)	24 (840)	0.28 (10)	0.59 (21)	0.62 (22)
Power, kw	Avg.	0.1	0.03	0.12	1.2	0.17	1.3	0.25	0.04	0.4	0.75	0.2
	Peak	0.5	0.5	0.16	1.6	0.30	4.0	1.20	1.2	1.0	1.8	0.75
Crew Skills	Thermodynamicist	1	1	1	1	1	1	1	1	0	0	0
	Electromech. Tech.	1	1	0	1	1	1	1	1	1	1	1
Data	Digital Rate, bps	760	192	25	5,780	160	160	160	160	160	1000	100
	TV Bandwidth, MHz	5.8	5.8	2.9	2.9	2.9	5.8	5.8	N/A	N/A	N/A	N/A
Logistics Up (per 30 days), kg (lb)		1.5 (3)	3.6 (8)	0	3.4 (8)	5.5 (12)	0	180 (400)	0	Negl.	Negl.	Negl.
Logistics Down (per 30 days), kg (lb)		1.5 (3)	3.6 (8)	0	3.4 (8)	5.5 (12)	0	0	0	Negl.	Negl.	Negl.
Pointing & Stability		←					N/A					→
Orbit Alt. & Inclin.		←					Any					→
Unique Envir. Reqmts.	Controlled g	•	•	•	•	•	•	•	•	•	•	•
	Controlled Temp.			•		•				•	•	•
	Vacuum		•				•	•	•			

It should be noted that the experiments all require positive control of the acceleration magnitude and direction over a range from 10^{-3} to 10^{-5} g. Additionally, those experiments which employ superinsulated cryogenic storage tanks require that the tanks be maintained in a low-pressure environment, e.g. 1.3×10^{-4} N/m^2 (10^{-6} Torr).

2.6 POTENTIAL MODE OF OPERATION

The potential modes of operation to be considered are:

Mode A. Limited on-orbit stay time attached to the Space Shuttle.

Mode B. Extended on-orbit stay time free-flying, periodically revisited by a Shuttle.

Mode C. Extended on-orbit stay time, either attached to the Space Station or in a free-flying mode supported by the Space Station.

Previous studies have indicated that the controlled acceleration levels required by the fluid management experiments are best attained by employing a free-flying vehicle utilizing an array of thrusters sized to yield the desired acceleration levels.

Accomodation modes B and C would both be applicable for this FPE. Mode B would be a logical choice for experiments which have short total durations, or for experiments which have long run times and do not need crew servicing for long periods of time. Mode C would be a logical choice for long duration experiments which require frequent servicing or changes of experiment parameters by man.

2.7 ROLE OF MAN

Man will play a significant role in the success of a number of the fluid management experiments. Beside the normal electromechanical technician support expected of fluids laboratory experiments, a specialist in the field of thermodynamics will be required to remotely monitor many of the experiments. Remote monitoring is necessary during the conduct of some experiments so that critical decisions concerning proper test sequence and data recording can be made. The specific details of the manned support necessary is contained in the discussion of each individual experiment. A summary of the skill level and time requirements is presented in Table 2-1.

2.8 SCHEDULES

The estimated development and flight schedules for each of the fluid management FPE experiments are shown in Table 2-7.

Table 2-7. FPE Development and Flight Schedule

Experiments		Schedule (Years)						
		1	2	3	4	5	6	10
2.4.1	Interface Stability							
2.4.2	Boiling Heat Transfer							
2.4.3	Capillary Studies							
2.4.4	Condensing Heat Transfer							
2.4.5	Two-Phase Flow Regimes							
2.4.6	Propellant Transfer							
2.4.7	Long Term Storage of Cryogenics							
2.4.8	Slush Hydrogen							
2.4.9	Two-Phase Dynamics							
2.4.10	Channel Flow Systems							
2.4.11	Conical Flow Systems							

Legend: Development (hatched bar)

Flight (solid bar)

2.9 PRELAUNCH SUPPORT REQUIREMENTS AND GSE

A somewhat unique support requirement is imposed by the fact that one of the fluid management experiments requires the use of slush hydrogen. The capability for making experimental quantities of the slush hydrogen must be available at the launch site therefore to prepare the experiment package. In addition, several of the experiments require the use of liquid hydrogen. If these experiments are fueled on the ground, special provisions must be made for continuously "topping-off" the test tanks and allowing for hydrogen venting during the ground hold condition. Experiments employing superinsulated cryogenic storage tanks will require a helium purge for the super insulation to preclude cryopumping of condensable gases into the multilayer insulation during the ground hold and boost phases of the mission.

2.10 SAFETY ANALYSIS

The majority of the experiments in this FPE require the use of either combustible or potentially toxic fluids. Special care must be taken to assure that proper precautions are made to allow for safe venting of the boiloff gases from the liquid hydrogen experiments. Special handling will be required in transferring and operating with these fluids to prevent their fumes from entering the supporting space vehicle environment during an accidental release. This may require separate containers (such as plastic bags) around the transfer equipment. Another approach would be to isolate the experiment vehicle environment from the support vehicle ECS during fluid transfer and experiment servicing. All tankage and plumbing systems containing hazardous fluids shall be thoroughly isolated and purged prior to breaking plumbing seals for experiment modification, maintenance or repair.

Spacecraft compartments in which combustible fluids are handled will probably require installation of large pressure relief valves which discharge through zero thrust ports. Experiment operations will have to be remotely controlled and in a structurally secure area or at a safe distance from the supporting spacecraft.

Incorporation of interlocks and discharge devices is required in the experiment equipment to prevent crewmen from being exposed to high voltage during the maintenance, servicing and checkout operations. Suitable bonding provisions will be made to ensure that all chassis and frames are at a common potential.

The experiment hardware shall be designed to preclude exposure of crewmen to any hazard during his performance of maintenance, repair, checkout or operating tasks. Power, liquids and gases shall be removed or secured prior to the performance of replacement or repair operations. Systems reactivation by restoration of power or pressure shall require a deliberate action by the crewman performing the maintenance. The hardware shall be devoid of sharp corners, rough surfaces or uninsulated wiring.

2.11 AVAILABLE BACKGROUND DATA

Background data on the individual experiments are listed with each experiment description. The following documents provide useful overall information as well as pertinent data for particular experiments.

References

2-35 Space Technology Experiment Program Summary, Langley Research Center (Additions to be included in Yellow Book).

2-36 Space Station Experiment Program for Advanced Technology, March 10, 1969, Langley Research Center (Additions to Yellow Book).

2-37 M. E. Nien and C. D. Arnett, P&VEL, MSFC, Program Plan for Earth-Orbital Low-g Heat Transfer and Fluid Mechanics Experiments, NASA TM X-53395, February 10, 1966.

2-38 G. O. Fredrickson and J. D. Schweikle, Douglas Missile and Space Systems Division, Thermo and Hydrodynamic Experiment Research Module in Orbit, DAC-60594, March 1967.

2-39 T. S. Webb, R. N. Austin, C. D. Brooks, "Saturn In-Flight Experimental Payload Study," 28 February 1966, Vol. II - Technical Report, Design of In-Flight Experiments, Fort Worth Division of General Dynamics Corporation.

2-40 Fluid Mechanics and Heat Transfer Under Low Gravity, Edited by H. Cohan and M. Rogers, Proceeding of a Symposium at Palo Alto, California, June 1965, Sponsored by USAF Office of Scientific Research and Lockheed Missile and Space Company.

VOLUME VII

SECTION 3

EXTRAVEHICULAR ACTIVITY

SECTION 3

EXTRAVEHICULAR ACTIVITY

3.1 GOALS AND OBJECTIVES

Future activities in space exploration will require additional emphasis on the ability of man to perform new extravehicular manipulations. Such activities will require the development of specific equipment and operational techniques to support currently planned and potential space mission requirements.

The overall goal of this FPE is to provide guidelines for the development of advanced extravehicular systems which will effectively perform the tasks required during manned extravehicular activity (EVA) in orbit. To achieve this goal, experiments are presented for the development and evaluation of the required EVA systems.

The objectives of these experiments are to: (1) assess and develop man's ability to efficiently use the maneuvering systems in performing extravehicular activities; (2) develop the operational skills required for navigation, docking/anchoring, cargo transfer, resupply, astronaut rescue, space assembly, maintenance and repair, and (3) develop the hardware and procedures required to support future extravehicular manipulations.

3.2 PHYSICAL DESCRIPTION

There are two experiments contained within the context of this FPE. First, the Astronaut Maneuvering Unit (AMU) experiment will involve various maneuvering tasks anticipated in future extravehicular activity. The AMU is a back-mounted unit containing a life support system with fixed multiple thrusters. Automatic stabilization and attitude control are provided through control moment gyros. Careful selection of the anticipated tasks will identify the preliminary design criteria and performance requirements for such a maneuvering unit. Both ground simulation and flight tests will be performed in the evolutionary process of establishing design requirements for an operational AMU.

Second, the Maneuvering Work Platform (MWP) experiment includes evaluation of a hard-suited astronaut's ability to perform selected tasks with the assistance of the MWP. The MWP is an open structure, unpressurized, hydrazine-propelled vehicle, with variable cargo-bed geometry. This vehicle consists of four basic elements: a forward module, an aft module, and two interchangeable payload modules. The forward module contains propulsion thrusters, flight controls and displays, a life support system, and forward anchoring/grappler arms. The aft module contains aft propulsion thrusters, an extendable antenna, and aft grappler arms. Forward and aft modules can be separated at variable distances by means of interchangeable, quick-disconnect structural joints.

The AMU experiment will begin with extravehicular maneuvers being performed while tethered to the parent spacecraft. Untethered maneuvers will follow and be constrained to close proximity to the parent spacecraft.

The MWP experiment will be accomplished first with flight control evaluations in close proximity to the spacecraft. Then, remote maneuvers will be performed to permit evaluation of guidance, navigation, and rendezvous operations.

Extravehicular activities associated with AMU and MWP experiments will be performed under the surveillance of CCTV and motion pictures. Extravehicular activity will be accomplished during daylight hours early in the experiment program and finally extended to include night conditions.

3.3 EXPERIMENT REQUIREMENTS SUMMARY

Requirements of the FPE experiments which affect the parent spacecraft are summarized in Table 3-1.

3.4 EXPERIMENT PROGRAM

3.4.1 ASTRONAUT MANEUVERING UNIT

3.4.1.1 Technical Objective. The objective of this experiment is to develop understanding and control over the problems associated with astronaut maneuverability in extravehicular activity. This objective is to be met by evaluating the Astronaut Maneuvering Unit (AMU) in tethered extravehicular maneuvers and untethered extravehicular maneuvers. Data will be collected to evaluate the AMU system and to establish further design and performance criteria applicable to future maneuvering units. Comparisons will be made between inflight experiment results and ground simulation data to establish the limitations and improve the capabilities of ground simulation techniques.

3.4.1.2 Physical Description. The Astronaut Maneuvering Unit (AMU) shown in Figure 1-1 is a back-mounted system with multiple fixed-position thrusters. Six Control Moment Gyros (CMG), arranged in pairs along the three body aces, provide automatic stabilization and attitude control. A cold-gas reaction control system is used to provide thrust for translation as well as to produce restoring torques for CMG momentum dumping. The AMU has electrical power data communication, gas supply, and life support subsystems to allow operation of the unit independent of umbilicals to the spacecraft. A hand controller is used to provide control signals to

Table 3-1. Experiment Requirements Summary

EXPERIMENT	MASS kg (lb)	VOLUME m^3 (ft^3)	ENVELOPE m (ft)	POWER	CREW SKILLS	EXPERIMENT TIME LIMITS	DATA REQUIREMENTS	RADAR	STABILIZATION AND CONTROL
3.4.1 ASTRONAUT MANEUVERING UNIT	120 (265)	0.6(20)	0.6 × 0.6 × 1.5 (2 × 2 × 5) Plus Support Equip.	Average = 330 W Peak = 370 W	Elect/ Mech Tech. (3 Req'd)	60 Days	Desired: 5000 Bits/sec Minimum: 3000 Bits/sec Also: TV Film Voice	None	Restricted Maneuvering of Parent Spacecraft During EVA
3.4.2 MANEUVER-ABLE WORK PLATFORM	1450 (3200)	6(200)	1.7 × 1.3 × 2.3 (5 × 4 × 7) Plus Support Equip.	Average = 330 W Peak = 400 W	Elect/ Mech Tech. (3 Req'd)	60 Days	Desired: 8000 Bits/sec Minimum: 5000 Bits/sec Also: TV Film Voice	Range = 10.5 KM Accuracy = ±0.3% to 2 KM	No Maneuvering of Parent Spacecraft During Docking or Undocking

torque the gyros for changing attitude. A separate hand controller is used to activate the thrusters for translational control.

Interchangeable high-pressure gas bottles will be used for supplying oxygen for LSS/propulsion gas. The 0.3m (13 in.) (OD) spherical tank contains 8 kg (18 lb) of oxygen at 41 MN/m^2 (6000 psia). The tank is made of Inconel and contains a built-in regulator restricting discharge pressure to 1150 kN/M^2 (165 psia). Therefore, a need for high-pressure plumbing is eliminated.

Total weight of the AMU (including one gas tank) is 86 kg (190 lb). An extra gas tank will also be required and weighs 34 kg (75 lb). Stowed volume of the AMU with associated equipment is approximately 0.6 m^3 (20 ft^3).

3.4.1.3 Observation/Measurements Program. The objective of this experiment is to be satisfied by accomplishing the following tasks:

a. Define inflight maneuvers for:

   1. Mode 1 — Tethered.

   2. Mode 2 — Untethered.

b. Perform ground simulations.

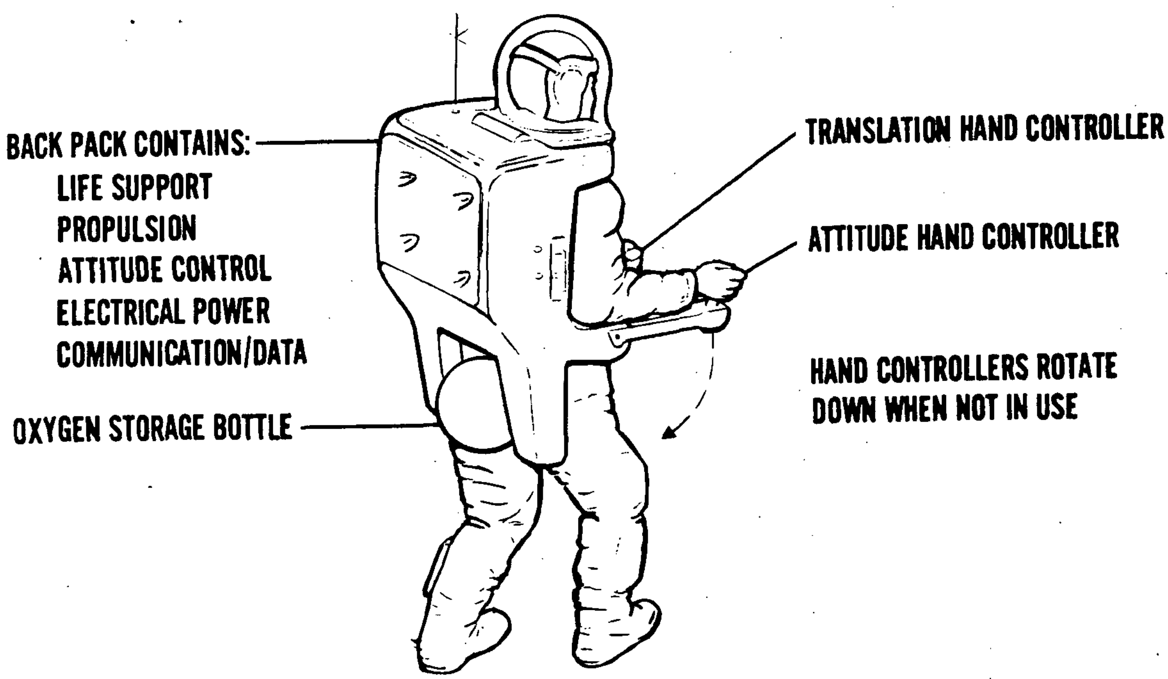


Figure 3-1. Astronaut Maneuvering Unit

c. Perform inflight maneuvers and experiment tasks.

d. Correlate inflight and simulator results.

e. Establish optimized mission requirements and design criteria.

3.4.1.3.1 <u>Define Inflight Maneuvers</u>. Mission tasks for astronauts supported by maneuvering units include: point-to-point transfer, assembly and maintenance; inspection and observation; resupply; mass transfer; and rescue missions. There are certain elements which are common to nearly all these tasks. The following identifiable elements are inherent to most maneuvering tasks while the proficiency required is dependent upon the particular tasks:

a. Stabilization (maintain, within limits, a given body attitude).

b. Attitude control (rotate to a desired body attitude).

c. Translation (thrust without inducing undesired rotations).

d. Midcourse corrections (attitude and velocity).

e. Decelerate (retro thrust without inducing undesired rotation).

f. Docking (seize target).

g. Recovery (capability to recover from inadvertent tumbles or system failures).

The above elements will be incorporate into sets of maneuvering tasks which are dependent on the maneuver mode being performed. The maneuver tasks defined for each mode are:

<u>Mode 1 — Tethered</u>

a. Stabilize, orient to proper attitude, and translate to end of 60 m (200 ft) tether.

b. Retrothrust prior to reaching end of tether.

c. Stationkeep, maintaining attitude relative to spacecraft.

d. Orient (translate to spacecraft).

e. Retrothrust (make terminal velocity and attitude corrections).

f. Dock at work platform.

g. Translate to 30 m (100 ft) from spacecraft.

h. Induce external force and evaluate recovery.

i. Translate to spacecraft and terminate experiment.

Mode 2 — Untethered

a. Stabilize, orient to proper attitude, and translate to a point within 60 m (200 ft) of spacecraft.

b. Stationkeep, maintaining attitude.

c. Orient, begin translation to spacecraft work platform.

d. Perform midcourse attitude and velocity variations.

e. Retrothrust and dock at work platform.

f. Transfer 90 kg (200 lb) mass from work platform to a point within 60 m (200 ft) of spacecraft and return.

g. Translate to a point 30 m (100 ft) from spacecraft.

h. Induce external force and evaluate recovery.

i. Begin translation to spacecraft.

j. Perform midcourse attitude and velocity variations.

k. Retrothrust and dock at spacecraft.

l. Terminate experiment.

3.4.1.3.2 Perform Ground Simulations. The mission requirements and performance characteristics of the AMU will be programmed into an analog/digital flight simulator with a visual display. This "closed-loop" simulation will provide a means to establish propulsion system operation, fuel consumption, stability and control, optimum accelerations, rates, and dead bands. These simulations which provide an accurate representation of flight dynamics and flight article electronics can be used to assure representative system response. The simulations will provide valuable astronaut training and establish the baseline data for the correlation with inflight results.

3.4.1.3.3 Perform Inflight Maneuvers and Experiment Tasks. Following astronaut simulator training and evaluation of the data collected from simulator runs, inflight maneuvers and experiment tasks will be performed. The experiment will consist of satisfactorily accomplishing such tasks as navigation, docking/anchoring, cargo transfer, astronaut rescue, space structure assembly, inspection, maintenance and repair. Performing the two modes of inflight maneuvers will provide the data required for an evaluation of the navigation, docking/anchoring and cargo transfer capability.

Astronaut rescue will be demonstrated by having a second astronaut on standby, equipped with an AMU and emergency oxygen supply. He will, on call, be sent to provide first aid to a "stricken" astronaut. First aid, within the context of this experiment will be limited to supplying emergency breathing oxygen and suit pressurization to the stricken EVA crewman. Transfer of the stricken astronaut to the spacecraft will also be performed in simulation of an AMU propulsion system failure.

Space structure assembly will be demonstrated using both conventional and special power tools. Although universal type tools appear desirable to reduce the number required, care must be taken that such tools do not become complex, requiring excessive adjustment or being difficult to manipulate. It may be desirable in developing erection/assembly techniques to consider methods for bringing power directly from the parent spacecraft to the assembly structure. Structural assembly in orbit will offer capabilities and limitations quite different from those afforded by the presence of gravity and atmosphere in Earth. Crewmen will be able to move and maneuver massive and expansive objects with the application of small forces and torques. The environmental forces — gravity gradient, aerodynamics, solar pressure, and magnetic reactions will be small. Effects of man and the forces and torques he applies or causes to be applied, will be the design constraints. Assembly in space involves the placement and attachment of components in proper alignment and relationship to each other. With the loss of the carpenters level and plumb bob, normal alignment requirements must be taken care of in the design and fabrication phases. Precise alignment of critical structural elements or surfaces will require optical tooling techniques.

Maintenance and repair capability will be demonstrated by performing such tasks as small component replacement, fastening, drilling and cutting in the space environment. The optimum joining process is one which requires little equipment, operates from a stored energy source, is simply and accurately aligned, and resulted in reliable, reproducible joints. Characteristics of such joints are ease of assembly, mechanical simplicity, repeatability, and quick positive action. Typical fasteners, fully developed and in production used, to be used in this experiment are toggle clamps, draw-pull catches, cam-action fasteners, quarter-turn fasteners, sliding latches, and expandable prong latches.

Observations and evaluations to be performed include not only the maneuverability, stability and control, and performance of the AMU but also astronaut requirements and procedures. These evaluations will consider:

a. Physiological Factors. The experiments will identify crew capability limitations imposed by marked increase in crew stress and energy expenditures required to perform work while wearing a pressure suit and protective garment. The increased heat, CO_2 and water vapor production rates, and oxygen use rates associated with the physiological responses to EVA will establish both biological and equipment constraints on task types, work performance rates, and task duration..

b. Personnel Equipment Limitation. The limitations on useful crew performance resulting from crew preoccupation with extravehicular mobility aids, artificial lighting, handholds, tethering devices, and prevention of entanglement or damage of personal equipment will be assessed.

c. Crew Hazards. Evaluation will be made of the potential hazards imposed on the astronaut by solar energy, ionizing radiation, ambient pressure change, micrometeorites, pressure suit performance, and communications with the parent spacecraft.

d. Supplementary Equipment Requirements. Evaluations will be performed to reduce supplementary equipment. Such items as mobility aids, restraint systems, tethering devices, portable bio-packs, mobile light sources, and special tools all impose weight penalties and will be analyzed in detail to determine if alternate techniques can be employed.

e. Mobility and Dexterity Limitations. Work capability is limited by the pressurized suit and associated support gear. Evaluations will be made of such things as: (1) reduced hand and finger tactical sense and dexterity which preclude fine adjustment tasks; (2) design of switches, removable parts and deploying devices that can be manipulated with a pressurized glove; (3) minimum reaction designed tools and fasteners; and (4) visibility through the faceplate.

All of the experiment inflight maneuvers and EVA tasks will be performed four times by each of three astronauts. One crewman will perform the EVA while a second crewman is suited and prepared to perform a rescue operation. The third crewman will observe. The crewmen will alternate their roles during the conduct of the experiment. Each will make eight flights as a test subject with the AMU. The in-orbit test program will require approximately 60 days. Later repetitions of the flight tests may be performed, following changes to hardware design or operational procedures.

Closed circuit television aboard the spacecraft will be utilized throughout this experiment and recorded on video tape. The observer will periodically use a motion picture camera to record specific sequences of events.

3.4.1.3.4 Correlate Inflight and Simulator Results. The purpose of the maneuvering unit evaluation is to determine through simulation and verify through flight test:

a. Feasibility of the AMU.

b. Commitment required by the astronaut.

c. Capability to recover from temporary loss of orientation.

d. Performance of the AMU in terms of time, propellant efficiency, astronaut fatigue, and utility at the work site.

Feasibility will be demonstrated by an objective evaluation as to whether or not the mission was satisfactorily accomplished. Frequent or consistent failure to achieve a task objective will indicate the unit is not suitable for that function, e.g., failure to reach the target object in specified time or inability to approach the remote object and stationkeep in a given attitude.

Astronaut commitment will be subjectively evaluated by studying the margin of control the crewman had and the attention he could devote to performing maintenance and assembly tasks at the work site. This will be evaluated through astronaut comments and filmed data.

AMU ability to recover from externally induced forces will be subjectively evaluated through pilot debriefing and filmed data. This ability will be objectively evaluated through instrumentation data of time to recover, acceleration, and rates obtained.

Performance of the AMU will be evaluated by analyzing propellant and/or electrical energy used in stabilization and propellant used in translation during transfer, docking stationkeeping, fly-around, etc. Time to perform individual maneuvers, accelerations will be evaluated. The piloting workload imposed on the astronaut will be investigated to determine any degradation of his utility at the work site.

3.4.1.3.5 Establish Optimized Mission Requirements and Design Criteria. Each individual task of the experiment will be evaluated to determine if it should or should not be made a requirement for the AMU. Tasks requiring high consumption of propellant provide a limiting constraint by imposing that unreasonable amounts of propellant be carried. Tasks which induce undue fatigue on the astronaut will have to be revised or compromised. Detailed evaluation of the adequacy of command rates, angular accelerations, translational accelerations, and dead bands will be made from postflight debriefings, voice tapes, and studies of mission performance. This detailed analysis will permit the determination of optimum mission requirements and design parameters for next generation astronaut maneuvering units.

3.4.1.3.6 Instrument. Parent spacecraft instrumentation requirements for this experiment will consist of the following:

a. CCTV and video recorder.

b. Motion picture camera.

c. TLM receiver and data displays.

d. Voice communication link and recorder.

CCTV will be utilized throughout the AMU experiment. Motion picture coverage is also required during the conduct of the experiment. Color film is desired. One camera with a 5 mm lens, run at 6 fps with a remote control for starting and stopping the camera will be required. Sixty minutes of film without reload is needed. To minimize film weight, only six hours of operations will be filmed. Voice will be recorded for both subject and observer.

Digital data transmitted from the AMU will be collected by the TLM receiver and recorder for the following parameters:

a. AMU thrusters valve operations.

b. Gas tank pressure and temperature.

c. Regulator output pressure and temperature.

d. LSS and pressure suit temperatures.

e. Translation commands.

f. Rotation commands.

g. CMG gimbal angles.

h. LSS input pressure.

i. Battery current and voltage.

j. Astronaut physiological monitors.

The digital data rate necessary to record this data is approximately 5000 bits per second.

3.4.1.4 Interface, Support and Performance Requirements. Provisions for the three crewmen required to perform this experiment will be supplied by the parent spacecraft. An airlock is required at the spacecraft to facilitate egress/ingress of the astronaut for extravehicular maneuvers. Throughout the extravehicular portion of the experiment, a second crewman must be suited and prepared to perform an emergency EVA using an AMU, MWP, or equivalent mobility aid.

The digital data rate desired for the experiment is 5000 bits/sec. This data rate could possibly be reduced to a minimum of 3000 bits/sec by selected reductions in sampling rates and/or frequency response of some measurements.

Power requirements from the spacecraft will include CMG spin-up, battery recharge, telemetry receiver operations, photo lights and cameras. The major power requirements are for CMG spin-up and photo lights. Peak power demand is 370 watts, provided that the photo lights and CMG spin-up are not operated simultaneously. During the experiment the average power requirement is estimated to be 300 watts. Table 3-2 indicates the power requirements of the various equipment.

High-pressure, 41 MN/m^2 (6000 psia), oxygen must be provided. The preferred operation would be the capability to reuse the AMU supply tank by recharging to 41 MN/m^2 aboard the parent spacecraft. The alternative would be to provide enough spare precharged supply tanks to complete the experiment.

Table 3-2. Parent Spacecraft Power Requirements

EQUIPMENT	PEAK (watts)	AVERAGE (watts)
Camera	60	20
Photo Lights	300	300
TLM Receiver	10	10
Battery Charger*	25*	20*
CMG Spin-Up*	230*	180*
Maximum Spacecraft Power	370	330

*Not operating concurrently with camera, lights and TLM.

During extravehicular maneuvers the parent spacecraft will be restricted from performing any propulsion thruster operations. This will preclude the possibility of any high temperature gas expulsion from interfering with the EVA.

Table 3-3 summarizes the significant interface, support and performance requirements.

Table 3-3. Interface, Support, and Performance Requirements

Mass	120 kg (265 lb)
Volume	0.6 m^3 (20 ft^3)
Power	Peak: 370 watts Average: 330 watts
Crew Skills	Electromechanical Technician (3 Req'd)
Data Rate	Desired: 5 kbps Minimum: 3 kbps
Logistics Up (per 30 days)	100 kg (220 lb)
Logistics down (per 30 days)	10 kg (22 lb)
Pointing and Stability	Restricted maneuvering at parent spacecraft during EVA
Orbit Altitude and Inclination	NA
Unique Environmental Requirements	NA

3.4.1.5 Potential Role of Man. The EVA will be accomplished by each crewman with time equally divided. This will provide data as to astronaut proficiency in maneuvers and navigation as well as fatigue level incurred due to work load. Total experiment operational time per experiment run is eight hours. Flight crew training will consist of briefings, hardware familiarization sessions, zero gravity simulations and flight simulations. Hardware familiarization, procedural checks, and fit checks will be conducted as appropriate. Training in donning and doffing procedures will be conducted in simulated zero gravity aircraft and/or a water immersion facility. Flight simulations will be conducted using the analog/digital computer programs and air bearing simulators. Several sessions on each are planned and it may also be desirable to conduct comparative simulations at other facilities.

3.4.1.6 Available Background Data

1. Astronaut Maneuvering Unit, Experiment M-509, NASA, June 13, 1967.
2. Experiment Requirements Document for Astronaut Maneuvering Equipment, (Experiment M509) NASA, dated May 12, 1970.

3.4.2 MANEUVERING WORK PLATFORM

3.4.2.1 Technical Objective. The objective of this experiment is to develop understanding and control over the problems associated with the utilization of a Maneuvering Work Platform (MWP) to perform specified extravehicular work assignments in orbit. Data will be collected to establish performance requirements and design criteria for a next generation MWP. Comparisons will be made between inflight experiment results and ground simulation data to establish the limitations of and improve the capability of ground based simulation techniques.

3.4.2.2 Description. The Maneuvering Work Platform (MWP) consists of four basic elements: (1) a forward control module; (2) an aft module; (3) a removable tools/spares module; and (4) a collapsible cargo frame. These four elements allow the MWP to take on three basic configurations: (1) a minimum configuration, containing only the fore and aft modules; (2) a nominal configuration containing the fore, aft and tools/spares module; and (3) an expanded configuration, where the cargo frame replaces the tools/spares module. Extending along each side of the forward module are hinged "running boards" which act as scaffolds at the work site. Figures 3-2 and 3-3 illustrate the three configurations of the MWP.

The forward control module contains all of the flight controls and displays, and the controls for the anchoring/grappler arms. Three of these arms are arranged in a triangular pattern on the forward face of the module. In addition, radar antennas, RCS thrusters, circuit breaker panel, emergency stub antenna, work lights and running lights are provided. An environmental control system/life support (ECS/LS) compartment is anchored to the module base and incorporates the body restraint for the astronaut.

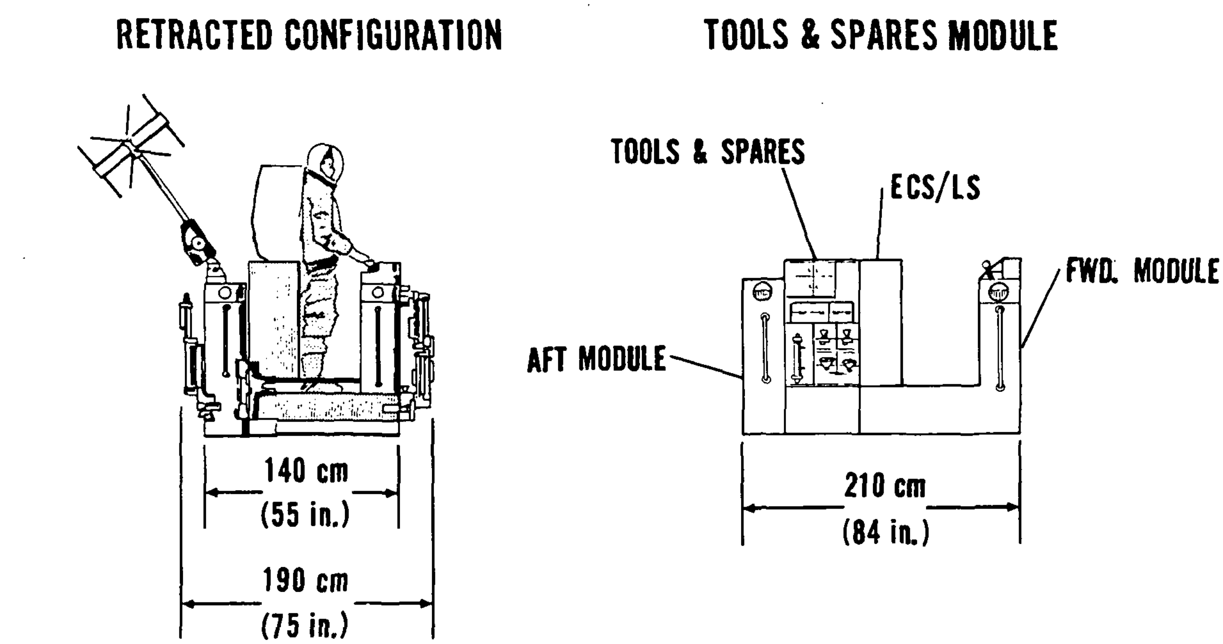


Figure 3-2. Maneuverable Work Platform - Retracted and Tools/Spares Module

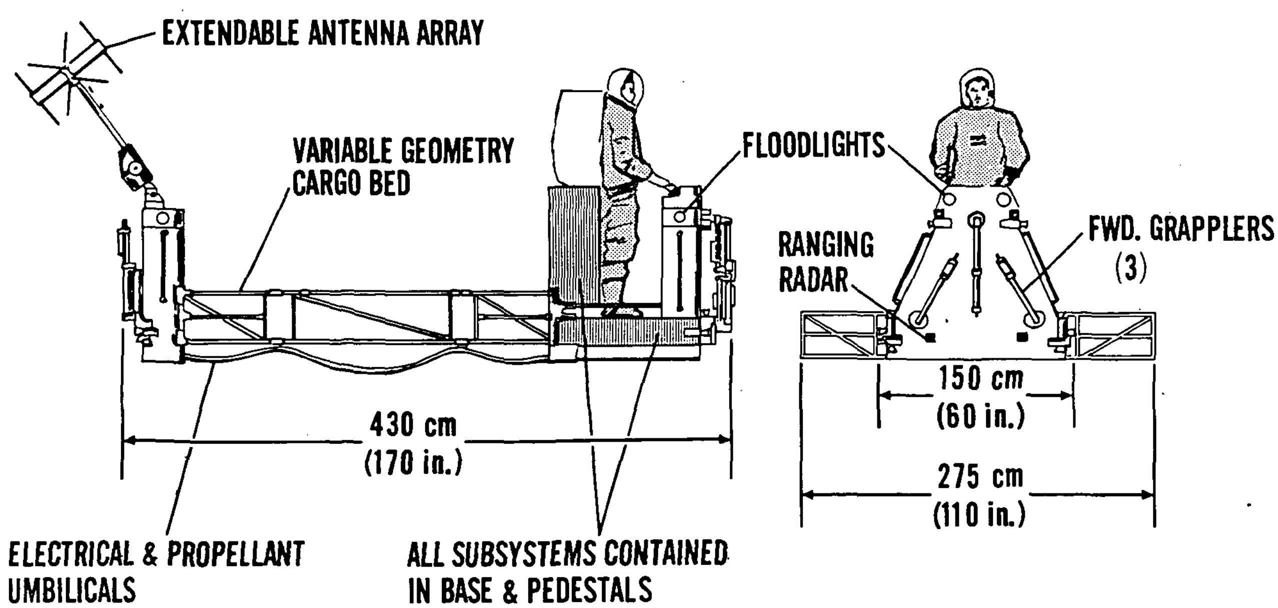


Figure 3-3. Maneuverable Work Platform - Extended Configuration

The top surface of the ECS/LS compartment provides a mount to secure the astronaut's Portable Life Support System (PLSS) or Astronaut Maneuvering unit (AMU) which is used to man the MWP from the parent spacecraft.

The aft module supports the aft grappler, the aft propulsion thrusters, and an extendable antenna. This antenna, which is controllable in azimuth and elevation, can be extended to a length of 6m (20 ft) to maintain line-of-sight communication with the parent spacecraft around an intervening work site.

The tools/spares module is designed in two sections with spare parts bins below and the tool box above. Covers for the tool compartment hinge to provide access; the upper covers form tool racks and the lower ones serve as work surfaces when open. The upper center panels of the tool bench serve for mounting gages, meters, test plugs and jacks for diagnostic and checkout equipment. The tool box will be accessible from either side, with the crewman restrained in a standing attitude on the "running boards."

The variable-geometry cargo frame is assembled without tools by means of quick-disconnect structural joints. The frame is made of interchangeable truss sections fabricated from welded aluminum tubing. Each section terminates in one-half of a sleeve-lock structural joint capable of transmitting structural loads in all directions. With the removable side sections inserted, the frame can be made approximately 2.5 m (100 in) square. Removal of these sections shortens the frame to 1.25 m (50 in) long.

The displays fall in two primary categories: Extravehicular Referenced Information (ERI) and Intravehicular Referenced Information (IRI). The former group pertains to the display of information required by the crewman to perform the flight control functions. The latter is concerned with the status of on-board systems. ERI parameters required for display in performing MWP missions are range and range rate. IRI requirements are derived from subsystem functions which have implications relative to mission performance or mission safety. These displays are subdivided into alerting and continuous displays. They provide information for several important parameters relating to: (1) electrical power system; (2) propulsion, stabilization and control; (3) communications; (4) docking and anchoring grapplers; and (5) environmental control and life support.

Total weight of one MWP (excluding crewman) 725 kg (1,600 lb). Stowed volume is approximately 4 m^3 (140 ft^3). Table 3-4 provides a weight summary for the MWP.

Table 3-4. Maneuverable Work Platform Weight Summary

	WEIGHT	
	kg	lb
Propulsion	39	85
ECS/LS	86	190
Electrical	98	215
Communications	14	30
Stability & CTL	5	10
Radar	4	10
Antenna	2	5
Grapplers	45	100
CTLS & Displays	7	15
Structure	86	190
Propellant	95	210
O_2	2	5
H_2O	11	25
LiOH	4	10
Pressure Suit	30	65
PLSS	30	65
Emergency O_2	2	5
Tools/Spares	120	265
Cargo Frame	45	100
Total	725 kg	1600 lb

3.4.2.3 Observation/Measurements Program. The objective of this experiment is to be satisfied by accomplishing the following tasks:

a. Define inflight maneuvers for:

   1. Mode 1 — Close Proximity Maneuvers

   2. Mode 2 — Remote Maneuvers

b. Perform ground simulations.

c. Perform inflight maneuvers and experimental tasks.

d. Correlate inflight and simulator results.

e. Establish optimized mission requirements and design criteria.

The optimized MWP is dependent upon mission and performance requirements such as length of EVA, number of EVAs, EVA range from parent spacecraft, mission work assignments, and desired flexibility. Satisfactory accomplishment of the aforementioned tasks will permit the establishment of hardware and technology requirements for the next generation MWP.

3.4.2.3.1 Define Inflight Maneuvers. Mission tasks for astronauts supported by the MWP included: point-to-point transfer; assembly and maintenance; resupply; inspection and observation; mass transfer; and rescue missions. The following identifiable elements are inherent to most maneuvering tasks which the MWP may be expected to perform.

a. Stabilization (maintain, within limits, a given attitude).

b. Attitude control (rotate to a desired attitude).

c. Translation (thrust without inducing undesired rotations).

d. Midcourse corrections (attitude and velocity).

e. Decelerate (retro thrust without inducing undesired rotation).

f. Docking and grappling (seize and secure to target).

g. Recovery (capability to recover from inadvertent tumbles or system failure).

The above elements will be incorporated into sets of maneuvering tasks which are dependent on the maneuver mode being performed. The maneuver tasks defined for each mode are:

Mode 1 — Close Proximity Maneuvers.

a. In retracted configuration, stabilize, orient to proper attitude, and translate to a point approximately 60 m (200 ft) behind parent spacecraft.

b. Stationkeep, maintaining attitude.

c. Orient, begin translation to spacecraft.

d. Perform midcourse attitude and velocity corrections.

e. Retrothrust and dock at spacecraft work platform.

f. Undock and translate to a point 30 m (100 ft) behind spacecraft.

g. Induce external force and evaluate recovery.

h. Translate to spacecraft and dock using forward grapplers.

i. Assemble MWP to the extended configuration.

j. Undock and transfer 225 kg (500 lb) mass to a point approximately 60 m (200 ft) behind spacecraft, then station keep.

k. Induce external force and evaluate recovery.

l. Translate to spacecraft performing midcourse attitude and velocity corrections.

m. Dock at spacecraft with forward grapplers.

n. Reassemble MWP to retracted configuration.

o. Terminate experiment.

Mode 2 — Remote Maneuvers.

a. In retracted configuration, stabilize, orient, and translate to a remote object approximately 2 km behind spacecraft.

b. Retrothrust without contacting object.

c. Stationkeep, maneuver around the object for inspection.

d. Reorient and begin translation to spacecraft.

e. Perform midcourse attitude and velocity variations.

f. Retrothrust and dock at spacecraft work platform using forward grapplers.

g. Assemble MWP to extended configuration.

h. Transfer 225 kg (500 lb) mass to remote position approximately 2 km behind the spacecraft and return.

i. Dock with spacecraft and reassemble MWP to retracted configuration.

j. Terminate experiment.

3.4.2.3.2 Perform Ground Simulations. The mission requirements and performance characteristics of the MWP will be programmed into an analog/digital flight simulator with a visual display. This "closed loop" simulation will provide a means to establish propulsion system operation, propellant consumption, stability and control, optimum accelerations, rates, and dead bands. These simulations provide an accurate representation of flight dynamics and flight article electronics and can be used to assure representative system response. The simulations will provide valuable astronaut training and establish the baseline data for the correlation analysis with inflight results.

3.4.2.3.3 Perform Inflight Maneuvers and Experiment Tasks. Following astronaut simulator training and evaluation of the data collected from simulator runs, inflight maneuvers and experiment tasks will be performed.

This experiment will consist of satisfactorily accomplishing such tasks as navigation, docking/anchoring, cargo transfer, astronaut rescue, space structure assembly, inspection, maintenance and repair. Performing the two modes of inflight maneuvers will provide for an evaluation of the navigation, docking/anchoring and cargo transfer capability.

Astronaut and immobilized MWP rescue will be demonstrated. During the EVA a second astronaut will be on standby with the second MWP. He will, on call, be sent to the aid of the "stricken" astronaut to supply emergency breathing oxygen and suit pressurization to the stricken EVA crewman. Transfer of the "immobilized" MWP to the spacecraft would also be performed in simulation of a propulsion system failure.

Space structure assembly will be demonstrated using both conventional and special power tools. Structural assembly in orbit will offer capabilities and limitations quite different from those afforded by the presence of gravity and atmosphere on Earth. Crewmen will be able to move and maneuver massive and expansive objects with the assistance of the maneuvering work platform. The MWP will be particularly useful in maneuvering and assembling large structure such as antennas and telescopes. Assembly in space involves the placement and attachment of components in proper alignment and relationship to each other. It is assumed that most of the alignment requirements will be taken care of in the design and fabrication phases. Joints must be designed to fit and lock in the proper orientation without external jigs or tooling. Numbering, color coding and non-matching ends may be used for complex assemblies. Close tolerance joints may also require vernier adjustment devices built into the assembly. Both antennas and telescopes require high accuracy boresighting. These problems will be evaluated in the performance of this experiment.

Maintenance and repair capability will be demonstrated by performing inspection, component replacement, drilling, cutting, and joining operations in the space environment. Components such as propulsion thrusters will be replaced to evaluate the astronaut's capability to perform such maintenance tasks. Simple drilling and cutting operations will be demonstrated. Such operations call for light weight tools, devices, and equipment which minimize the influence of center-of-mass change, and which operate without upsetting astronaut equilibrium. Universal type tools should be evaluated which function in a variety of applications with minor changes and within the capability of man operating in a space suit or repair vehicle.

The hard vacuum offers possibilities in the development and evaluation of new concepts in the materials joining processes.

Joining methods and equipment which may be evaluated are: exothermic brazing; ultrasonic, laser, and electron beam welding; fastener installation tools; cold welding; and adhesive bonding.

Observations and evaluations to be performed include not only the maneuverability, stability and control, and performance of the MWP, but astronaut requirements and procedures. These evaluations will consider such things as: physiological factors; personnel equipment limitations; crew hazards; supplementary equipment requirements; mobility and dexterity limitations; and training requirements.

All of the experiment inflight maneuvers and tasks will be performed four times by each of three astronauts. One crewman will perform the EVA while a second crewman is suited and prepared to perform a rescue operation using another MWP. The third crewman will observe. The crewman will alternate their roles during the conduct of the flight experiment. Each will make eight flights as a test subject with the MWP. The in-orbit test program will require approximately 60 days. Later repetitions of the flight tests may be performed, following changes to hardware design or operational procedures.

Closed circuit television aboard the spacecraft will be utilized throughout this experiment. The observer will control the motion picture camera operation to record specific sequences of events.

3.4.2.3.4 Correlated Inflight and Simulator Results. The purpose of the maneuvering work platform evaluation is to determine through simulation and verify through flight test:

a. Feasibility of the MWP.

b. Commitment required by the astronaut.

c. Capability to recover from temporary loss of orientation.

d. Performance of the MWP in terms of time, propellant efficiency, astronaut fatigue, and utility at the work site.

Feasibility will be demonstrated by an objective evaluation as to whether or not the mission was satisfactorily accomplished. Frequent or consistent failure to achieve a task objective will indicate the unit is not suitable for that function, e.g., failure to reach the target object in specified time or inability to approach the remote object and stationkeep in a given attitude.

Astronaut commitment will be subjectively evaluated by studying the margin of control the crewman had and the attention he could devote to performing maintenance and assembly tasks at the work site. This will be accomplished through astronaut comments and filmed data.

MWP ability to recover from external forces will be subjectively evaluated through pilot debriefing and filmed data. This ability will be objectively evaluated through instrumentation data of time to recover, accelerations, and rates obtained.

Performance of the MWP will be evaluated by analyzing propellant and/or electrical energy used in stabilization and propellant used in translation, docking, and stationkeeping. Time to perform individual maneuvers and accelerations will be evaluated. The piloting workload imposed on the astronaut will be investigated to determine his utility at the work site.

3.4.2.3.5 Establish Optimized Mission Requirements and Design Criteria. Each individual task of the experiment will be evaluated to determine if it should or should not be made a requirement for the MWP. Tasks requiring high consumption of propellant provide a limiting constraint by imposing that unreasonable amounts of propellant be carried. Tasks which induce undue fatigue on the astronaut will have to be revised or compromised. Detailed evaluation of the adequacy of command rates, angular accelerations, translational accelerations, and dead bands will be made from postflight debriefings, voice tapes, and studies of mission performance. This detailed analysis will permit the determination of optimum mission requirements and design parameters for the design of next generation maneuvering work platforms.

3.4.2.3.6 Instrumentation. Parent spacecraft instrumentation requirements for this experiment will consist of the following:

a. CCTV and video recorder.

b. Motion picture camera.

c. Voice communication link and recorder.

d. TLM receiver and data displays.

CCTV will be used throughout the experiment. Motion picture coverage is also required during the conduct of the experiment. One camera with color film, a 5 mm lens, run at 6 fps and with a remote control for starting and stopping the camera will be required. Sixty minutes of film without reload is needed. To minimize film quantity, only six hours of operations will be filmed. Voice will be recorded for both subject and observer.

Digital data transmitted from the MWP will be collected for the following parameters:

a. MWP thruster valve operations.

b. Propellant pressure.

c. Propellant quantity.

d. Propellant temperatures.

e. Translation commands.

f. Rotation commands.

g. CMG gimbal angles.

h. LSS status.

i. Battery current and voltage.

j. Astronaut physiological monitors.

The digital data rate desired to record this data is approximately 8,000 bits per second. This rate could possibly be reduced to 5,000 bps by selected reductions in samping rates and/or frequency response of some measurements.

3.4.2.4 Interface, Support and Performance Requirements. Facilities must be provided aboard the parent spacecraft to support three crewman and to house the experiment support equipment and consumables. During all EVA maneuvers a second astronaut will be suited and prepared to perform an emergency rescue using another MWP or an equivalent rescue vehicle.

An air lock must be provided to permit astronaut egress/ingress. It is desirable to have this air lock sufficiently large to accommodate the MWP. Servicing, inspection and repair of the MWP is desired in a shirtsleeve environment aboard the spacecraft.

Power requirements from the spacecraft are indicated in Table 3-5. It is not neccessary to operate the photo lights, battery charger of perform CMG spin-up simultaneously. Scheduling these operations separately limits the peak power demand to 400 watts during the MWP experiment.

Table 3-6 lists the volume and weight of the consumables required to support the MWP experiment. Orbital support equipment is itemized in Table 3-7.

Parent spacecraft propulsion thrusters must remain inoperative when the MWP is in close proximity. No maneuvering of the parent spacecraft will be permissible during MWP docking or undocking.

Table 3-5. Parent Spacecraft Power Requirements

EQUIPMENT	PEAK (WATTS)	AVERAGE (WATTS)
Camera	60	20
Photo Lights	300	300
TLM Receiver	10	10
Propellant Transfer Station*	40	20
Battery Charger*	250	210
CMG Spin-Up*	400	250
Maximum Spacecraft Power	400	330

*Not operating concurrently with camera, lights, and TLM.

Table 3-6. Experiment Consumables

	TOTAL WEIGHT kg	(lb)	VOLUME m^3	(ft^3)	COMMENTS
Hydrazine	500	(1100)	0.34	(12)	Positive propellant expulsion tank
O_2	68	(150)	0.09	(3)	12 Refills
Emergency O_2	3	(6)	0.006	(0.2)	2 Replacements (PLSS)
LiOH	45	(100)	0.2	(7)	
H_2O	270	(600)	0.2	(7)	Bladder equipped tank

Table 3-7. Orbital Support Equipment

	TOTAL WEIGHT kg	(lb)	VOLUME m^3	(ft^3)	COMMENTS
Propellant Transfer Station	28	(61)	0.1	(3.4)	20 Watts Average
Battery Recharge & Monitor Station	55	(120)	0.1	(3.4)	210 Watts

Table 3-8 summarizes the interface, support, and performance requirements for the MWP experiment.

3.4.2.5 Potential Role of Man. The MWP EVA evaluations are to be performed by three different test subjects. This will provide statistically reliable data on astronaut proficiency in maneuvers and navigation as well as fatigue level incurred due to work load.

Flight crew training will consist of hardware familiarization, procedural checks, fit checks, and simulations as appropriate. Flight simulations will be conducted using an air-bearing simulator and analog/digital computer programs. Several sessions on each are required.

Table 3-8. Interface, Support and Performance Requirements

Mass	1450 kg (3200 lb)
Volume	6 m^3 (200 ft^3)
Power	Peak: 400 watts Average: 330 watts
Crew Skills	Electromechanical Technician (3 Req'd)
Data Rate	Desired: 8 kbps Minimum: 5 kbps
Logistics Up (per 30 days)	450 kg (1000 lb)
Logistics Down (per 30 days)	10 kg (22 lb)
Pointing and Stability	No maneuvering of parent spacecraft during docking or undocking
Orbit Altitude and Inclination	NA
Unique Environmental Requirements	NA

3.4.2.6 Available Background Data

1. Definition of Experiment Program in Space Operations Techniques and Subsystems Executive Summary Report, NASA TMX-53705, dated February 12, 1968.

2. Independent Manned Manipulator, LTV Contract No. NAS8-20316, dated 15 November 1968.

3.5 FPE INTERFACE, SUPPORT, AND PERFORMANCE REQUIREMENTS

The two experiments outlined in this FPE are complementary as they both require many of the same life support considerations and experiment data support requirements. The data collection for the two experiments could be accomplished by a common recording module. Data requirements in terms of transmission rate is very comparable for the two experiments. Primary difference between the two experiments is the volume/weight increase and corresponding support requirements for the MWP. The FPE interface and support requirements are summarized in Table 3-9.

Table 3-9. FPE Interface, Support and Performance Requirements Summary

PARAMETERS		EXPERIMENTS AMU	MWP
Mass		120 kg (265 lb)	1450 kg (3200 lb)
Volume		0.6 m^3 (20 ft^3)	6 m^3 (200 ft^3)
Power	Peak:	370 watts	400 watts
	Average:	330 watts	330 watts
Crew Skills		Electromehanical Technician (3 Req'd)	Electromechanical Technician (3 Req'd)
Data Rate	Desired:	5 kbps	8 kbps
	Minimum:	3 kbps	5 kbps
Logistics Up (per 30 days)		100 kg (220 lb)	450 kg (1000 lb)
Logistics Down (per 30 days)		10 kg (22 lb)	10 kg (22 lb)
Pointing and Stability		Restricted maneuvering of parent spacecraft during EVA.	No maneuvering of parent spacecraft during docking or undocking
Orbit Altitude and Inclination		NA	NA
Unique Environmental Requirements		NA	NA

3.6 POTENTIAL MODE OF OPERATION

The potential modes of operation to be considered are:

<u>Mode A</u> Limited on-orbit stay-time attached to the Shuttle.

<u>Mode B</u> Extended on-orbit stay-time free flying, periodically revisited by the Shuttle.

<u>Mode C</u> Extended on-orbit stay-time attached to the Space Station, or in a free-flying mode supported by the Space Station.

The support requirements for these experiments can be accommodated in either Mode A or Mode C.

3.7 ROLE OF MAN

The same basic skills are required for the two experiments. Each requires a minimum of three crewmen with skills equivalent to an electromechanical technician. The same crewmen would be most appropriate in accomplishing both experiments.

3.8 SCHEDULES

The development and flight test schedules for the FPE experiments are shown in Tables 3-10 and 3-11.

Table 3-10. AMU Development and Flight Schedule

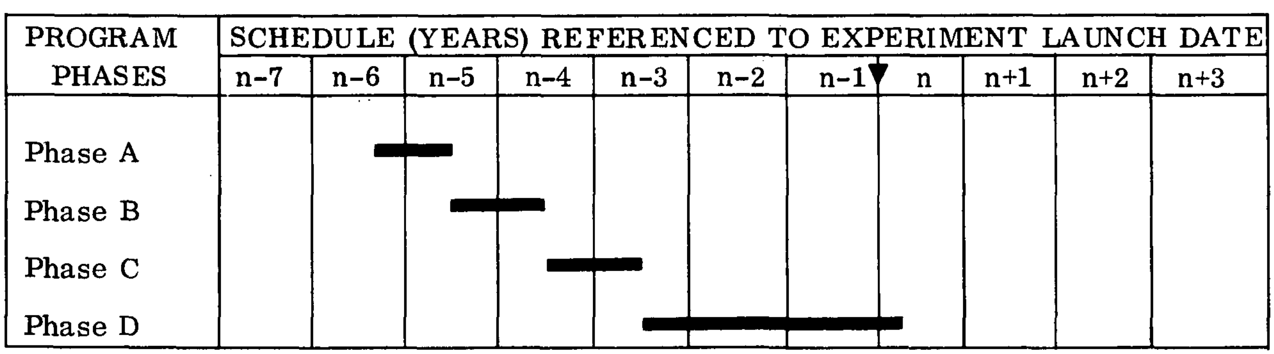
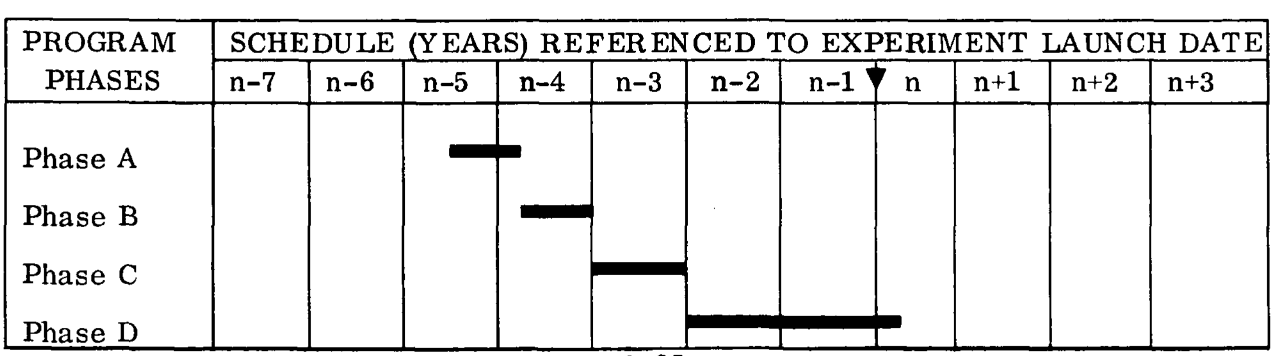


Table 3-11. MWP Development and Flight Schedule



3.9 PRELAUNCH SUPPORT REQUIREMENTS AND GSE

Principal GSE will include the propulsion system service cart, ECS/LS service cart, system test cart handling dollies and shipping containers for the MWP, and system test cart and shipping container for the AMU. GSE to be used during checkout at the launch site will also be utilized at the factory. No repair of the AMU or MWP is anticipated at the launch site. A failed unit would be returned to the factory for repair.

3.10 SAFETY ANALYSIS

Safety of the EVA astronaut is of primary concern. Among the most significant considerations are: (1) possibility of damage to the space suit and loss of life support; (2) getting snagged or caught on structure either directly or through tethers; (3) overexposure to thermal radiation; (4) losing contact with the parent spacecraft; (5) immobility or loss of control of the AMU or MWP. Serious injury could occur to the crewmen through loss of control in the vicinity of structures.

Possibility of damage to parent spacecraft equipment and structure should also be considered, particularly in docking operations involving the MWP. Fragile structures could easily be damaged, and/or precise optical alignments could be disturbed accidently.

Visibility is an accepted requirement if crews are to perform tasks effectively. In near-earth orbits, normal sunlight plus reflected light will be sufficient for most operations on the light side of the earth. Portable work lights will be required for dark side operations and key factors to be considered are the location and distribution of light to minimize deep shadow contrasts.

3.11 AVAILABLE BACKGROUND DATA

The background data from which this FPE description was prepared are listed in Sections 3.4.1.6 and 3.4.2.6.

VOLUME VII

SECTION 4

ADVANCED SPACECRAFT SYSTEMS TESTS

SECTION 4

ADVANCED SPACECRAFT SYSTEMS TESTS

4.1 GOALS AND OBJECTIVES

The goal of this FPE is the development of new technology which will benefit all phases of space flight. The objective of these experiments is to insure that advanced components and systems will function properly when integrated into the operational Space Shuttle, Space Station, or other future spacecraft.

These experiments are representative of the advanced systems that are currently envisioned, however, advances in technology could preclude the flight test of these specific experiments.

4.2 PHYSICAL DESCRIPTION

Twelve experiments are described in this FPE. The experiments may be categorized into six groups as follows:

a. Life Support

   4.4.1 - Oxygen Recovery and Biowaste Resistojet.

   4.4.4 - Absorption Refrigeration Cycle Experiment.

b. Maintainability

   4.4.2 - Maintainable Flight Electronics Package

   4.4.3 - Thermal Coating Refurbishment in Space

   4.4.6 - Maintainable Attitude Control Propulsion System

c. Exposure

   4.4.7 - Ball Bearing Lubrication

   4.4.10 - Space Exposure Effects on Material Bulk Properties

   4.4.11 - Space Exposure Effects on Material Fatigue Properties

d. Guidance Systems

   4.4.8 - Advanced Guidance Subsystems Evaluation

e. Safety Experiments

   4.4.5 - Leak Detection and Repair

   4.4.12 - Fire Sensing and Suppression

f. Calibration

4.4.9 - Space Calibration of Solar Cell Standards

The experiments detailed in this FPE fall into three general physical categories: those that are performed inside the spacecraft; those that are performed in an air lock; and those that are performed outside the spacecraft. Some experiments are conducted in two of the previously defined categories. Table 4-1 illustrates the physical location requirements for the experiments. In general, all of the experiments are "suitcase" in nature, in that they could be delivered on-orbit and installed in an orbiting spacecraft which is equipped with the necessary FPE interface as described in Section 4.5.

A brief description which summarizes the intent of each experiment is given in Table 4-2.

4.3 EXPERIMENT REQUIREMENTS SUMMARY

The requirements of the Advanced Spacecraft Systems Tests experiments are summarized in Table 4-3.

Table 4-1. Summary of Physical Location of FPE Experiments

Experiment Number	Title	EVA	Air-Lock	Inside
4.4.1	Oxygen Recovery and Biowaste Resistojet	●		●
4.4.2	Maintainable Flight Electronics Package			●
4.4.3	Thermal Coating Refurbishment in Space	●		
4.4.4	Absorption Refrigeration Cycle Experiment		●	●
4.4.5	Leak Detection and Repair	●	●	
4.4.6	Maintainable Attitude Control Propulsion System	●		●
4.4.7	Ball Bearing Lubrication		●	
4.4.8	Advanced Guidance Subsystems Evaluation	●		
4.4.9	Space Calibration of Solar Cell Standards		●	
4.4.10	Space Exposure Effects on Material Bulk Properties	●	●	
4.4.11	Space Exposure Effects on Material Fatigue Properties		●	
4.4.12	Fire Sensing and Suppression			●

Table 4-2. Experiment Summary

Number	Title	Description
4.4.1	Oxygen Recovery and Biowaste Resistojet	A CO_2 concentration unit, a Sabatier reactor, an electrolysis cell and an electrically powered resistojet integrated into an advanced system
4.4.2	Maintainable Flight Electronics Package	A representative assembly of several types of packaging, and fault detection techniques designed for maintenance evaluation
4.4.3	Thermal Coating Refurbishment In Space	Evaluation of representative thermal control, coating degradation in space and the evaluation of several repair methods
4.4.4	Absorption Refrigeration Cycle Experiment	A developmental refrigeration experiment designed to improve cooling system efficiency and thereby reduce radiator size
4.4.5	Leak Detection and Repair	An evaluation of developmental models and methods used for leak detection, location and repair
4.4.6	Maintainable Attitude Control Propulsion System	A representative monopropellant system designed to evaluate man's ability to effect necessary maintenance and repair of the system
4.4.7	Ball Bearing Lubrication	A variety of lubricants will be systematically tested in a space environment at various operating temperatures
4.4.8	Advanced Guidance Subsystems Evaluation	Astronomy and fluid management free flying modules are used as test beds for these subsystems
4.4.9	Space Calibration of Solar Cell Standards	An array of standard solar cells is tested in orbit to obtain calibration data from accurately known solar exposure
4.4.10	Space Exposure Effects on Material Bulk Properties	A wide selection of materials are systematically exposed to space conditions and data obtained on changes in their bulk properties
4.4.11	Space Exposure Effects on Material Fatigue Properties	A group of structural materials are exposed to space conditions and then tested in a fatigue machine
4.4.12	Fire Sensing and Suppression	A developmental group of fire detectors and suppression systems are given an evaluation test in zero-g conditions.

Table 4-3. Experiment Requirements Summary

Experiment	Weight Kg (lb)	Volume m^3 (ft^3)	Power MJ (kw-hr)	Crew Skills	Environ. Rqmt's	Expmt' Time Limits	Data Rqmt's	Pointing and Stability	Mode of Operation
4.4.1 Oxygen Recovery and Biowaste Resistojet	190 (420)	0.54 (20)	7500 (2070)	Electromech. Tech. (2)	Space Cond. for Thruster	3 mo	16.5×10^8 Bits	N/A	IVA/EVA; Airlock
4.4.2 Maintainable Flight Electronics Package	18 (40)	0.03 (1.2)	11.5 (3.2)	Electronic Engr. Electromech. Tech.	Shirtsleeve	60 hr	Notes, Film	N/A	IVA
4.4.3 Thermal Coating Refurbishment in Space	22 (50)	0.2 (9)	4500 (1300)	Electromech. Tech. Thermodynamicist	Space, with Solar Orientation	3 yr	4.7×10^8 Bits	Maximum Solar Pointing	EVA
4.4.4 Absorption Refrigeration Cycle Experiment	90 (200)	0.01 (3.5)	1000 (300)	Electromech. Tech. Mechanical Engr.	Shirtsleeve, Airlock for Radiator	3 mo	1.1×10^{10} Bits	Maximum Solar Pointing	IVA, Airlock
4.4.5 Leak Detection and Repair	9 (20)	0.06 (2)	50 (14)	Electromech. Tech. Mechanical Engr.	Shirtsleeve, Possible Exterior Exam.	3 mo	Notes, Film	N/A	IVA, EVA
4.4.6 Maintainable Attitude Control Propulsion System	45 (100)	0.15 (6)	32 (9)	Electromech. Tech. Mechanical Engr.	Space Exposure & Shirtsleeve	6 mo	Cine and Video Film 11 kg (25 lb)	N/A	EVA & Glovebox
4.4.7 Ball Bearing Lubrication	18 (40)	0.1 (4)	2680 (740)	Electromech. Tech. Mechanical Engr.	Space Cond. Away from Sun	3 mo	1.8×10^6 Bits	Away from Sun	Airlock, IVA
4.4.8 Advanced Guidance Subsystems Evaluation	70 (150)	0.2 (8)	110 (30)	Electronic Engr. Electromech. Tech.	Stability, Controlled g, Position	160 hr	2×10^{11} Bits	4.8×10^{-8} rad (0.01 arc-sec) 10^{-8} g	Remote Module
4.4.9 Space Calibration of Solar Cells	9 (20)	0.03 (1)	0.8 (0.22)	Electronic Engr. Electromech. Tech.	Solar Orientation	15 hr ea.	2.5×10^6 Bits	1.7×10^{-3} (0.1 deg)	Airlock Deployed

Table 4-3. Experiment Requirements Summary, Contd

Experiment	Weight Kg (lb)	Volume m^3 (ft^3)	Power MJ (kw-hr)	Crew Skills	Environ. Rqmt's	Expmt' Time Limits	Data Rqmt's	Pointing and Stability	Mode of Operation
4.4.10 Space Exposure Effects on Material Bulk Properties	160 (350)	(Area) 2 m^2 (20 ft^2)	740 (210)	Physical Chemist Electromech. Tech.	Space Envt. & Solar Orientation	2 yr	6.3×10^9 Bits & Specimen Return	Maximum Solar Exposure	EVA
4.4.11 Space Exposure Effects on Material Fatigue Properties	19 (42)	0.025 (0.8)	800 (500)	Metallurgist Physical Chemist	Space Envt.	2 yr	Specimen Return	N/A	Airlock, Vacuum Gloves
4.4.12 Fire Sensing and Suppression	103 (220)	0.15 (5.3)	8.6 (2.4)	Thermodynamicist Electromech. Tech.	Fireproof Chamber	3 mo	Film, Reports 9 kg (20 lb)	N/A	IVA

In general, the major impact that these experiments impose is that of crew time. They all require man as an active participant in test setup, operations, data correlation, and as a test subject in the maintainability experiments.

4.4 EXPERIMENT PROGRAM

It should be noted that these experiments are representative examples of Advanced Spacecraft Systems yet to be designed and fabricated, and by necessity are described in general terms.

4.4.1 OXYGEN RECOVERY AND BIOWASTE RESISTOJET

4.4.1.1 Technical Objective. This experiment is intended to provide a flight test of an integrated oxygen recovery/bio-waste resistojet propulsion system.

4.4.1.2 Description. The system, schematically shown in Figure 4-1, will have two major subsystems. The first is the biowaste reactor sub-system whose primary outputs are methane and water. The methane is used in the resistojet as a working fluid and the water is dissociated in an electrolysis cell for oxygen recovery. The experimental system will be sized to operate using the CO_2 produced by three crewmen.

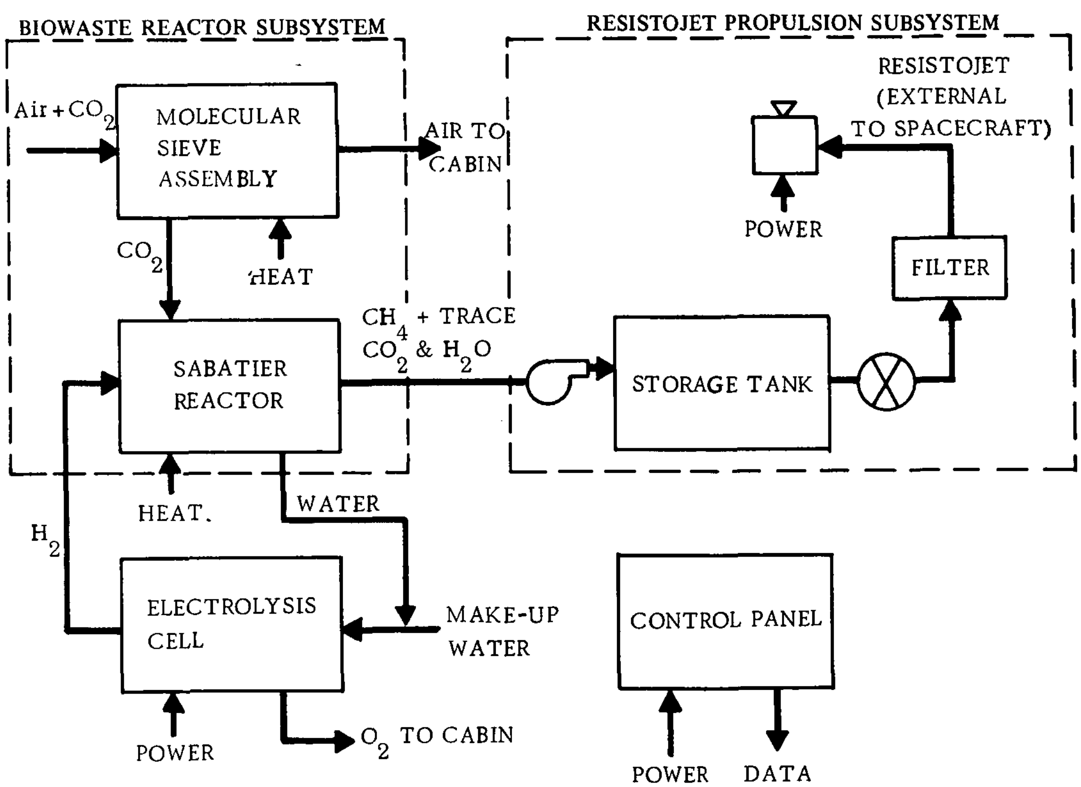


Figure 4-1. Oxygen Recovery and Biowaste Resistojet Experiment Schematic

The biowaste reactor subsystem will contain a molecular sieve for CO_2 concentration from cabin air. The concentrated CO_2 will be routed through a Sabatier catalytic reactor whose outputs are methane and water. The water will be routed to an electrolysis unit for reduction to H_2 and O_2. The H_2 will be fed back into the Sabatier reactor, and the O_2 will be recycled to the crew compartment atmosphere. The methane will be routed to the resistojet subsystem along with traces of CO_2 and water vapor.

The resistojet subsystem consists of an accumulator, pump, heater, filters, valves, and resistojet thrust chamber(s). Provision for drawing of a sample of the propellant gas for analysis will be made. This subsystem, or at least the thrust chamber(s), will be mounted externally on the spacecraft. At times when spacecraft attitude changes are required, the system will be available for providing attitude change impulse.

A control panel provides the power and data interface between the experiment equipment and the spacecraft.

4.4.1.3 Measurement Program. The experiment equipment may be delivered to the orbiting spacecraft as a "suitcase" type payload, or alternately could be installed prior to launch. The biowaste reactor subsystem will operate in parallel with the normal spacecraft life support system. The test period will be 90 days.

Data on the state of the system will be taken at an average of one sample per 10 seconds for each of 100 measurements. During the firing of the resistojet(s), the data system will monitor the resistojet performance at a rate of 100 samples per second for each of 20 measurements. The firing times will vary from less than 10 seconds to several minutes with an average of 30 seconds.

The experiment data will be processed and stored for periodic transmission to earth by the spacecraft data system.

4.4.1.4 Interface, Support and Performance Requirement.

4.4.1.4.1 Crew Support. The crew will mount the resistojet external to the spacecraft by the use of an air lock and integral mounting platform. Periodic checks of system operation will be made by the crew as well as any routine maintenance (e.g., cleaning the resistojet thruster). The control panel will be interfaced with the spacecraft RCS and be allowed to provide attitude control thrust as required by spacecraft operations.

4.4.1.4.2 Digital Data Communications. During the three-month test program, the basic data acquisition requirements will generate 9.3×10^8 total bits, assuming 12 bits per data sample. During the firing of the resistojet, data from 20 measurements would be taken at a nominal rate of 100 measurements/second for an average firing period of 30 seconds. These firings would total about 1000 during the life of the experiment, generating 7.2×10^8 data bits, for an experiment total of 16.5×10^8 bits.

4.4.1.4.3 Power. The Sabatier reactor, CO_2 molecular sieve and H_2O electrolysis systems will consume 900 W. The resistojet propulsion system will require a peak of 500 W and 40 W during standby, assuming an Isp of 200 and a thrust level of 0.45 N (0.1 lb). For a firing duration of 40 hours, total energy required is 7500 MJ (2070 kW-hr) for the 90 day test period.

4.4.1.4.4 Size and Weight. The oxygen recovery equipment will weigh 145 kg (320 lb) and have a volume of 0.27 m^3 (10 ft^3). The resistojet subsystem will weigh 45 kg (100 lb) and have a volume of 0.27 m^3 (10 ft^3).

4.4.1.4.5 Orbit Altitude and Inclination. No restrictions.

4.4.1.4.6 Data Return. Performance data from both the Sabatier reactor and the resistojet system will be relayed to Earth for complete analysis of system energy balances, resistojet specific impulse and similar performance calculations. Crew remarks on the maintainability and control of the system will also be reported.

4.4.1.4.7 Unique Environmental Requirements. The resistojet thrusters must be placed external to the spacecraft.

4.4.1.4.8 Special Prelaunch Requirements. None

4.4.1.4.9 Torque Outputs. During firing of resistojet thrusters, torques will be imparted to the spacecraft. To eliminate fuel expenditure, it is suggested that the experimental resistojet be used as a secondary RCS thruster.

4.4.1.5 Potential Role of Man. Crew members will supply the biowaste input to the reactor system. In addition, control of gas analysis, thruster firing, repair and maintenance of the system and initial installation of the system (if not previously installed) will be done by the crew. EVA installation and maintenance will be used only if the mission requirements dictate.

4.4.1.6 Available Background Data.

a. Gerald P. Star, "On-line Display of Pulsed Rocket Engine Performance Data," Proceedings of 15th International ISA Aerospace Instrumentation Symposium, May 1969, P. 297.

In addition, current and/or recent research work has been conducted under the following NASA contracts:

b. Technology Development of a Biowaste Resistojet, NAS 1-9474

c. Resistojet Studies Directed to the Space Station/Bus, NAS 1-10127

d. Space Station Program Definitions, NAS 8-25-140

4.4.2 MAINTAINABLE FLIGHT ELECTRONICS PACKAGE EXPERIMENT

4.4.2.1 Objective. The objective of this experiment is to evaluate under actual flight conditions an electronic packaging system designed for easy maintenance from the major assembly level down to the printed circuit board level. Various techniques of fault detection and correction as well as various packaging systems will be included in the experimental package. In addition to fault detection and repair, ease of system updating will be evaluated.

4.4.2.2 Description. The experimental package will consist of two or more packaging systems integrated into a single enclosure. Each system will contain several typical electronic circuits such as power supplies, discrete and LSI analog circuits, conventional integrated and LSI digital circuits, and RF circuits using both discrete and integrated circuits. Special emphasis will be placed on evaluation of fault detection and isolation methods, designs for ease of removing and replacing components, and on designs which permit updating of assemblies with new versions with a minimum of effort. Several methods used to connect wires will be evaluated. Candidates for these studies are: soldering, welding, wire-wrap methods, and crimped connections. Soldering operations will require the use of an enclosure equipped with a viewing port, captive gloves, and ports for installing and removing equipment. Removal of molten globules of metal will be one of the operations investigated.

4.4.2.3 Observation Program. During the life of the experiment, observer comments will be recorded as the primary data source. Time and motion studies of film taken during certain phases of the experiment will assist in making quantified conclusions regarding the merits of one kind of packaging versus another and in comparing the ease of repair of various construction methods. Assume 20 operations occur lasting three hours each.

4.4.2.4 Interface, Support and Performance Requirements

4.4.2.4.1 Crew Support Requirements. A crew member will be required to conduct the various phases of the experiment program. A second crew member will be required for filming those portions of the experiment to be used in a time and motion study.

4.4.2.4.2 Spacecraft Support Requirements. The experiment will require approximately 40 W of electrical power. Cooling for thermal control can be through the ambient station atmosphere or via heat pipes to the station ECS. Total energy required will be 11.2 MJ (3.2 kW-hr), assuming a 80-hour equipment-on period.

The experiment package will be mounted on a workbench during conduct of the experiment and will be stowed during periods of non-activity.

No special instruments will be needed for maintenance functions except those supplied as part of the experiment package.

General purpose instruments such as a DVM and oscilloscope will be required to perform subassembly testing.

The experiment package will weigh approximately 18 kg (40 lb) and have a volume of 0.03 m^3 (1.2 ft^3).

4.4.2.4.3 Data Requirements. Data requirements will be audio tapes or written notes and motion picture film or videotape. It is expected that no more than 9 kg (20 pounds) of notes and video tape will result from the entire experiment.

4.4.2.4.4 Summary of Other Requirements.

a. Gravity - Normal Spacecraft

b. Vacuum - None

c. Environment - Normal Spacecraft

d. Pointing - None

e. Attitude - None

f. Stabilization - None

g. Prelaunch Requirements - Stowage for launch only

4.4.2.5 Role of Man. The experiment is intended to investigate maintainability and requires the crew as active participants in the experiment.

Skill level required for the maintenance operations will be that of an Electromechanical Technician. An Electronic Engineer should be available for in-orbit evaluation of experiment results and to assist in troubleshooting.

The services of a photo technician may be needed for processing the films used in the time and motion studies.

4.4.2.6 Background Data. This experiment description revises the maintainability experiment described in FPE 5.24e, Maintenance and Repair, of the June 1970 Blue Book.

4.4.3 THERMAL COATING REFURBISHMENT IN SPACE

4.4.3.1 Objective. This experiment will evaluate materials, methods, and astronaut techniques for refurbishing thermal control coatings in the vacuum and zero-gravity environment of space.

4.4.3.2 Description. There has not been much long term experience with coatings having special radiative properties. Past design efforts in thermal control have utilized active thermal control techniques (shutters, etc.). This design approach is essentially overdesigning.

The types of damage to be studied include the effects of ultraviolet radiation, RCS plume impingement, waste dumps and micro-meteoroid impact. Analysis of the damage sustained and an assessment of the repairability of the coatings will be made. Measurements of the degree of degradation will be accomplished using instruments such as the portable spectro-reflectometer of the type described in Experiment 1.4.3, Surface Degradation Experiment, Section 1. In addition, photographs of the coating samples and temperature readings of the underlying structure will be used to assist in this analysis.

The coatings listed below are examples of candidate coatings for this experiment. Other coatings will be developed prior to the deployment of the experiment and will also be tested.

a. IITRI ZNO Silicone (S-13)

b. IITR ZNO Silicate (Z-9)

c. LMSC Thermatrol TiO_2 Silicone (6A-100)

d. Schjeldahl GT-1015.

The thermal control coating materials will be applied to sample plates simulating a spacecraft structure or radiator surface. The sample plates will be installed on exposure racks mounted on the spacecraft exterior for varying durations up to three years. Four exposure racks will be employed. Each rack will accommodate eight 15 × 30 cm (6 × 12 in.) sample plates. Each sample plate will be instrumented with temperature transducers which can be monitored and recorded within the spacecraft. An instrumentation panel will interface the four exposure racks with the spacecraft power and data subsystems. The experiment apparatus is schematically shown in Figure 4-2.

Periodically an EVA astronaut will inspect the test samples and make measurements of the extent of degradation incurred. When the degradation exceeds specified limits, the coating samples will be refurbished. Refurbishment of these surfaces will be accomplished by various methods such as cleaning, painting, vacuum deposition, and

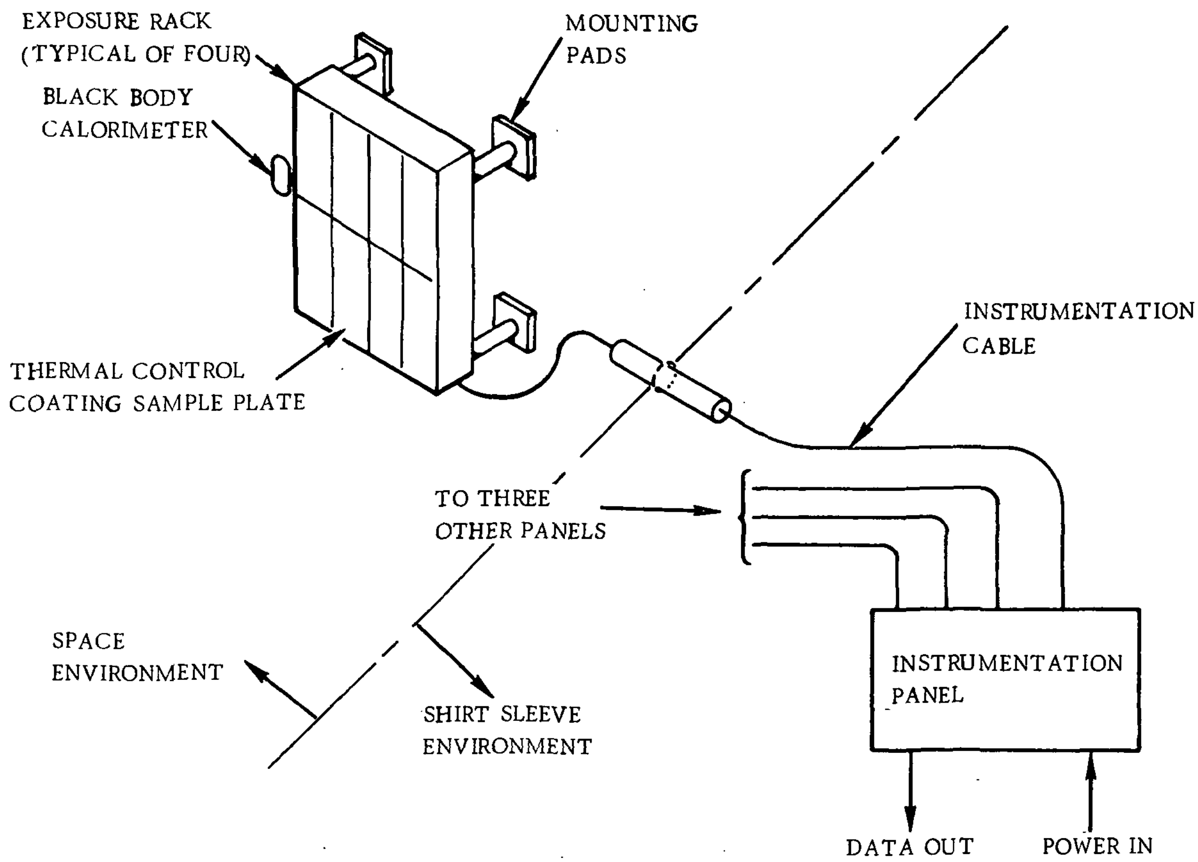


Figure 4-2. Thermal Control Coating Refurbishment Experiment Equipment

the application or removal of thermal control tapes. Effectiveness of the repair will be determined by comparing the temperatures of the sample plates before and after refurbishment, and by measuring the extent to which the original optical properties of the surfaces have been restored.

Refurbishment will be accomplished using EVA tools and procedures which, if successful, can be scaled-up to be used for operational spacecraft maintenance.

In addition to the planned repair of the simulated spacecraft surfaces, several of the samples will be sent to Earth in protective containers for further study and evaluation of the protective surfaces.

4.4.3.3 Measurement Program. The radiation properties of each test panel will be determined by temperature data and by the spectro-reflectometer. The range of temperatures is from 122 to 394°K measured to ±0.5°K. For control purposes, a black body calorimeter will be mounted on each exposure rack, and its output signal recorded at frequent intervals. A record of spacecraft position and attitude will also be made.

Temperature data will be obtained at a rate of one set of data per hour for each of the 32 sample plates and the four calorimeters. This data will be digitized and acquired by the spacecraft digital data subsystem. The data requirements are 5 bits per second for a total of 4.7×10^8 bits for an experiment life of 3 years.

In addition to the temperature and spectroreflectometer data logging, EVA crew members will use voice communication recording for remarks on visual appearance of the sample panels and will take still photos of the panels.

To preclude radiation and micro-meteorite damage to the black-body calorimeter reference, a shutter will be used to cover it except during the period of data acquisition. In addition, a periodic check and replacement with an alternate calorimeter will be made.

4.4.3.4 Interface, Support and Performance Requirements

4.4.3.4.1 Crew Support. The experiment is designed to determine the feasibility of in-orbit replacement, by crew members in EVA garments, of various types of thermal control coatings. As such, EVA excursions are an important part of the experiment. It is estimated that 20 EVA excursions per year will be required during the three-year life of the experiment for a maximum of one hour EVA per excursion. Occasionally, as during refurbishment of a specific panel, a second crew member will be required to provide EVA photographic coverage of the repair operation. This coverage may be accomplished by IVA if the experiment panels are located adjacent to a viewing port.

Retrieval of specific specimens for return to Earth in sealed containers will also be required by crew members. Occasional replacement and repair/recalibration of the black-body reference will have to be made which will require a short EVA and some activity in the general purpose laboratory. It is estimated that this replacement will be done every six months.

4.4.3.4.2 Data Communications. The sample plate temperature data rate will be 5 bits per second. In addition, cine film or video magnetic tape of the EVA operations will be produced. It is estimated that 25 hours of film will be produced throughout the life of the experiment. These photo coverage records will be supplemented by audio recordings of the crew during and following the EVA activities.

4.4.3.4.3 Power. The instrumentation panel which is designed to condition the temperature signals to levels compatible with the on-board digital data system and to control the shutter on the black body will require 40 W of power, for a total energy requirement of 4500 MJ (1300 kW-hr).

The cameras used for filming the EVA activities will consume approximately 50 W for cine film, and 400 W for the video camera-recorder combination, requiring 20 MJ (5.6 kW-hr).

4.4.3.4.4 Size and Weight. The exposure racks will have a total volume of 0.22 m^3 (8 ft^3) and weigh 18 kg (40 lb). The instrumentation panel will have a volume of 0.03 m^3 (1 ft^3) and weigh 5 kg (10 lb).

4.4.3.4.5 Pointing and Stabilization. The experiment requires that the sample panels be exposed to sunlight the maximum amount of time that flight vehicle orientation scheduling will allow.

4.4.3.4.6 Thermal Control. The experiment is designed to give information on thermal control coatings. As such, the exterior panel assembly will use no thermal control power except as required by the black body reference calorimeter. The instrumentation panel will be cooled by the ECS coolant loop.

4.4.3.4.7 Orbit Altitude and Inclination. No restriction.

4.4.3.4.8 Data Return. Data from this experiment consists of temperature and optical properties data from the sample plates, crew member reports on the ease of applying a refurbishment coat on various plates, cine film or video tape of EVA activities, still photos of various plates and the return to Earth of various test plates. The temperature data represents a total of 4.7×10^8 bits of data for the experiment life of three years. The cine film required will represent 60 kg (125 lb) for the 25 hours of film. If video tape recording is used the data would be telemetered to ground and the tape reused. The return of panels and still photos represents a return weight of approximately 22 kg (50 lb).

4.4.3.4.9 Unique Environments. Maximum sunward orientation of the panel array is desired.

4.4.3.4.10 Special Prelaunch Requirements. There are no special prelaunch requirements.

4.4.3.5 Potential Role of Man. The experiment activity includes putting the sample plates in position, removing sample plates, applying adhesive tapes, spraying coatings, operating cleaning devices, and taking measurements with the spectroreflectometer. Film coverage and crew reports will be used to document the role of man during the experiment.

4.4.3.6 Available Background Data. Current and/or recent research work has been conducted under the following NASA contracts:

a. Investigation of Transient Degradation/Contamination of Thermal Coatings, NAS 8-26004

b. Integrated Real Time Contamination Monitor, NAS 8-26132

c. Solar Reflectometer, NAS 8-20676

d. A Study of Proton Incident Effects on Reflective Surfaces of Space Mirrors, NAS 1-7627

e. A Study of Gas Surface Interaction in the Upper Atmosphere, NAS 5-11163

4.4.4 ABSORPTION REFRIGERATION CYCLE EXPERIMENT. The absorption refrigeration cycle has potential application for advanced spacecraft environmental control systems. Since the radiator operates at higher temperature than in conventional fluid loop systems, radiator size could be reduced, and aging effects on thermal control coatings are less critical.

4.4.4.1 Objectives. The objectives of this experiment are to verify the design of components in the fluid system which may be affected by low-gravity conditions, and to obtain performance data for the overall system.

4.4.4.2 Description. The experimental absorption refrigeration cycle system will include the following elements: gas absorber, generator, desorber, a simulated spacecraft condensing radiator, an evaporator, and a method of providing heat input to the system. The experiment apparatus is shown schematically in Figure 4-3.

The processes which are gravity-dependent are those occurring in the absorber, the desorber, the condensing radiator, and possibly the evaporator.

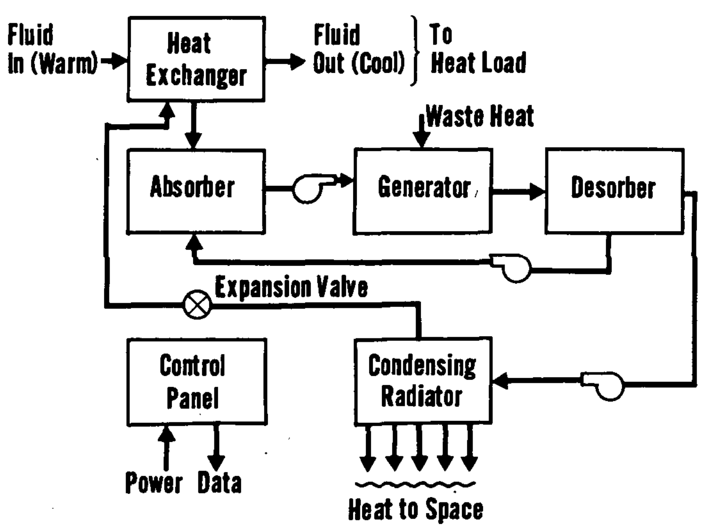


Figure 4-3. Absorption Refrigeration Cycle Experiment Schematic

4.4.4.3 Observation/Measurement Program. Following delivery into orbit, the experimental absorption refrigeration system can be set up using the facilities of a general purpose laboratory. The radiator will have to be mounted externally on the spacecraft structure or deployed from an airlock. During operation, it will usually be oriented toward the Sun as a "worst case" heat sink.

Heat input could come from the station ECS or, if this is not practical, from electric heaters.

Electric power for the system pumps and boiler heating power must be provided.

The system will be furnished with various transducers for measurement of system performance. It is assumed that 50 channels of data will be required so that the system performance can be accurately determined and subsequently modeled on a computer.

It is assumed that the measurement program will last for 100 hours over an in-orbit period of three months.

A number of different parameters will be varied during the experiment program. These include: heat input; system flows and pressures; radiator effective area; and the make-up of the two phase refrigerant-absorbing liquid system.

During the conduct of the test, the 50 data channels will be monitored at a rate of 50 readings per second.

4.4.4.4 Interface Support and Performance Requirements

4.4.4.4.1 Crew Support. The crew will be required to unpack the refrigeration system, set it up in the general purpose laboratory, perform the experiment and return the system to Earth.

None of these activities will require EVA if the radiator is deployed from an airlock.

4.4.4.4.2 Digital Data Requirements. The sampling of 50 channels per second of 12 bit accuracy data will require that the general purpose lab equipment and the refrigeration system be interfaced with the spacecraft digital data system.

The experiment will collect 1.1×10^{10} bits throughout its lifetime.

4.4.4.4.3 Power. The refrigeration system will require 3000 W of thermal energy to handle 500 W of simulated ECS input if actual ECS heat input is not used. For the 100-hour test period, the energy requirement will be 1000 MJ (300 kW-hr). With no standby power, this is also the energy requirement for the 90-day in-orbit period.

4.4.4.4.4 Size and Weight. The experiment equipment will weigh about 90 kg (200 lb). The equipment installed within the general purpose laboratory will have a volume of 0.1 m^3 (3.5 ft^3). The radiator, having a deployed area of about 18 m^2 (200 ft^2), will occupy a volume of about 2.2 m^3 (80 ft^3) prior to deployment from the airlock.

4.4.4.4.5 Pointing and Stabilization. The airlock in which the system radiator is mounted must be pointed toward the Sun for a large percentage of the time. Exact position is unimportant.

4.4.4.4.6 Thermal Control. The thermal control coating of the radiator will be used to transfer the system heat to deep space at the design temperature. The rest of the system is located within the general purpose laboratory and requires no special thermal control.

4.4.4.4.7 Orbit Altitude and Inclination. No restriction.

4.4.4.4.8 Data Return. The test data acquired during the 100-hour test period over the three-month mission will be handled by an automatic data acquisition system. This data, stored on magnetic tape or other storage media, will be periodically transmitted to Earth as digital telemetry data.

Upon conclusion of the test, the refrigeration system will be returned to Earth.

4.4.4.4.9 Unique Environmental Requirements. The system radiator must be in an airlock open to space conditions during the time that the system is working.

4.4.4.4.10 Special Prelaunch Requirements. No restrictions.

4.4.4.4.11 Torque Outputs. None

4.4.4.5 Potential Role of Man. As an active investigator, man will control the conduct of the test, and will adjust and modify the refrigeration system and its components as design problems are discovered during the test runs. Flow rates, pressures and emissivity of radiators are examples of parameters that will, by design, be amenable to in-orbit control.

4.4.4.6 Available Background Data. A development program and prototype fabrication task will be completed by Lockheed Missiles and Spacecraft in June 1971.

4.4.5 LEAK DETECTION AND REPAIR

4.4.5.1 Objectives. The objectives of this experiment are to evaluate and verify the performance of various leak protection systems considered applicable for an orbiting space station or other extraterrestrial vehicle. Included in this concept of leak protection are all of the activities required for the detection, location and repair of leaks.

4.4.5.2 Description. During this experiment, efforts will be expended to develop and qualify advanced leak detection, location and repair techniques. Test apparatus will be transported to orbit and installed in a spacecraft laboratory. The test apparatus will consist of equipment for detecting, locating and repairing leaks purposely caused in test panels installed in a laboratory airlock. Repair techniques will consist of self-sealing foams or other viscous fluids that harden to impermeable films when exposed to vacuum, special plugs, or substances to be applied by a crew member after locating the leak. Numerous leak detecting methods have been proposed and some have had preliminary tests conducted, but, to date none seem to fit the overall requirements of a leak detecting, locating, and repair system. Hopefully a suitable system will evolve within the next few years and show promise as a system applicable to Space Station and Space Base requirements.

The maximum permissible leak rates now thought acceptable are 0.04 kg per day per meter of seal on active hatches plus 0.1% of volume lost per day for all other sources.

These rates can be considered the low limit for a leak detection system. The upper limit for such a system is about 45 to 54 kg (100 to 120 lb) of gas lost per hour for a 1.2 cm (0.5 in.) diameter hole. This rate would reduce the pressure from 95 kN/m^2 (14 psia) to 40 kN/m^2 (6 psia) in 1 hour from a 30 m^3 (1000 ft^3) chamber.

Detecting leaks within the range described above will require action to be taken in proportion to the rate of the leak. If a decision to repair a leak is made, the system must then provide a means of locating the leak. This will be most easily accomplished if the leak is large, when it would be characterized by audible sounds within the compartment, and by gas and/or ice crystal clouds in the vicinity of the vacuum side of the leak. For slow leaks, somewhat in excess of the minimum acceptable rates, the system must provide means for locating the leak even though it is surrounded by other small leaks. A possible instrument might be a mass spectrometer adjusted to respond to nitrogen or carbon dioxide. Another possible instrument might be one attuned to the emissions of a tracer gas which could be introduced into a chamber which has a leak.

4.4.5.3 Observation/Measurement Program. The evaluation and verification program of leak detecting, locating and repair concepts will require numerous measurements by various pieces of support equipment. The detection of the presence of a leak whose rate is just slightly more than the maximum allowable is probably the most difficult task. Experiments will be performed using test panels mounted in an airlock chamber to evaluate the various instruments designed to detect such a leak. The instrument used to locate a specific leak and for determining its leak rate may or may not be the same instrument.

Following the evaluation of the leak detection and location systems in the test panels, various types of sealant systems will be tried. Development of viscous fluids for small leaks and self-adhesive patches for large ones will be accomplished.

Data from these tests will be mostly narrative in nature, as the crew members perform the evaluation of the various systems. It is assumed that there will be four types of leak detectors/locators evaluated and four types of sealant systems evaluated, during a period of 12 weeks.

4.4.5.4 Interface, Support and Performance Requirements

4.4.5.4.1 Crew Support. Active support in performing the experiment is needed from the crew. It is anticipated that the test program for the experimental detectors and sealant systems would occupy two crewmen for 12 weeks. This would include 20 hours of EVA by one crewman during evaluation of external leak sensing and repair systems.

4.4.5.4.2 Digital Data Communications. None required.

4.4.5.4.3 Power. The equipment that will require power are the developmental leak detector, flowmeter, pressure sensing device with alarm. The total power requirement for these devices will be 50 to 200 W during operation, for a total energy requirement of 25.2 MJ (7 kW-hr).

4.4.5.4.4 Size and Weight. The leak detector, which will probably be a development of the "quadrapole" type, will probably weigh from 1.3 to 4.5 kg (3 to 10 lb) and have a volume of no more than 0.03 m^3 (1 ft^3). The other equipment will probably weigh no more than 4.5 kg (10 lb) and have a volume of less than 0.03 m^3 (1 ft^3).

4.4.5.4.5 Pointing and Stabilization. No requirement.

4.4.5.4.6 Thermal Control. No thermal control requirements except for the cooling requirements of the sensor electronics.

4.4.5.4.7 Orbit Altitude and Inclination. No restrictions.

4.4.5.4.8 Data Return. Experiment data will consist of test reports, either verbal or written, describing the ability of the sensors to detect the presence of a known leak and to measure the leak rate, and an evaluation of the effectiveness of the various methods used for leak stoppage.

4.4.5.4.9 Unique Environmental Requirements. An airlock will be used as a test chamber. Leaks of known rates will be introduced into test panels installed in the pressurized airlock while the experimental equipment is used either within or on the outside of the airlock.

4.4.5.4.10 Special Prelaunch Requirements. None required.

4.4.5.4.11 Torque Outputs. There will be some torquing of the spacecraft during the venting of large leaks, e.g., 2.5 cm (1 in.) in diameter.

4.4.5.5 Potential Role of Man. Man will be used as a full time experimenter in this experiment. He will be required to handle the test detectors, patch leaks, and report on the test results.

4.4.5.6 Available Background Data

a. Tradeoff Study and Conceptual Designs of Regenerative Advanced Integrated Life Support Systems, Contract NAS-1-7905, Hamilton Standard Division of United Aircraft Corp., Pages 110-115.

b. Requirement Study for a Bio-technology Laboratory for Manual Earth Orbiting Missions, Final Report Volume I, McDonnell Douglas Corp.

4.4.6 MAINTAINABLE ATTITUDE CONTROL PROPULSION SYSTEM

4.4.6.1 Objective. The objective of this experiment is to evaluate under actual EVA space flight conditions the maintainability of an attitude control propulsion system.

4.4.6.2 Description. One or more reaction control systems using high temperature gas jets will probably be used to help control the advanced spacecraft attitude, and to overcome atmospheric drag. These systems may also be used to maneuver prior to docking with another spacecraft. Attitude and drag control may be accomplished by very small thrust engines which could, for example, use electrically heated gases and vapors from space station waste products. Larger engines may use either monopropellants or bipropellants with the main emphasis on propellant storability and "cleanliness" of the exhaust products (that is, exhuast products which will form minimum harmful deposits on the exterior of the spacecraft and its related equipment).

Obviously, these rocket engines will be designed for high reliability over a long life period. However, it may not be economically practical to obtain unlimited life or reliability, and repairs or replacement of parts or subassemblies must be a part of the equipment design and anticipated operational maintenance activities. In particular, thruster nozzles, valving, or other control components may have to be replaced.

A sketch of a proposed experimental system is shown in Figure 4-4.

In this experiment, replacement of a complete thruster module subassembly and replacement of critical components (such as thrusters, regulators, and valves) will be conducted under EVA conditions. With a system utilizing liquid propellants, the feed line cannot be parted or opened without depressurization and purging to remove excess propellant. To reduce complexity and increase reliability, manual shutoff and purging valves may be considered which would require EVA manipulation. Removal and replacement of components will also require EVA manipulation, and will require special wrenches and possibly other tools. The astronaut will also have to use foot and body restraints to exert forces and torques while working. Resupply of propellant and pressurization fluid will also be required.

The established procedures for servicing the RCS will be evaluated and possibly revised as a result of this experiment. The final evaluation will decide on the adequacy of tools, body restraints, and hardware arrangement relative to replacing RCS parts or subassemblies. Familiarity with EVA maintenance will be obtained by the participating astronauts so that enforced repairs may be completed with satisfactory foreknowledge of the time required and possible problem areas.

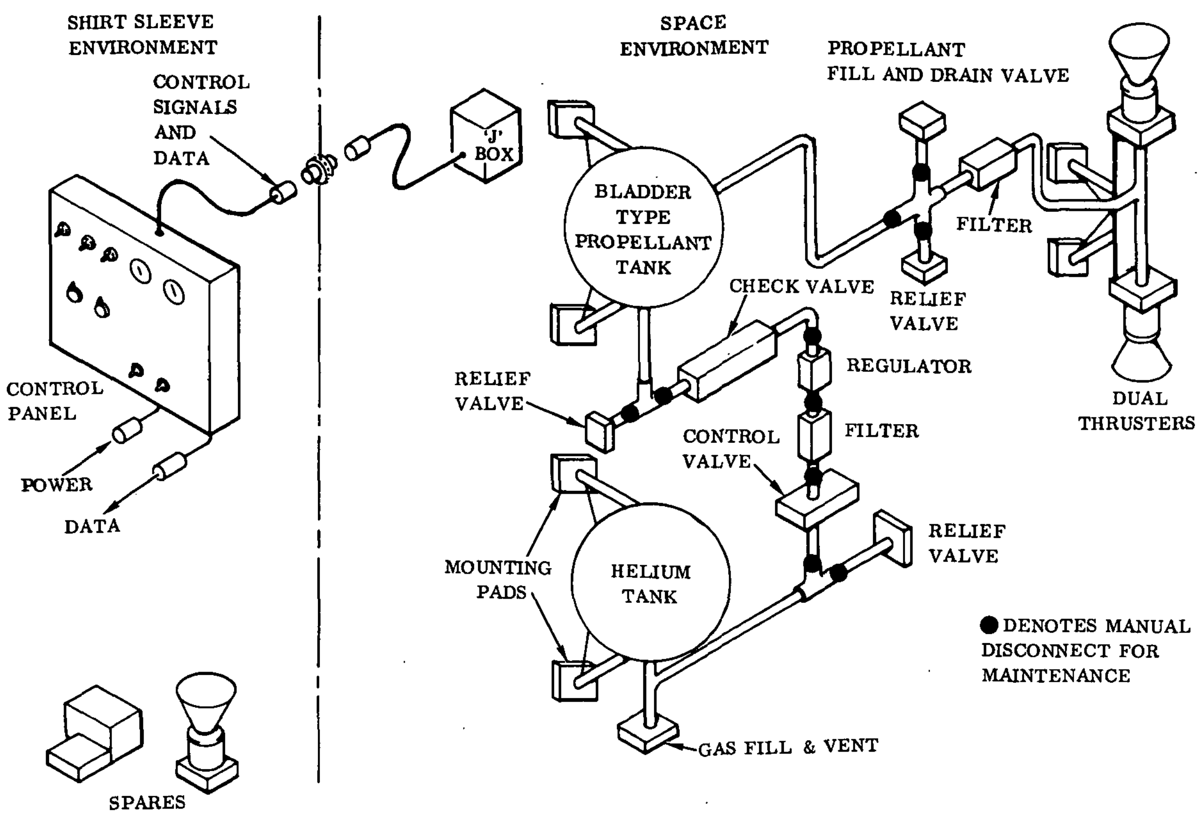


Figure 4-4. Maintainable Attitude Control Propulsion System

In addition to the EVA maintenance activities, other on-board maintenance activities will be investigated to study possible problems related to toxic liquids and gases within the maintenance work area, and will evaluate maintenance equipment and procedures. A general purpose workshop area would suffice for these studies, provided that adequate protection can be given to equipment and crew from hazardous RCS liquids and gases. Glove box enclosures should be employed for confining the toxic fluids, and for preventing contamination of the components being serviced.

Maintenance activities will be observed by another crewman either directly or through a remote TV camera. Performance of the astronauts will be evaluated with regard to time to complete the assigned tasks, wasted motion, ease of manipulating tools and parts, etc.

4.4.6.3 Observation Program. The observations and measurements to be made are:

a. Time to complete a specified task.

b. Physical movements of astronaut during the maintenance and/or repair activity.

The tasks to be accomplished in a typical EVA excursion are as follows:

a. Prepare tools, replacement part(s), and body restraints.

b. Prepare camera and related equipment.

c. Prepare EVA suit and life support pack.

d. Put on suit, attach tools, hardware and camera. (A second astronaut will suit-up and be immediately available for emergency aid or rescue.)

e. Exit spacecraft through airlock.

f. Mount camera on spacecraft skin so that working area is covered. (This step is omitted if work area can be viewed from window.)

g. Attach body restraint harness (or cage, etc.) at work site.

h. Proceed with maintenance operations.

i. Detach body restraints, camera, etc., and return to spacecraft through airlock.

The six-month experiment mission will include five hours of intermittent propulsion system firings interspersed with 10 EVA maintenance tasks lasting about 1 hour each.

On-board maintenance tasks will consist of disassembly, repair, cleaning, and reassembly of propulsion system components. Time required to complete specific tasks, adequacy of tools and equipment, and the safety aspects of on-board handling of hazardous fluids will be evaluated. On-board tasks will consist of 80 hours of maintenance activities.

Experiment results will be evaluated as soon as possible after maintenance tasks, so that desirable procedure changes can be incorporated into subsequent steps of the experiment.

4.4.6.4 Interface, Support and Performance Requirements

4.4.6.4.1 Crew Support. One crew member will be required to accomplish the various phases of the experiment. Another crew member will be required to film the activities and assure that voice comments are properly recorded. Following each phase of the experiment, a critique of the operations will be conducted to determine if any procedural changes should be made which would affect the following phases of the experiment.

4.4.6.4.2 Communications Support. Standard EVA communications support will be required during the experiment as well as a sound-on-film cine camera or audio recording on video tape of the experiment voice communications.

4.4.6.4.3 Power Requirements. It is anticipated that about 400 W of power will be required for the TV camera/recorder and 50 W for the cine film camera. The experimental propulsion system control panel will need 50 watts of power. Total maximum energy required will be 32.4 MJ (9 kW-hr) assuming 100 hours of system operation and 10 maintenance operations.

4.4.6.4.4 Pointing and Stabilization Requirements. No specific pointing requirements exist, except that some of the experiment phases should be accomplished in direct sunlight and some in the Earth's shadow so as to evaluate the relative difficulty of working under various illumination levels. No specific stabilization requirements exist, except that the EVA astronaut should be warned prior to significant attitude changes to preclude accidental loss of experiment tools or components, and to avoid thruster plume impingement.

4.4.6.4.5 Thermal Control. No requirements for thermal control exist.

4.4.6.4.6 Data. Propulsion system instrumentation will output data at a rate of 10 kbps while the system is operating, and at a rate of 0.1 kbps when not operating. If the time and motion data are taken via a sound-on-film cine camera, then the use of approximately 10 rolls of film weighing 11 kg (25 lb) is anticipated. If the data is recorded on video tape, it could be telemetered to ground stations for recording and subsequent analysis.

4.4.6.4.7 Unique Environmental Requirements. The standard spacecraft EVA environments are required to support the conduct of the experiment. The film or TV camera may have to be mounted on the outside of the spacecraft if a viewport is not available for filming the experiment activity. A standard EVA airlock must be provided. An external mounting base for the experimental RCS module is needed with nearby feed-throughs for commands and data. Restraint strap mountings must also be located adjacent to the experimental area.

4.4.6.4.8 Prelaunch Requirements. No special prelaunch requirements exist.

4.4.6.4.9 Torque Outputs. Occasional venting of pressurant gas and operation of a single RCS experimental thruster will induce torques to the spacecraft.

4.4.6.4.10 Summary of Interface and Support Requirements

a.	Crew Support	One subject astronaut, one observer astronaut
b.	Communication	Standard EVA with recording
c.	Size	Experimental RCS 0.15 m^3 (6 ft^3)
d.	Weight	Experimental RCS 45 kg (100 lb)
e.	Power	50 W; 32 MJ (9 kW-hr)
f.	Pointing	No requirement
g.	Stabilization	No requirement - Warning to EVA crew if stabilization movements are to occur
h.	Thermal Control	None
i.	Data Return	Movie film or video data link
j.	Unique Environments	Standard EVA suit environment
k.	Prelaunch	No requirements
l.	Torque Outputs	Some minor torques
m.	Thruster Fuel	Per Month: 75 kg (165 lb)

4.4.6.5 Role of Man. This experiment requires that man function in an active role since his ability to perform various maintenance operations is an integral part of the experiment.

Crew skills required for the subject and observer are those of an electromechanical technician. The experiment will be conducted under the supervision of a mechanical engineer.

4.4.6.6 Available Background Data. Current and/or recent studies have been conducted under the following NASA contracts:

a. Phase B Space Station Study; NAS 8-25140

b. Resupply/Repair of Monopropellant Subsystems; NAS 8-26194

c. Resupply/Repair of Solid or Hybrid ACPS; NAS 8-26196

d. Space Station Propulsion, Resupply, and Repair; NAS 8-25067

4.4.7 BALL BEARING LUBRICATION

4.4.7.1 Objective. This experiment is intended to evaluate several wet and dry lubrication systems for long term operation in space. The experimental environment will consist of vacuum and various bearing temperatures.

4.4.7.2 Description. The experimental setup will consist of a mounting system provided with 24 holding receptacles designed to hold 24 electric motors, each equipped with two bearings. Each of the bearings will be mounted so as to obtain a different thrust load.

Each motor, currently planned to be direct current motors, will have electrical power connections and tachometer connections arranged to mate with similar connections mounted on the basic mounting system.

A motor control system will provide power to each motor, provide overcurrent cutout circuits for those motor/bearing systems which have failed, tachometer signal processing circuitry which will determine constant current speed and run-down time for each motor/bearing system and a timing system which will turn the motors on for a specified time, remove power (to allow for run-down time measurement) for a specified time, and sequence the heating of the mounting system. The control system will have operational controls mounted within the spacecraft for access by the crew. Data from the experiment will be digital in nature and can be easily processed and stored for eventual transmission to Earth. The number of bits per 24 hours to report on experiment performance is estimated to be 20,000 bits. This estimate is based upon 8 bit words describing motor speed, rundown time and experiment status; a nominal 15 minute "on" time and a 15 minute "off" time and at least 3 temperatures for each motor/bearing assembly.

At the conclusion of the experiment, or at any other time deemed necessary, the experiment mounting system will be retrieved by a crew member using standard EVA practices. The mounting system, with the installed motors, will be encased in a sealed container and the entire package shipped to earth for analysis of the bearings.

The experiment setup is shown in Figure 4-5.

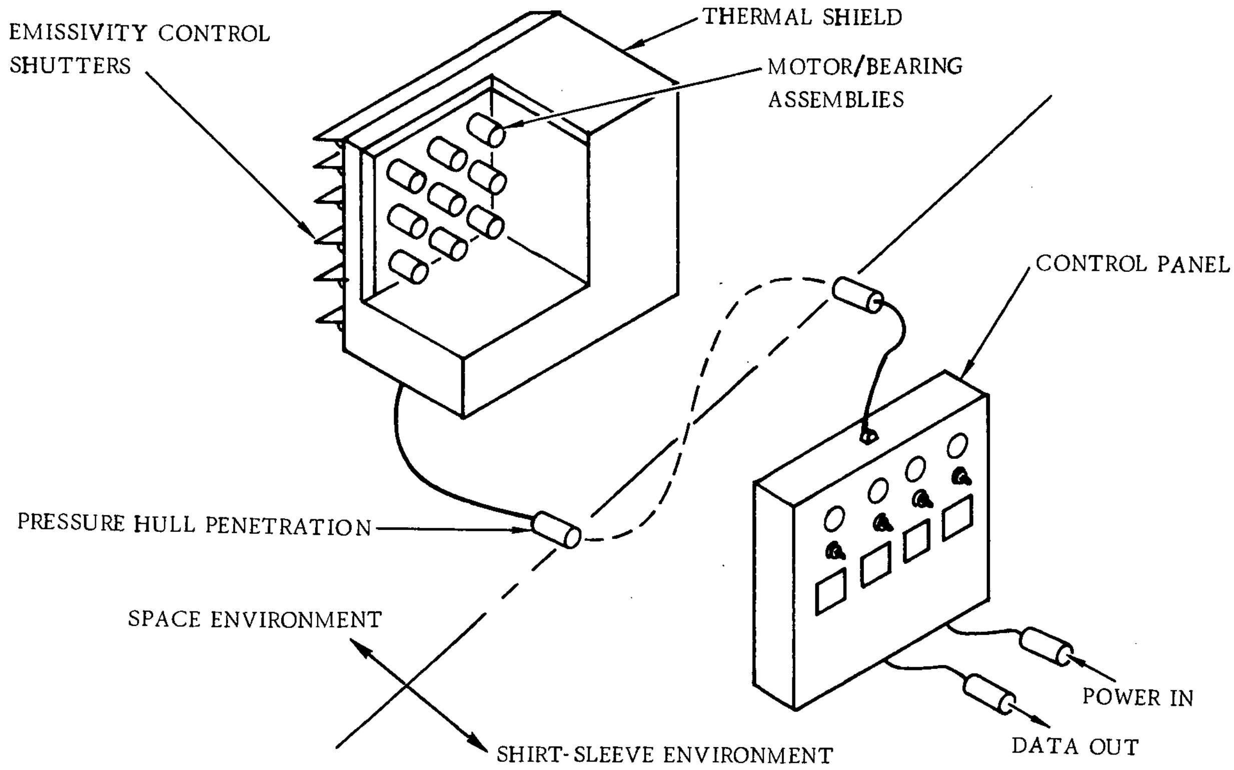


Figure 4-5. Ball Bearing Lubrication Test

The physical characteristics of the experiment equipment are:

a. Motor Mounting System — Size: 60 x 30 x 45 cm (24 x 12 x 18 in.) Weight: 11 kg (25 lb)

b. Control Panel — Size: 30 x 60 x 7.5 cm (12 x 24 x 3 in.) Weight: 7 kg (15 lb)

4.4.7.3 Measurement Program. After being delivered to orbit, the experiment equipment with the motor-bearing assemblies installed will be mounted for exposure to the vacuum of space. This operation could be accomplished by crew EVA operations, or by remotely opening an airlock test chamber to vacuum conditions. Following a period of 48 hours (to allow for outgassing) the mounting system will be stabilized at a temperature of 273°K (0°C). This temperature will be obtained using a louvered shroud with passive coatings and orientation of the mount toward deep space. To maintain the 273°K (0°C) accurately, the equilibrium temperature will be 268°K (-5°C). A small amount of electric heater power will bring the temperature to 273°K (0°C). The emissivity required will be about 0.7. Following stabilization at the 273°K (0°C) temperature, the motors will be started, allowed to run for 15 minutes, turned off for 15 minutes, run down time measured, and the cycle repeated.

This cycling will be continued for 30 days. At the end of this period the mounting system temperature will be raised to 373°K (100°C) and the entire 30-day cycle repeated. This new temperature will be attained and maintained with electric heaters and louvers to drop the emissivity to 0.3. Following this test period, the temperature will be raised to 473°K (200°C) and the entire 30-day cycle repeated.

At the completion of the 90-day test period the mounting system and motors will be retrieved and will be shipped to Earth for evaluation of the bearings and their lubricants.

4.4.7.4 Interface, Support and Performance Requirements

4.4.7.4.1 Crew Support. Crew support will be required to unpack the experimental package, set up the control system, mount (via EVA or airlock) the experimental package, connect the control assembly to the spacecraft power and data subsystems, start the experiment, and perform occasional monitoring functions. The crew may be called upon to retrieve the package at any time and, if the design of the experiment permits it, retrieve an individual motor-bearing assembly and replace it with another. When the experiment is concluded the experimental package will be packed for shipment in a container that will prevent contamination of the bearings.

4.4.7.4.2 Data. The control panel will provide the interface with the spacecraft digital data system. The data rate of 20,000 bits/24 hours is equivalent to 3.2 bits/second for a total of 1.8×10^6 bits for the duration of the experiment.

The only other communications necessary will be occasional verbal or written reports by the crew pertaining to the general experiment program or to any unusual events which affect the conduct of the experiment.

4.4.7.4.3 Power. There are two separate requirements for power in this experiment. The first is for the 24 motors and the experiment control system. The second requirement is for the heaters in the motor-bearing mounting system.

The power required for the 24 motors is about 4 W each, with 12 W for 5 sec. while starting plus 50 W for the control system. The motors will be sequenced to run one-half of them while the other half is off, then reversing the sequence. The motors will be started and stopped sequentially at 10 sec. intervals.

The power required for maintaining the 373 and 473°K (100 and 200°C) mounting system temperatures will depend upon the effectiveness of the thermal shield surrounding the mounting system. In addition, the power expended in the 24 motors will tend to increase the mounting system temperature. The motor-bearing assemblies must be in good thermal contact with the mounting system in order to insure that the bearings are at the desired test temperature. As one or more of the motors stop running due to bearing failure, the thermal control for the other bearings will become more complicated. At this time the power requirement to achieve a 473°K (200°C) mounting system temperature is estimated to be 400 W, assuming the mounting system louvers are adjusted for an emissivity of 0.3.

The total energy required will be 360 MJ (100 kW-hr) for the first 30 days, 940 MJ (260 kW-hr) for the second 30 days and 1300 MJ (360 kW-hr) for the third 30 days for a total of 2600 MJ (720 kW-hr).

4.4.7.4.4 Size and Weight. The mounting system, motors and thermal shield are estimated to weigh 11 kg (25 lb) and the volume will be 0.09 m^3 (3 ft^3). The control system is estimated to weigh 7 kg (15 lb) and has 0.02 m^3 (0.8 ft^3) of volume.

4.4.7.4.5 Pointing and Stabilization. The pointing requirement for the passive thermal control system is deep space, away from the Sun or Earth.

If EVA is used to install and remove the experiment, minimum spacecraft maneuvers commensurate with established EVA requirements will be required.

4.4.7.4.6 Thermal Control. Thermal control of the experiment mounting system is a prerequisite to the conduct of the experiment to minimize electrical power demand. The thermal shroud will control the emissivity from 0.7 for 273°K (0°C) to 0.3 for the 473°K (200°C) temperature.

The control system is internally installed in the spacecraft and dissipates 50 W of electrical power.

4.4.7.4.7 Data Return. The primary experimental data will be collected and stored with other experimental data in the spacecraft digital data analysis and communication equipment. Once per orbit, or whenever else required, the data will be dumped to the ground for analysis. In addition, the crew audio record will be transmitted in a similar record for assistance in experiment correlation.

At conclusion of the experiment the mounting system, enclosed in a protective container, will be returned to Earth for complete bearing analysis.

4.4.7.4.8 Environmental Requirements. The experiment requires exposure to the vacuum of space.

4.4.7.4.9 Special Prelaunch Requirements. None.

4.4.7.5 Role of Man. A crew member will be required to set up and install the mounting system, hook up the various electrical connections, start the experiment and report on its progress.

The installation will require an EVA excursion unless vacuum exposure is within an airlock. In like manner, a crew member will be required to retrieve the experimental package, package it for shipment and send it to Earth.

4.4.7.6 Background Data. Current and/or recent research work has been conducted under the following NASA contracts:

a. Development of Solid Lubricants for Use in Space, NAS 8-21165

b. Development of Fluid Lubricants for Use Near Nuclear Reactors in Space, NAS 8-25318

c. The Evaluation of Lubricants for Use in Reuseable Space Vehicle, NAS 8-26282

4.4.8 ADVANCED GUIDANCE SUBSYSTEMS EVALUATION

4.4.8.1 Objective. The objective of this experiment is to test advanced inertial guidance subsystems and components that cannot be adequately tested in an Earth laboratory environment.

The tests evaluate the accuracy and drift characteristics of these components and subsystems in a space environment and investigate the associated operational problems.

4.4.8.2 Description. Numerous advanced inertial guidance subsystems and components will be tested. It is convenient to consider the test specimens in three separate groups, i.e.:

a. Angular motion measurement devices

b. Linear motion measurement devices

c. Complete inertial measurement subsystems.

The cryogenic electrostatic gyroscope is considered typical of angular motion measurement components, and its testing requirements and procedures are representative for this class of advanced guidance devices. These components have potential accuracies of better than 4.8×10^{-8} rad (0.01 arc sec) and extremely low drift rates. A highly stabilized free-flying module such as that used for astronomy technology experiments (Volume II, Section 4.1.2.c) will be used as a test bed.

The gyroscope to be tested will be mounted on the instrument platen of the astronomy module. The telescope pointing system will acquire guide stars and the instrument platen will be stabilized in three axes to this reference. Drift data will then be acquired from the experimental gyro system, along with torquing sensitivities, null point data, and hysteresis data. Telescope pointing system error signals will also be recorded to improve the accuracy of short term drift measurements. An accurate knowledge of module orbital position is also required.

Low-g accelerometers (10^{-5}g) are representative of linear motion sensors to be tested. A free-flying, low-g level module such as may be used in fluid management experiments, for example, could be used as an accelerometer test bed in the range 10^{-5} to 10^{-8}g if appropriate micro thruster kits are employed. It would be desirable to extend the testing range down to 10^{-11}g for tests of interplanetary spacecraft guidance instruments; however, the problems introduced by precise drag acceleration cancellation and gravity gradients are very severe in low earth orbit.

Complete inertial measurement subsystems will be flown on remote free-flying modules, and, using appropriate tracking equipment, the experimental subsystem's estimate of its position can be compared with the known position of the module. A possible method of accomplishing this would be to fly the remote module some distance ahead of or behind the parent spacecraft. Then, while obtaining constant ranging information, the position and velocity of the remote module as measured by the experimental inertial subsystem would be compared to the computed position and velocity.

4.4.8.3 Observation/Measurement Program. During the test program on advanced gyroscopes, a 20-hour period of stable platform operation will be required for determining the gyro drift rates, sensitivity hysteresis, breakaway torquing sensitivities, and measurements of similar types.

This test data will be acquired by the free-flying module's data subsystem and transmitted to the parent spacecraft or support module. The test data will include the telescope pointing system data.

The testing of low-g accelerometers imposes severe measurement problems on the reference instrumentation. Typically, the accelerometer package will be mounted on a three-axis table installed in the free-flying module. A controlled thrust will be imparted to the module to impart a specific, and known, g-level to the package. The precise thrusting level must be very accurately known. The three-axis table would be used to orient the test package during thrusting. Test data will be acquired by the module data system and transmitted to the parent spacecraft and/or to ground stations. A test period of 40 hours will be required.

The testing of the inertial subsystem will also require highly accurate measurement methods. In this experiment phase, the experimental parameters are the inertial position and the velocity vector of the free-flying module. This position will be compared with the observed position of the module and the performance of the experimental subsystem will be analyzed. A measurement program of 100 hours duration will be required.

4.4.8.4 Interface, Support and Performance Requirements

4.4.8.4.1 Crew Support. The crew will be required to install and check out the experimental systems while the free-flying module is docked to the parent spacecraft. The module will then be flown to its operational area and the experiment conducted. Following completion of the experiment, the module will be re-docked and the experiment equipment removed.

4.4.8.4.2 Digital Data. These experiments will be designed to interface with the digital data acquisition system on board the astronomy and fluid physics modules.

For a test of low drift cryogenic gyros, the amount of data acquired during a 20-hour test would be about 6×10^7 bits. The accelerometer test program would produce about 72×10^9 bits. The data requirements for an inertial measurement subsystem test are about 2×10^{11} bits.

4.4.8.4.3 Power. Power requirements for testing of a cryogenic electrostatic gyro system would require about 150 W. For the accelerometers, 50 W would be required. The inertial subsystem power would require about 200 W. This energy does not include the stabilized platform or star tracker power requirements. Total energy is 110 MJ (30 kW-hr).

4.4.8.4.4 Size and Weight. The gyroscope test packages will weigh up to about 22 kg (50 lb) and have a volume of about 0.09 m^3 (3 ft^3). The accelerometer package will weigh about 14 kg (30 lb) and have a volume of about 0.03 m^3 (1 ft^3).

The inertial subsystem will weigh about 33 kg (75 lb) and have a volume of about 0.09 m^3 (3 ft^3).

4.4.8.4.5 Pointing and Stabilization. The instrument platen in the astronomy module must have a pointing stability of 2.4×10^{-8} rad (0.005 arc seconds).

4.4.8.4.6 Thermal Control. The free-flying module thermal control system must provide for cooling of the experiment packages by conduction.

4.4.8.4.7 Orbit Altitude and Inclination. To permit testing of accelerometers in residual g fields (due to atmospheric drag) of less than 10^{-5} g, orbit altitudes of 500 km (270 n.mi.) or more will be required.

4.4.8.4.8 Data. The experimental data will be acquired by the free-flying module's data subsystems and returned to the parent spacecraft or ground station by digital telemetering. Total data return for the candidate experiments is about 2×10^{11} bits.

4.4.8.4.9 Unique Environmental Requirements. The experiment requires very accurate pointing and stabilization.

4.4.8.4.10 Special Prelaunch Requirements. Protection of the guidance components and subsystems during launch is a necessity.

4.4.8.4.11 Torque Outputs. None.

4.4.8.5 Potential Role of Man. The crew will play a vital role in the conduct of the experiment. They will accomplish the installation of the experiment on the module platform, insure that the experiment is working properly, undock and fly the module to its remote point, track the module and compute position and velocity data, monitor the experiment progress, retrieve the module, and remove the experimental equipment.

4.4.8.6 Available Background Data

4.4.9 SPACE CALIBRATION OF SOLAR CELL STANDARDS

4.4.9.1 Scientific Objective. The objective of this experiment is to acquire data on a group of "standard" solar cells in a space environment and return them to Earth to provide primary standards for use in Earth based testing of spacecraft solar arrays.

4.4.9.2 Description. The experiment package will consist of an array of approximately 100 solar cells which have been established as standard solar cells, a data acquisition system, a mounting system for interface to an existing deployment boom platform and an operating panel which provides experiment control and an interface with electrical power and digital data collection and transmission systems. The mounting of the package is shown in Figure 4-6.

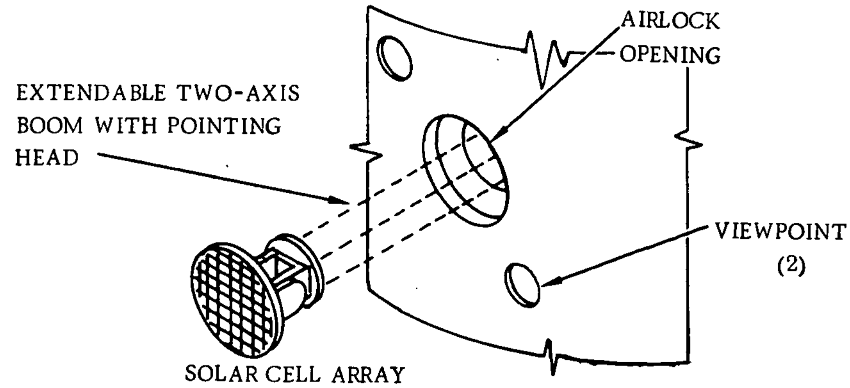


Figure 4-6. Solar Cell Calibration Setup

4.4.9.3 Measurement Program. The experiment equipment will be provided as a suitcase type payload designed to interface with the spacecraft subsystems. The experiment operating panel will be connected to the spacecraft power and data subsystems and the array deployed through an airlock. Solar radiation must be maintained normal to the plane of the solar cell array to within 1.7×10^{-3} rad (0.1 deg) throughout the calibration run. Voltage, current and temperature data from the solar cells and orientation data will be acquired. A calibration run time of 20 minutes per orbit will be required to insure temperature stabilization of the cells and mounting structure. Nominally, a sequence of 10 runs will be required for each array calibration.

Following successful completion of an in-orbit calibration sequence, the array will be retrieved and the experiment equipment returned to Earth.

Calibration of standard solar cell arrays will be performed once every three months throughout the two-year mission.

4.4.9.4 Interface, Support and Performance Requirements.

4.4.9.4.1 Crew Support. The crew will unpack the experiment package, install the array on the deployment boom platform, and insure that power and data connections are made. The crew will deploy the array through the airlock and monitor the experiment performance. Upon completion of the calibration the crew will retrieve the array, and repackage the equipment for return to Earth.

4.4.9.4.2 Data. Data from this experiment may be recorded on board the spacecraft for later transmittal to Earth. The data must be measured, stored, and recovered on Earth with an overall accuracy of at least ± 0.05 percent. To insure this, a 12-bit binary word will be used to describe the voltage and current data. Temperature data could be measured to an eight-bit accuracy. The data rate from the experiment operating panel is 1 kbps sampled for 6 seconds each 30 seconds during each 20 minute run for a total of 2.4×10^6 bits per calibration

4.4.9.4.3 Power. The experiment equipment will require 25 W during the active measurement period. The total energy required is 1.4 MJ (0.22 kW-hr) per calibration.

4.4.9.4.4 Size and Weight. The size of the experimental package is 0.028 m^3 (1 ft^3), typically 0.18 m^2 (2 ft^2) square by 0.15 m (0.5 ft) deep.

Weight of the package is 9 kg (20 lb).

4.4.9.4.5 Pointing and Stabilization. The solar cell array must be oriented to the local solar flux to within 1.7×10^{-3} rad (0.1 deg) during the calibration runs.

4.4.9.4.6 Orbit Altitude and Inclination. No restriction is now known for orbit altitude and inclination, except that exposure time in higher level radiation zones must be minimized.

4.4.9.4.7 Environmental Requirements. No unique environmental requirements are known at this time, except for minimizing exposure to radiation.

4.4.9.4.8 Prelaunch Requirements. The experiment equipment will be packaged to withstand normal launch and recovery environments. It is assumed that a complete set of preliminary standard cell data is obtained on the array before it is committed to launch.

4.4.9.5 Role of Man. In addition to unpacking, installation, retrieval and returning the equipment to Earth, the crew will monitor the progress of the experiment. The calibration runs must be coordinated with other spacecraft activities to avoid contamination of the array.

4.4.9.6 Background Data. To supplement the ground-based and orbital data, high altitude data from aircraft and balloon flight is available.

4.4.10 SPACE EXPOSURE EFFECTS ON MATERIAL BULK PROPERTIES

4.4.10.1 Objective. The objective of this experiment is to obtain information on the effect of extended space exposure on various materials that have potential application for future space program elements such as the Space Station, Space Shuttle, Lunar Station, Interplanetary Probes, etc.

4.4.10.2 Description. Samples of materials such as thermal control coatings, plastics, composites, adhesives, insulating materials, metals, lubricants, elastomers, seals, sealants, potting materials, etc., will be exposed to space environments. In some cases, the samples should be Sun oriented, but in all cases efforts should be directed toward simulating the expected application exposure as much as possible. Periodically samples will be retrieved, tested, packed in vacuum tight containers, and returned to Earth for further evaluation.

An experiment mounting assembly will be used to support the various material samples in the space environment to determine the effect of this environment on the bulk properties of the materials. Exposure will be in both shadowed areas and in view of direct solar radiation.

The mounting assembly for the samples (1000 in number) will be secured to a spacecraft solar cell array. Those panels requiring direct solar radiation flux will be mounted in the same plane as the solar cell array and facing the Sun. Those samples not requiring solar radiation will be mounted on the back of the assembly, facing away from the Sun. Following an exposure period, certain samples will be retrieved via EVA and returned to a spacecraft general purpose laboratory for measurement of bulk properties. Measurements may be made using conventional laboratory instrumentation; however, it will be necessary to perform the measurements in situ in an unpressurized compartment without exposing the samples to the spacecraft internal atmosphere. An airlock/glovebox chamber could be employed for measurements which require manual manipulation. Following these on-board measurements, the specimens will be sealed in containers that will be filled with inert gas and returned to Earth for additional bulk property measurements.

The mounting assembly will be designed to accomodate the mounting of the individual specimens in a standard mounting module 5 x 5 cm (2 x 2 in.) in area by 1.2 cm (0.5 in.) deep. These modules will be installed in a frame which will accomodate 25 modules per side, or 50 total. Twenty frames will be attached to the mounting assembly, thus accomodating all 1000 material samples, 500 samples to a side.

4.4.10.3 Measurement Program. The test program to determine the effects of the space environment on the bulk properties of materials will consist of space exposure, bulk property determination and shipment of various samples back to Earth for those measurements which cannot be accomplished in the spacecraft. It is planned to have 15 samples of each material exposed. All samples should be from the same piece or batch. Measurements will be made prior to exposure to the space environment. The measurements will then be repeated after exposures to space environment for 1, 3, 6, 12 and 24 months. Sample configuration will vary for the different tests and for different materials. To determine changes in bulk properties, measurements will be taken to determine, as appropriate, properties such as the following:

Density

Volume

Thermal Conductivity

Electrical Properties

Modulus of Elasticity - in compression, tension and shear

Ductility

Light Transmittance

In addition to these, other properties will be measured depending upon the material exposed. Some properties may require destructive tests while most will be non-destructive.

Examples of items to be tested are:

Windows

Lenses

Solar Cell Covers

Potting Compounds

Plastics

Elastomers

Metals

Alloys

Transistors

Diodes

Resistors

Where light transmittance is of concern, two samples with about a 3 to 1 ratio in thickness will be used to separate the surface effect from the bulk effect.

Exposure environment reference data and a record of experiment orientation shall be obtained and time correlated over the duration of the experiment.

The bulk properties measurements will be made in a spacecraft general purpose laboratory. In the case of semiconductors, a simple electrical condutivity test will not be sufficient, and provisions for complete parametric testing will be required. The exposure environment reference data will be obtained using sensors such as: Solar radiation flux calorimeters, ionizing radiation detectors, particulate radiation detectors and mass spectrometers. Data from all of these instruments must be time correlated to determine the effects of the varying environmental factors integrated over the exposure time.

4.4.10.4 Interface, Support and Performance Requirements

4.4.10.4.1 Crew Support. If the experimental mounting assembly is to be secured to the solar cell array, an EVA operation is required. In addition, the environment monitoring instruments must be deployed and connected to the spacecraft power and data subsystems. Samples will be retrieved and replaced with others at intervals of 1, 3, 6, 12 and 24 months to permit the bulk properties measurements to be made. Following these measurements, some of the samples will be returned to the mounting assembly. Total EVA for two crew members to initially deploy the experiment is expected to be 20 hours. The retrieval and partial reinstallation of the 1000 specimens during the course of the experiment will require a total of 54 EVA hours.

This assumes that the specimens are retrieved in the following manner: retrieval at various times and transshipped to Earth - 33%; retrieval at various times and subjected to destructive tests - 33%; the remainder are retrieved, tested, then reinstalled for later retrieval and retesting. With standard sample sizes, the bulk properties measurements can be accomplished in a standard set of fixtures using a vacuum glove box to handle and test the specimens in situ. It is estimated that these measurements will take from one to three hours per measurement interval. Of some importance then is the speed at which these measurements can be made.

4.4.10.4.2 Digital Data. The data from the exposure environment reference instruments will be acquired by automatic means. The total bit rate for the solar radiation black body calorimeters, radiation detectors and mass spectrometers is estimated to be 1 kbit/second based on an instrument interrogation rate of once per minute for six seconds. During the 24-month exposure period the total data acquired is 6.3×10^9 bits.

4.4.10.4.3 Power. The power required by the environmental monitoring equipment is estimated to be: 20 W for the calorimeter, 40 W for the radiation detectors and 60 W for the mass spectrometer. Assuming a duty cycle of 0.1 the average power is 12 W for a total energy required of 740 MJ (210 kW-hr).

4.4.10.4.4 Size and Weight. The mounting assembly will be 2 m^2 (20 ft^2) in area and 0.075 m (0.25 ft) thick. It will accommodate the 1000 standard specimen mounting modules as described in Section 4.4.10.2. Weight of the mounting system, exclusive of test specimens, will be about 70 kg (150 lb). A complete set of specimens installed in modular holders will weigh about 90 kg (200 lb).

4.4.10.4.5 Pointing and Stabilization. The experiment requires a maximum amount of incident solar radiation for half of the test samples, which is attained by utilizing the spacecraft solar cell array for pointing.

4.4.10.4.6 Thermal Control. No thermal control is required of the bulk specimen samples.

4.4.10.4.7 Orbit Altitude and Inclination. Any spacecraft operational altitude and inclination are acceptable, however, results may require extrapolation for some applications.

4.4.10.4.8 Data Return. Data taken from the instruments used to monitor the space environment will be telemetered to Earth using the spacecraft data-down link. Bulk property data will be returned with the test samples as filled in data sheets from the spacecraft laboratory.

4.4.10.4.9 Unique Environmental Requirements. The material samples shall not be exposed to the internal spacecraft environment prior to completing the bulk properties measurements.

4.4.10.5 Potential Role of Man. Without a complicated remote manipulator device, the sample mounting assembly cannot be mounted on the solar array without crew members in EVA garments. It is assumed therefore that initial installation and periodic sample retrieval will be accomplished with EVA. In any case, man must be used as the operator in measuring the bulk properties.

4.4.10.6 Available Background Data. Current and/or recent research work has been conducted under the following NASA contracts:

a. NAS 8-2450, NAS 8-18024; Effects of Combined Environments of Vacuum and Radiation on Engineering Materials.

b. NAS 8-20210; Investigation of Combined Effects of Space Environment Parameters on Space Vehicle Materials.

4.4.11 SPACE EXPOSURE EFFECTS ON MATERIAL FATIGUE PROPERTIES

4.4.11.1 Objective. The objective of this experiment is to obtain data on the effect of extended space exposure on the fatigue properties of various structural materials which have potential application on such programs as Space Station, Space Shuttle, Lunar Vehicles, Interplanetary Probes, etc.

4.4.11.2 Description. The assembly used to perform fatigue testing will be housed in a vacuum box equipped with vacuum gloves to allow manipulation of the test specimens while they remain in a vacuum. During the extended period of space exposure (1 to 24 months) the test specimens (about 100 in number) will be positioned external to an airlock by a remote manipulator (to eliminate the need for EVA) so that the solar radiation and contamination substances as well as the space vacuum will be able to affect the materials being exposed.

When the exposure period for a specific specimen is completed, a crew member will retrieve it, deposit it in the vacuum box, place it (via the vacuum box gloves) in the fatigue testing machine, and start the testing sequence. It is expected that the fatigue test time will vary from 1 to 10,000 minutes. After completion of the fatigue test, the test samples will be returned to Earth along with the untested samples for further analysis and data correlation. The setup is shown in Figure 4-7.

4.4.11.3 Measurement Program. The fatigue test program is expected to yield data on fatigue cracking of structural materials in the space environment.

It has been demonstrated that fatigue cracking in an aluminum alloy occurs in hard vacuum almost as readily as within atmospheric pressure. This is contrary to general belief. Experiments now indicate trends toward increased crack growth rates which may eventually result in characteristics more critical than those from in-air tests.

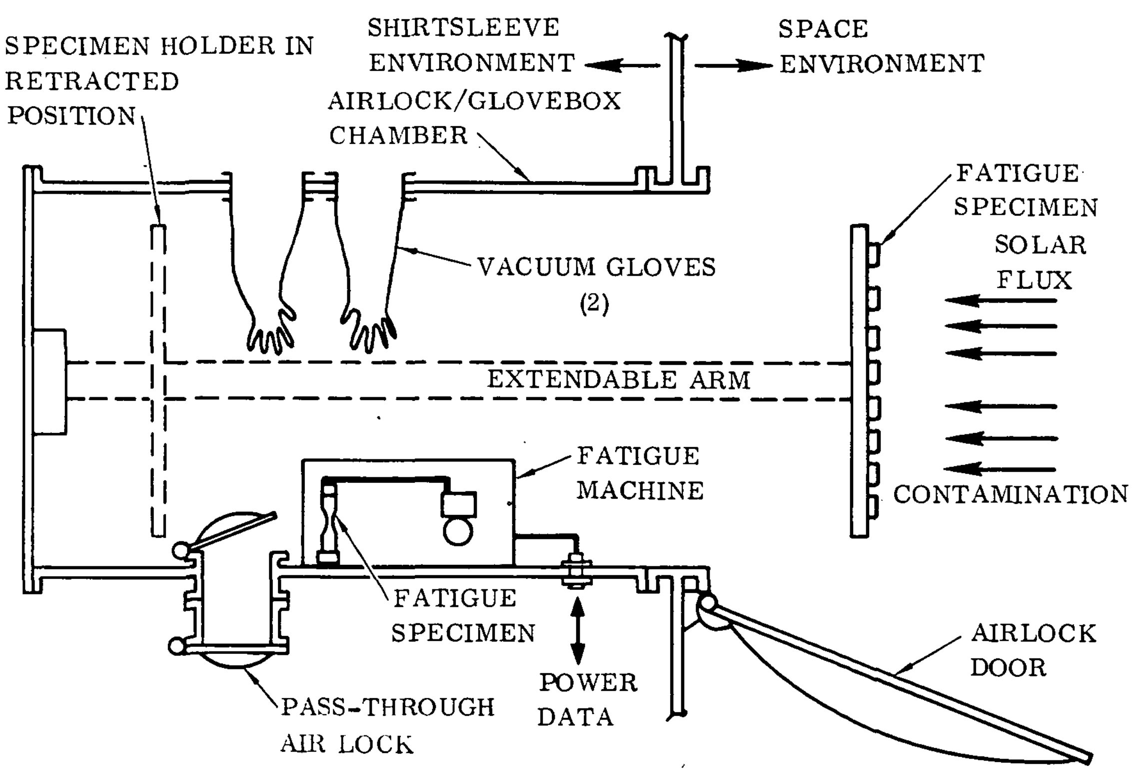


Figure 4-7. Fatigue Properties Test Setup

The experiment will employ a low-speed cyclic loading device and notched test coupons 0.5 cm (0.2 in.) wide by 0.025 cm (0.01 in.) thick that can be fatigue fractured under a 220 N (50 lb) axial force. Manipulation of the experiment will be handled by means of vacuum gloves from the side wall of an air lock as shown in Figure 4-7.

During the fatigue cycling, crack growth may be monitored visually through a view port and the data correlated with amount of stress and number of stress cycles. To achieve correlation of data, identical coupons will be tested in air in an Earth based laboratory. Following failure of the test coupon, or the completion of a specific number of stress cycles, the coupons will be packaged for shipment to earth, using a vacuum or inert gas filled container to prevent contamination.

4.4.11.4 Interface, Support and Performance Requirements.

4.4.11.4.1 Crew Support Requirements. Crew support is required to deploy the test coupons in a test chamber vented to space. A crew member will be required to periodically install a coupon in the tensile test machine, turn the machine on, and monitor the progress of the test. After the coupon has broken, or after a specific number of fatigue cycles, the coupon must be retrieved and packed in a vacuum tight container for shipment to Earth. Some EVA will be required for this experiment unless a specially designed airlock is included as a supporting facility.

4.4.11.4.2 Digital Data. No requirement.

4.4.11.4.3 Power. The fatigue tests will consume 100 W during the testing of 30 specimens for a maximum of 10,000 minutes per specimen. This is a total energy requirement of 800 MJ (500 kW-hr).

4.4.11.4.4 Size and Weight. The 100 specimens can be contained in a 0.02 m^3 (0.66 ft^3) chamber. The weight of the specimens is about 2.7 kg (6 lb). A hermetically sealed shipping container will be provided which weighs 9.1 kg (20 lb) and occupies 4.9×10^{-2} m^3 (1.8 ft^3). The fatigue tester has a volume of 0.0065 m^3 (0.225 ft^3) and weighs 15.8 kg (35 lb).

4.4.11.4.5 Pointing and Stabilization Requirements. No requirement.

4.4.11.4.6 Thermal Requirements. No thermal control of the test coupons is necessary. The design of the fatigue tester will allow radiation of the electric motor heat to the walls of the test chamber.

4.4.11.4.7 Orbit Altitude and Inclination. No requirement.

4.4.11.4.8 Data Return. Data sheets on exposure interval, number of cycles to failure, and similar data will accompany the test specimen container to earth.

4.4.11.4.9 Unique Environmental Requirements. To eliminate the need for EVA operations, an airlock/test chamber equipped with a deployable specimen holder, vacuum gloves, and fatigue test machine will be required.

4.4.11.4.10 Special Prelaunch Requirements. None.

4.4.11.5 Potential Role of Man. Man will install, monitor, retrieve and ship back to Earth the material coupons which have finished their testing sequence. An alternative would be to use remote teleoperator manipulators if their development is sufficiently advanced at the time.

4.4.11.6 Available Background Data. Current and/or recent research work has been conducted under the following NASA contracts:

a. NAS 8-2450, NAS 8-18024, Effects of Combined Environments of Vacuum and Radiation on Engineering Materials.

b. NAS 8-20210, Investigation of Combined Effects of Space Environment Parameters on Space Vehicle Materials.

4.4.12 FIRE SENSING AND SUPPRESSION

4.4.12.1 Objectives. The objectives of this experiment are to evaluate and verify the performance of fire suppression techniques in the reduced gravity environment of an orbital vehicle. Included in this concept of fire suppression are all of the activities required for fire detection, location, isolation and extinguishment.

4.4.12.2 Description. This experiment will test, in the reduced-gravity environment of space, advanced concepts for protecting the crew, equipment and vehicle from the effects of fire.

Tests have been conducted on many materials on Earth to determine burning characteristics in the normal one-g environment, and with drop towers and aircraft flying zero-g trajectories to study the phenomena of burning in reduced gravity. These limited tests have identified materials acceptable for use in current generation spacecraft from a flammability, toxicity and chemical reactivity point of view. Studies are presently being conducted to evaluate alarm systems and extinguishment methods. The results of these earth-based tests will identify methods which will be tested in orbit.

Tests in orbit will be on a small scale basis in well-confined equipment to minimize hazards to the crew and the spacecraft. Specific materials will be ignited or heated to produce smoke and/or flame. Time required for action by each of the elements of the suppression system will be measured. Characteristics of smoke distribution, flame shape, size and duration of visibility will be observed and recorded on film. Quantity of extinguishing agent required and length of time to extinguish the fire will also be recorded.

4.4.12.3 Observation/Measurement Program. The evaluation of fire detecting and locating concepts will require numerous measurements by heat sensors, light sensors, optical transmissibility sensors, mass spectrometers, and O_2 partial pressure sensors. The test setups will be designed to protect the crew, equipment and vehicle and will assure the safety of the spacecraft during testing as well as provide meaningful data for evaluating concepts of fire suppression applicable to spacecraft. The measurements to be made include: response time of detection sensors at various distances from fires of known energy; location of combustion sources by infrared scanners; and a fire severity measurement made by noting the rate of usage of O_2 in the affected compartment.

Fire extinguishment evaluation will test the relative merits of suppression agents such as foams, gels, inert gases and, where applicable, compartment venting to vacuum. In addition to the time required to extinguish the fire, the amount of suppression agent expended will be measured. Also, the presence of any gases due to the extinguishment agent itself will be detected and measured. This evaluation program will require such instruments as mass spectrometers, gas chromatographs, flowmeters, temperature sensors, and infrared detectors. During the fire extinguishment evaluation, cine cameras will take color and infrared films of the processes so that the best methods of extinguishment can be selected and further developed.

It is expected that eight types of detection instruments will be tested for a total of 40 tests during a four-week period. Two types of fire location systems will be tested 10 times within a two-week period. Fire extinguishment systems will be tested for four weeks, using about six extinguishment agents in a total of 30 tests. The experiment mission would span a period of about 90 days. All or portions may be repeated at several year intervals as new concepts are conceived.

4.4.12.4 Interface, Support and Performance Requirements

4.4.12.4.1 Crew Support. The evaluation of the various suppression systems requires active crew participation in the preparation and operation of the various equipment and the supervision of a controlled fire. The extinguishment tests will also be photographed by the crew.

4.4.12.4.2 Digital Data. None required.

4.4.12.4.3 Power. The power requirement for the four typical fire detection instruments will be about 50 W during a 1 hour operating period for each test.

The infrared scanner fire location instrument will require about 100 W during its operating period of 1 to 5 minutes for each test.

The evaluation of extinguishment methods will require no power except for the two cine cameras for a five-minute period for each test. This power requirement is 50 W for each of the two cameras.

The total energy requirement for the experimental period is 8.6 MJ (2.4 kW-hr).

4.4.12.4.4 Size and Weight. The eight various fire detection systems are expected to weigh a total of 36 kg (80 lb) and have a total volume 0.06 m^3 (2 ft^3). The fire location instruments will weigh about 11 kg (25 lb) and occupy 0.008 m^3 (0.3 ft^3). The extinguishment systems, including piping, valves and tanks are expected to weigh 22 kg (50 lb) and occupy 0.2 m^3 (6 ft^3) and the consumables are expected to weigh 34 kg (75 lb) and have a volume of about 0.08 m^3 (3 ft^3).

About 7 kg (15 lb) of combustibles will be required as well as a supply of bottled gas (propane, etc.). Usage of the gas is expected to not exceed 2.2 kg (5 lb).

4.4.12.4.5 Thermal Control. The experiments will be performed in a laboratory test chamber and the resultant heat load must be handled by the spacecraft environmental control subsystem.

4.4.12.4.6 Orbit Altitude and Inclination. No restriction.

4.4.12.4.7 Data Return. About 9 kg (20 lb) of cine film can be expected as well as recorded audio-visual reports on the entire experiment.

4.4.12.4.8 Unique Environmental Requirements. The requirement for a safe and isolated test cell is very critical. A test cell/airlock in a spacecraft laboratory must be provided to permit this type of experiment to be conducted safely.

4.4.12.4.9 Special Prelaunch Requirements. None.

4.4.12.5 Potential Role of Man. Man will be a full time experimenter during the conduct of this test. Operation of a combustion apparatus, hand held survey instruments and hand held extinguishers will be required. Documentation requires the use of film cameras.

4.4.12.6 Available Background Data

4.5 FPE INTERFACE, SUPPORT, AND PERFORMANCE REQUIREMENTS

The summary data presented in Table 4-4 represents, in the best judgment of NASA scientists, the overall facility and experimental requirements to accomplish a realistic experimental program. The rationale for selection of the summary parameters is in some instances arbitrary but has as a basis the total NASA experience and knowledge of prior flight and experiment definition and integration programs.

Table 4-4. Summary Interface, Support, and Performance Requirements

Mass	670 kg (1500 lb)
Volume	13 m^3 (460 ft^3)
Power	2.8 kW
Crew Skills	Electromechanical Technician Mechanical Engineer Electronic Engineer Thermodynamicist Metallurgist Physical Chemist
Data Rate	18 kbit/sec
Logistics Up (per 30 days)	70 kg (160 lb)
Logistics Down (per 30 days)	70 kg (160 lb)
Pointing & Stability	4.8×10^{-8} radians (0.01 arc-sec)
Orbit Alt & Inclination	N/A
Unique Environmental Reqmts.	Complete spectrum of spacecraft operational environments

A tabular summary of some major items of support equipment and instrumentation is given on Table 4-5. These items could be kept on hand in a general purpose laboratory

Table 4-5. FPE Support Equipment Requirements

EXPERIMENT / EQUIPMENT	4.4.1, Oxygen Recovery and Biowaste Resistojet.	4.4.4, Absorption Refrigeration Cycle Experiment.	4.4.2, Maintainable Flight Electronics Package.	4.4.3, Thermal Coating Refurbishment In Space.	4.4.6, Maintainable Attitude Control Propulsion System.	4.4.7, Ball Bearing Lubrication.	4.4.10, Space Exposure Effects on Material Bulk Properties.	4.4.11, Space Exposure Effects on Material Fatigue Properties.	4.4.8, Advanced Guidance Subsystems Evaluation.	4.4.5, Leak Detection and Repair.	4.4.12, Fire Sensing and Suppression.	4.4.9, Space Calibration of Solar Cell Standards.
	Life Support		Maintainability Experiments			Exposure Experiments			Guid.	Safety Exper.		Calibration Exper.
Digital Data Acquisition System	●	●		●	●	●	●		●			●
Cameras, Cine, Still or Video		●	●	●	●					●		
Gas Chromatograph	●									●	●	
Chemical Analysis Equipment	●			●							●	
Calorimeter (in space)				●			●					●
Radiation Detectors (in space)							●					
Mass Spectrometer							●			●	●	
IR Detectors										●	●	
Pressure, Flow, Temperature	●									●	●	
Spectroreflectometer, M-31				●								

where dictated by workload and space availability, or could be delivered and returned with experiment payloads for sortie type missions.

4.6 POTENTIAL MODE OF OPERATION

Three modes of accommodation are envisioned as follows:

MODE A. Limited on-orbit stay-time attached to the Shuttle.

MODE B. Extended on-orbit stay-time free flying, periodically revisited by the Shuttle.

MODE C. Extended on-orbit stay-time attached to the Space Station, or in a free-flying mode supported by the Space Station.

Accommodation preferences for each experiment are shown in Table 4-6. The accommodation preferences shown appear to be logical choices at the present time but should not be construed to be final direction to user of this document.

Table 4-6. Experiment Accommodation Mode Preferences

Experiments	Accommodation Preference*		
	MODE A	MODE B	MODE C
1. O_2 Recovery/Resistojet	2	0	1
2. Maint. Flt. Electronics	1	0	1
3. Thermal Coating Refurb.	0	2	1
4. Absorp. Refrig. Cycle	3	2	1
5. Leak Detection	1	0	1
6. Maintainable ACPS	1	2	1
7. Ball Bearing Lubr.	0	2	1
8. Adv. Guid. Subsystems Eval.	0	2	1
9. Space Calib. of Solar Cells	1	0	1
10. Space Environ. Effects on Material Bulk Properties	0	2	1
11. Space Environ. Effects on Fatigue Properties	0	2	1
12. Fire Sensing and Suppression	1	0	1
Legend: 1. Preferred Mode 2. 2nd Preference 3. 3rd Preference 0. Not Applicable			
* Note: Not final direction to users of this document			

4.7 ROLE OF MAN

As an active investigator, man will perform the following functions in the conduct of these experiments:

a. Install, checkout, and deploy experiment apparatus

b. Control the conduct of the experiment

c. Evaluate results and modify test conditions where necessary

d. Relay results to Earth and consult with ground based personnel as required

e. Retrieve test apparatus and samples, and package for return to Earth

For some of the experiments, man is a subject of investigations into his ability to perform maintenance and refurbishment tasks on various types of equipment, using the tools and procedures provided as elements of the experiments.

Where the experiment program is implemented using a spacecraft general purpose laboratory, man will fulfill the role of a laboratory facility manager. He will plan and control the utilization of the laboratory resources to best satisfy the experiment program requirements, and insure the safety of the crew, spacecraft, and experiment equipment.

4.8 SCHEDULES

A summary of the experiment development and flight schedules is given in Table 4-7. The schedules are shown independently since no priorities have been established and none of these experiments are prerequisites to the conduct of others.

4.9 PRELAUNCH SUPPORT AND GSE

All of the experiments described in this FPE will be handled as "suitcase" type payloads. Some experiments will involve the return of test samples to Earth laboratories in hermetically sealed containers; after their return, these samples cannot be exposed to ambient environmental conditions prior to laboratory analyses.

4.10 SAFETY

4.10.1 EVA ACTIVITIES. During any EVA activities described in the various experiments the attitude control system of the spacecraft should not be operated. In addition to the danger of impingement of exhaust gases from the RCS thrusters on the EVA crewman, the loss of tools, components and similar items will be minimized by not maneuvering the spacecraft.

Table 4-7. FPE Development and Flight Schedule

Experiments	Schedule (Years)							
	1	2	3	4	5	6	--	10
4.4.1, Oxygen Recovery and Biowaste								
4.4.2, Maintainable Flight Electronics Package								
4.4.3, Thermal Coating Refurbishment in Space								
4.4.4, Absorption Refrigeration Cycle Experiment								
4.4.5, Leak Detection and Repair								
4.4.6, Maintainable Attitude Control Propulsion System								
4.4.7, Ball Bearing Lubrication								
4.4.8, Advanced Guidance Subsystems Evaluation								
4.4.9, Space Calibration of Solar Cell Standards								
4.4.10, Space Exposure Effects on Material Bulk Properties								
4.4.11, Space Exposure Effects on Material Fatigue Properties								
4.4.12, Fire Sensing and Suppression								
Legend: Development / Flight								

4.10.2 PROPULSION SYSTEMS. The maintainable attitude control propulsion system experiment, Section 4.4.6, has several thrusters and other typical RCS components incorporated in the system. In accomplishing the repair and maintenance activities on this system, safety procedures will have to be prepared and evaluated by the crew.

4.10.3 REMOTE MANIPULATIONS. To reduce the amount of EVA required for experiments with materials in extended space exposure, the use of a "vacuum glovebox" is suggested for handling specimens for measuring bulk properties of materials and for servicing the fatigue test machine. The possibility of a glove rupture must be considered and safety precautions (rapid closure and re-compression of the box, etc.) established.

4.10.4 FIRE SAFETY. Experiment 4.4.12, Fire Sensing and Suppression, requires the use of a combustible gas to perform the experiment. The handling of this gas poses a serious safety hazard and proper handling procedures must be devised. In addition, the "fire proof" test cell in the spacecraft laboratory should be considered for any other potentially flammable experiment.

4.11 AVAILABLE BACKGROUND DATA

Background data pertaining to this FPE are listed in the appropriate experiment sections.

VOLUME VII

SECTION 5

TELEOPERATION

SECTION 5

TELEOPERATION

5.1 OBJECTIVES

The objectives of this FPE are to develop and evaluate an experimental teleoperator (T/O) system. Such a system would be a precursor to an operational system and would provide a means for evaluating teleoperator performance, safety, and suitability for performing various tasks in space.

Upon completion of this experimental phase, the system would be converted to an interim operational tool for use with the Space Shuttle or Space Station while final design of a fully operational system was being completed.

5.2 PHYSICAL DESCRIPTION

The experimental teleoperator (T/O) system comprises a small, free-flying T/O spacecraft and a control station. A two-way RF link provides commands to the T/O spacecraft and feedback information to the control station. The T/O system concept is depicted in Figure 5-1.

The T/O manipulator arms duplicate the motions of a human controller operating the master manipulator at the control station. A stereoscopic TV system and manipulator force feedback provide the controller with a feeling of presence at the T/O work site.

The control station may be located in a parent spacecraft or in a ground installation.

An operational T/O system would be used to perform various inspection, assembly, maintenance, and servicing tasks in lieu of performance of these tasks by an astronaut in EVA. The experimental T/O system will be designed to perform representative tasks which will serve as the basis for comparing T/O capabilities versus those of an EVA astronaut. The experimental teleoperator system is comprised of the following elements:

a. Teleoperator spacecraft.

b. Control station.

c. Support equipment.

d. Ground-based control station.

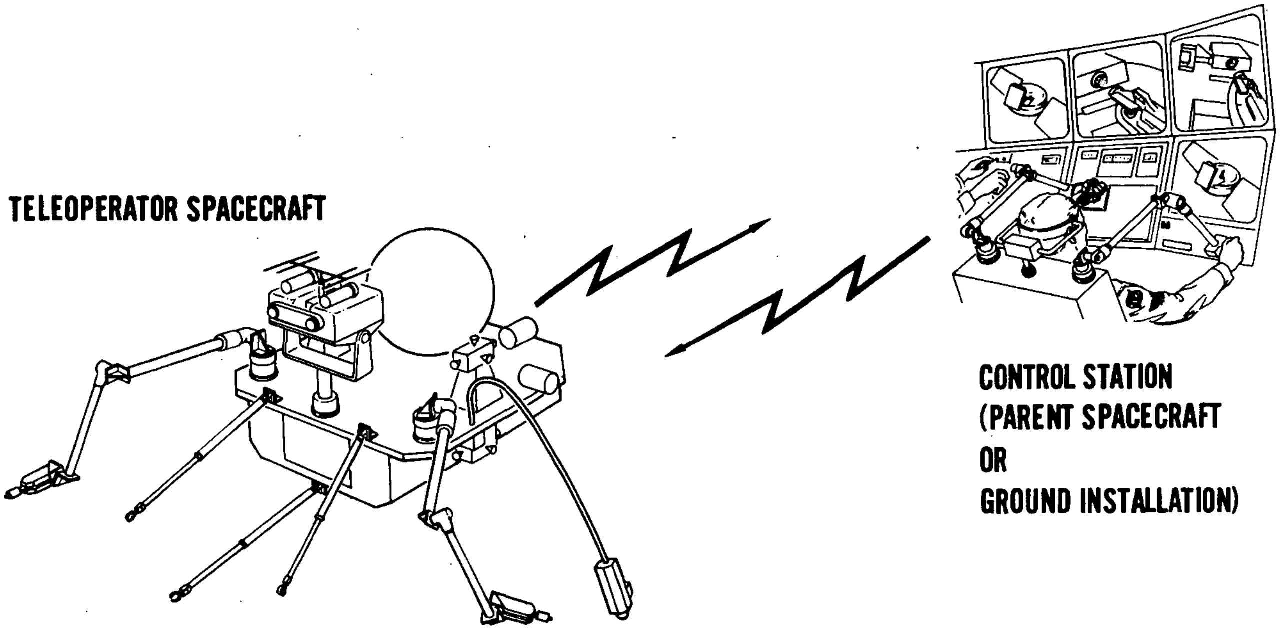


Figure 5-1. Teleoperator System Concept

The teleoperator spacecraft, illustrated in Figure 5-2, consists of a structure housing the spacecraft subsystems, a propellant supply tank, four sets of quad thrusters, a two-axis camera mount, binocular TV cameras and lights, a single close-up TV camera, two manipulator arms with interchangeable end effectors, and three docking arms.

Control of the T/O is accomplished from the control station depicted in Figure 5-1. This illustrates how a crewman would utilize the master manipulator arms to cause the T/O slave manipulator arms and end effectors to insert an electrical plug into a receptacle on another satellite.

Figure 5-3 is a functional diagram of the system.

The manipulators used on the T/O will be a three-joint design with a separable end effector. The manipulator arms will fold to reduce the envelope of the T/O for docking and stowage as shown in Figure 5-2. The manipulators will use a closed-loop control system with force feedback to the master manipulator arms at the control station. The basic end effector will be the parallel jaw grasping mechanism. End effectors will be replaceable with special purpose tools, such as power driven

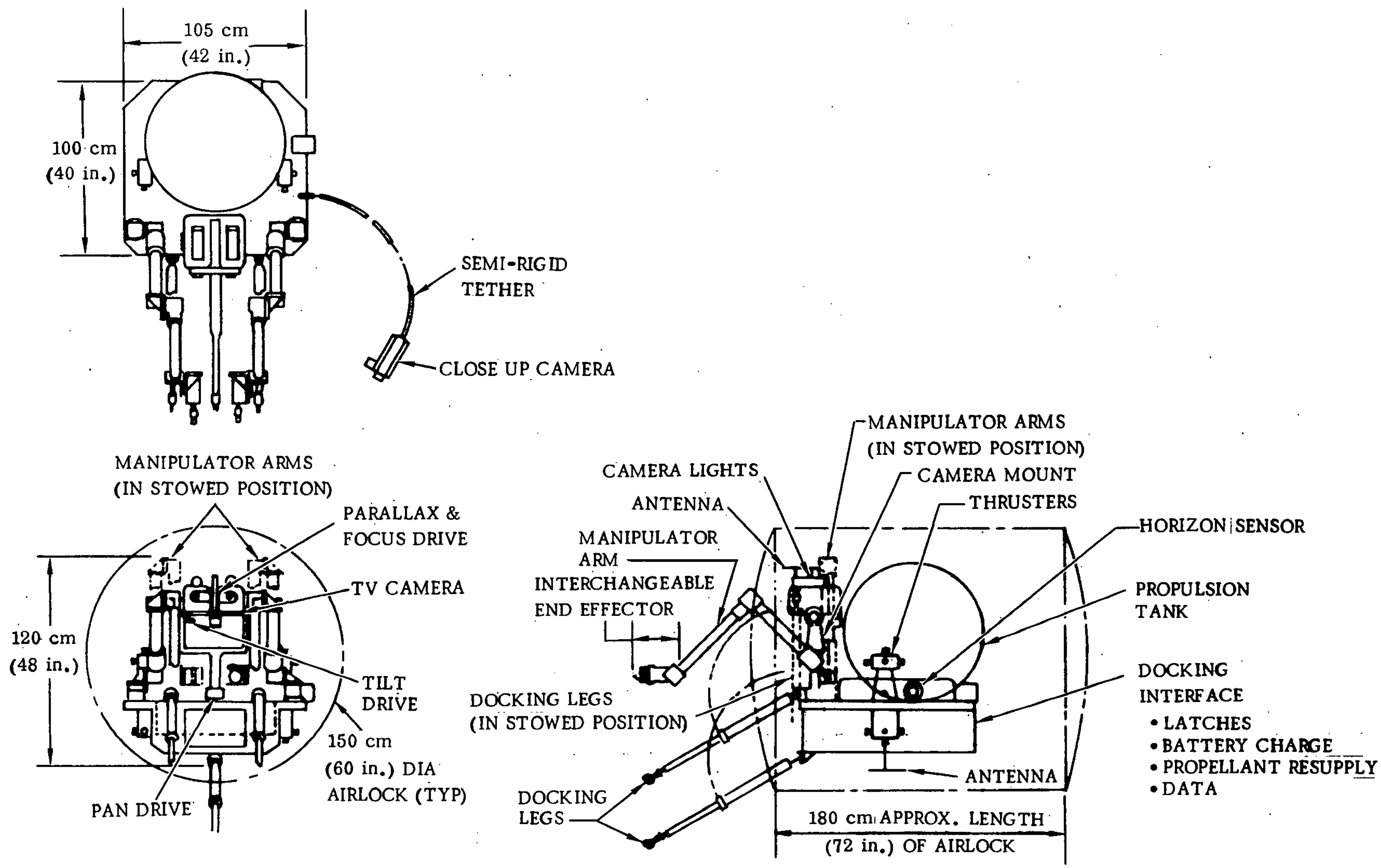


Figure 5-2. Experimental Teleoperator Spacecraft Configuration

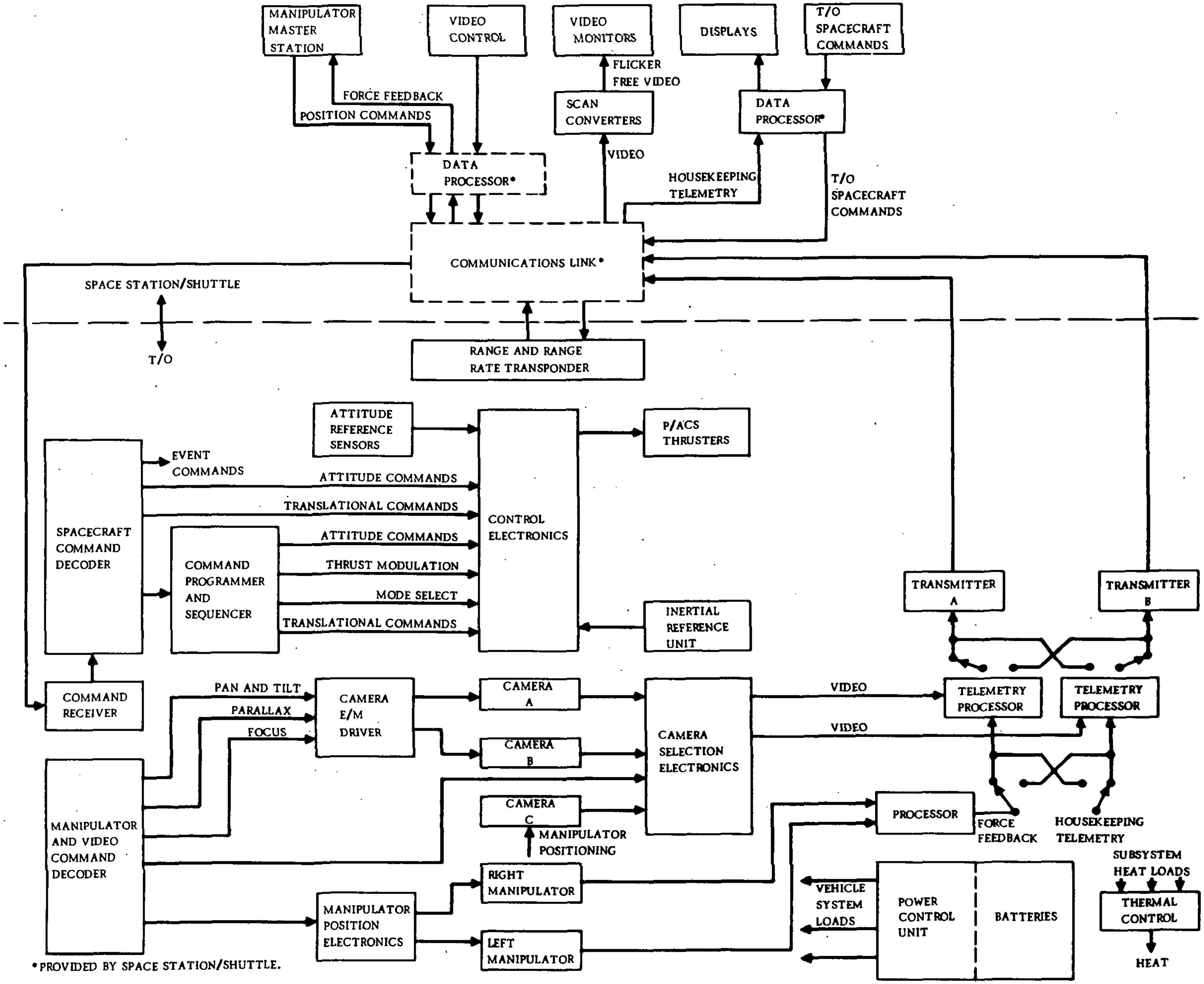


Figure 5-3. System Functional Block Diagram

wrenches, for specific tasks. Power for the manipulator arms will be provided by dc motors driving through a harmonic drive gear train. Heat output from the drive motors will be radiated to space from the manipulator arm structure.

The video system enables the T/O controller to observe the task being performed almost as if he were present at the work site. The basic video link will be from two black and white TV cameras with an adjustable binocular mounting, variable focus lens, wide or narrow angle lens and with built-in illumination lights. These cameras will be mounted on a pan and tilt assembly which moves in unison with motions of the controller's head. Supplementing these two cameras is a third camera, mounted on a rigidizible tether, to be used for close up viewing. Any two of the three cameras can be used simultaneously. Automatic light level controls will be used on all cameras.

The communication subsystem includes a tracking transponder, the receiver for the T/O command link, PCM encoders and decoders, dual telemetry processors and transmitters, and an antenna system. The electrical power subsystem consists of two 28-volt batteries, regulators, and a distribution system. Figure 5-3 includes a block diagram of the communication and electrical power subsystems.

The propulsion/attitude control subsystem (P/ACS) provides both translational mobility to the T/O and attitude control. The system is depicted in Figures 5-4 and 5-5.

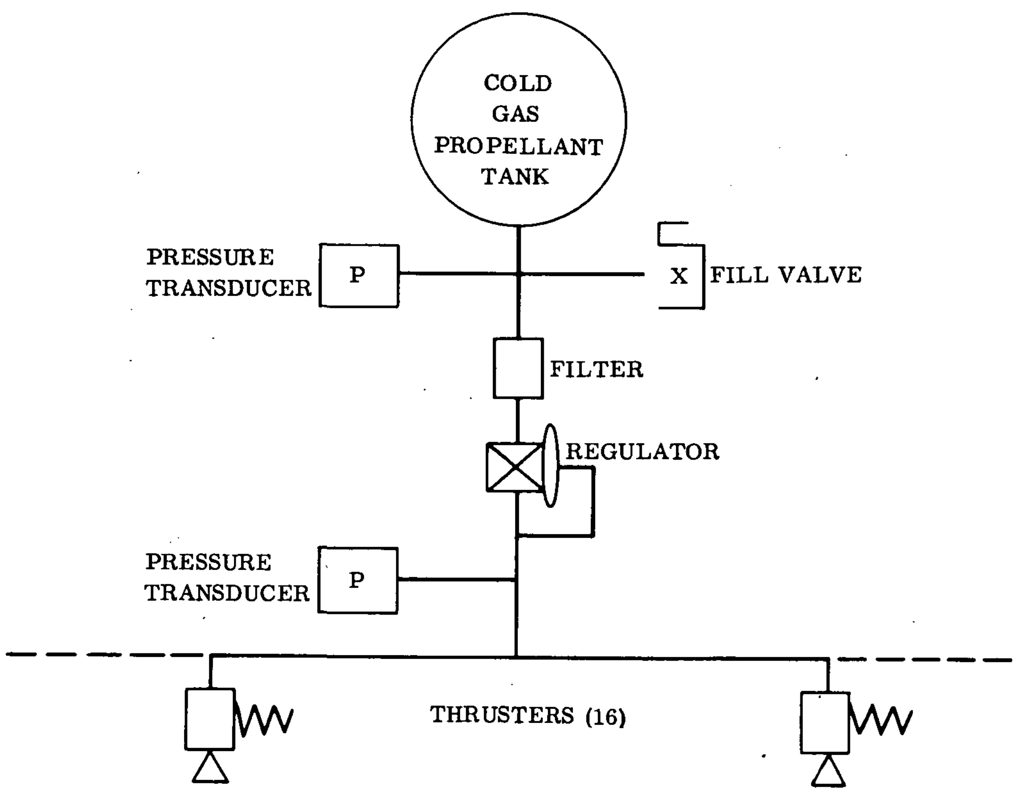


Figure 5-4. Propulsion/Attitude Control System Schematic

TRANSLATION	NOZZLES	ROTATION	NOZZLES
+X	1,5,9,13	+X	4,12 (ALSO 7 AND 15 AS ALTERNATES)
-X	2,6,10,14	-X	8,16 (ALSO 3 AND 11 AS ALTERNATES)
+Y	7,11	+Y	9,13,2,6
-Y	3,15	-Y	1,5,10,14
+Z	4,8	+Z	5,9,2,14
-Z	12,16	-Z	1,13,6,10

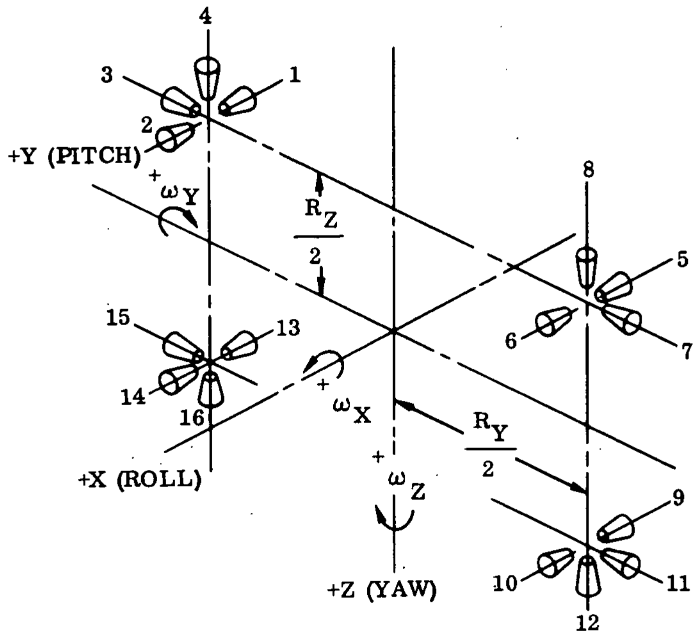


Figure 5-5. Thruster Configuration

A cold gas system using nitrogen is utilized to take advantage of proven reliable performance and minimal contamination potential.

The cold gas system is designed to supply a total impulse of 18 kN/sec (6000 lb/sec). The total gas supply carried aboard the T/O is about 36 kg (80 lb) contained in a 0.28 m^3 (10 ft^3) tank at about 21 MN/m^2 (3000 psi). This impulse will be sufficient for any of the single steps in the experiments described in the following sections. Approximately 25 kg (50 lb) of nitrogen gas will be expended on each flight and will be resupplied between flights.

The stabilization and control subsystem provides the T/O with automatic stability about all three axes, capability of reacquiring a reference if a control interruption occurs, attitude information for use in navigation, and the ability to stabilize inertial masses (such as satellites) when docked to them. The inertial reference unit will be a three-axis, rate-integrating, strapped-down gyro and accelerometer package. Attitude reference will be provided by two horizon scanners and a sun sensor.

The stabilization and control system will provide fail-safe reaction to an emergency situation, e.g., loss of communications with the parent spacecraft. In response to a sensed emergency, the system will reduce attitude and translation rates (relative to the parent spacecraft) to zero.

Thermal control of the T/O subsystems is provided by using the structure as both a heatsink and radiator. Temperature control will be achieved by passive means if possible.

The T/O control station provides both flight control and manipulator control for all T/O operations. These may be grouped into four basic T/O functions: (1) passive visual inspection of a target; (2) docking of the T/O to a target; (3) manipulation functions; and (4) mobility and attitude control of the T/O. The system must be capable of maintaining fail-safe communication and control when the T/O is operating close to the parent spacecraft where RF null zones are likely to be encountered, as well as when the T/O is operating at distances out to 15 km from the parent spacecraft.

Since the control station is the interface between the human controller and the T/O, it must provide display and control functions required for performing the previously described functions. The following controls and displays are provided by the control station:

a. T/O video displays (monocular and binocular).

b. T/O attitude, attitude rates, position, and translation rates relative to parent spacecraft.

c. Target range, azimuth, elevation, and rates relative to the T/O.

d. Flight controls.

e. Camera controls.

f. Manipulator controls.

g. Manipulator status.

h. Housekeeping information on teleoperator subsystems, i.e.: battery condition, gas pressure, temperatures, etc.

i. Docking adapter controls.

j. Refueling controls.

k. Battery recharging controls.

l. Emergency controls.

During T/O flight operations, the control station will draw 160 watts of electrical power from the parent spacecraft. The parent spacecraft data and communication system must receive data and transmit commands to the teleoperator spacecraft as follows:

Digital Data - 1500 bps

Analog Data - 8.4 MHz (2 TV channels)

Command and Control: 3400 bps

The parent spacecraft information management system must perform the computations required for T/O controls and displays. These computations include time to fire thrusters, range and range rate information, and T/O telemetry information. Approximately 16,000 words of memory are required. The internal data and communication data rate will be about 40 kbps.

The basic support equipment items for the T/O experiment are: (1) the docking adapter (installed in a parent spacecraft airlock); (2) the refueling system; (3) the battery charger; (4) a task board installed on the exterior door of the airlock; and (5) a task board subsatellite.

The airlock will house the T/O during prelaunch checkout and during servicing and repair operations. The docking adapter will contain receptacles for refueling the propulsion system and recharging the electrical system. A docking platform is included as a part of the docking adapter design. This platform can be extended from the airlock (by means of extendable arms) to provide an external docking access for the T/O. After the T/O is latched to the platform, it is drawn into the airlock where electrical and cold gas umbilical connections are made between the T/O and the docking adapter. In this configuration, the airlock can be sealed, repressurized, and the T/O made accessible to the crew via the airlock internal door. The airlock used to house the T/O and docking adapter must provide clear dimensions of at least 1.7 m (5 ft) diameter and 2 m (6 ft) long.

During T/O servicing, the battery charger will draw 300 watts of electrical power from the parent spacecraft. Nominal recharging time will be five hours.

The refueling system must be provided with a supply of high-pressure nitrogen gas from the parent spacecraft. Refueling system power consumption is negligible.

Spares for the teleoperator system will be housed within the parent spacecraft. Appropriate tools will also be available for component removal and replacement.

The task board subsatellite is a passive device, equipped with a manipulator task board and docking points. It may be stored in an airlock or an externally mounted holding fixture. It will be removed from the parent spacecraft by the T/O and released either ahead of or behind the parent spacecraft in a concentric orbit. The subsatellite will subsequently be used in repeated experimental steps as a simulated spacecraft or spacecraft element.

The ground-based T/O control station will duplicate the monitoring and control functions of the parent spacecraft T/O control station.

To evaluate the effects of communication transit time delays which would be encountered at lunar and interplanetary distances, a ground-based computer will introduce appropriate time delays in the manipulator command and force feedback signal paths and in the video link.

Operation from the ground-based control station also provides an opportunity for multi-operator control without the weight, volume, and power restrictions associated with spaceborne operations.

The physical characteristics of the elements of the teleoperator system are summarized in Table 5-1.

Table 5-1. T/O Experiment Equipment Characteristics

Equipment	Mass kg (lb)	Envelope m (ft)	Volume m^3 (ft^3)	Power W	Data
T/O Spacecraft	340 (750)	1.1 x 1.1 x 1.2 (3.7 x 3.7 x 4)	1.4 (50)	(Internal)	4.9 kbps 8.4 MHz
Control Station	68 (150)	1.5 x 0.6 x 0.3 (5 x 2 x 1)	0.28 (10)	160	40 kbps 8.4 MHz
Docking Adapter	45 (100)	1.1 x 1.2 x 0.6 (3.7 x 4 x 2)	0.8 (5)	Negligible	Negligible
Refueling System	110 (245)	0.8 x 1.6 x 1.2 (2.5 x 5.5 x 4)	1.50 (55)	Negligible	Negligible
Battery Charger	25 (55)	0.8 x 0.6 x 0.3 (2.5 x 2 x 1)	0.14 (5)	300	Negligible
Spares and Tools	36 (80)	-	0.09 (3)	-	-
Task Board Subsatellite	45 (100)	1.4 dia (4.5 dia)	0.45 (16)	-	-
Airlock Task Board	(35)	0.75 x 0.75 x 0.15 (2.5 x 2.5 x 0.5)	0.08 (3)	-	-

5.3 EXPERIMENT REQUIREMENTS SUMMARY

Each of the experiments described in following sections requires use of the T/O, the control station, the docking adapter, and the T/O servicing equipment. The experiments also require data and communications support from the parent spacecraft and use of an airlock. The experiment requirements are summarized in Table 5-2.

5.4 EXPERIMENT PROGRAM

The experiment program for this FPE is comprised of three experiments - each designed to fulfill a set of objectives. The experiments are:

a. Initial flight experiment.

b. Functional manipulation experiment.

c. Ground control experiment.

The experiments are described in the following sections.

5.4.1 INITIAL FLIGHT EXPERIMENT

5.4.1.1 Technical Objective. The objective of the initial series of T/O flights will be the evaluation of T/O flight performance and safety characteristics. These flights will be conducted under control of the T/O controller aboard the parent spacecraft. Determination of communication "dead" zones and multipath effects, confirmation of the anticipated handling and docking characteristics and a thorough checkout of all T/O visual and manipulator subsystems will also be accomplished during the initial flight series.

5.4.1.2 Description. Prior to the start of the initial flight experiment the T/O will be mated to the docking adapter within the parent spacecraft airlock. While in this configuration, preliminary subsystem checks will be made. Following these initial checks, the airlock will be evacuated and the outer door opened. The docking platform will carry the T/O out of the airlock where it will be released and flown from the parent spacecraft under control of the T/O controller.

At a distance of about 30 meters (100 ft) from the parent spacecraft the T/O will be put through an initial series of maneuvers which will confirm the ability of the T/O to be controlled from the control station. Any required changes to the overall system procedures or control settings will also be determined at this time.

After the completion of this phase the T/O will be flown in close proximity to the parent spacecraft to conduct an external survey of the parent spacecraft. This will provide initial operational data on the video system during both the day and night

Table 5-2. Experiment Requirements Summary

Requirements / Experiment	Mass kg (lb)	Volume m^3 (ft^3)	Envelope	Power W	Crew Skills	Envt. Reqmts.	T/O Total Flight Time	Data Reqmts.	Stability and Control	Orbit Alt. and Incln.
5.4.1 Initial Flight Experiment	610 (1365)	3.9 135	See Table 5-1	160 during flight 300 during battery charge	Electromech Technician Electronic Engineer Mechanical Engineer	N.A.	16 (Hr)	4.9 kbps and 8.4 MHz	N.A.	N.A.
5.4.2 Functional Manipulation Experiment	670 (1500)	4.4 (155)					48 (Hr)			
5.4.3 Ground Control Experiment	625 (1400)	4. (140)					40 (Hr)			

portions of the orbit. Daytime evaluations will be made both in the direct sunlight and in shadowed areas, which will require use of the video illumination system. Initial data on communication dead zones and multipath effects will also be obtained.

After completion of this survey phase, the T/O will be flown to a remote point that is 5 to 10 kilometers (3 to 6 miles) away and then returned to the parent spacecraft. This exercise will provide a test of the navigational and guidance subsystem of the teleoperator system. The T/O will then be docked to the docking adapter, drawn into the airlock, and resupplied.

This sequence of operations will require about four hours. Four similar flights will be performed, for a total of 16 hours.

5.4.1.3 Measurement Program. During the entire initial flight experiment, T/O performance parameters will be measured and recorded for real-time preliminary performance analysis and for later, more detailed, system analysis.

Critical measurements include electrical subsystem performance and flight control subsystem performance. Other measurements will include the video subsystem performance and preliminary data from the manipulator subsystem.

A total impulse of about 22 kN/sec (5000 lb/sec) will be required for the maneuvers described. The cold gas resupply required for this is about 42 kg (90 lb).

If severe communication dead zones are found, a reorientation of existing antennas on the parent spacecraft may be necessary. Additional antennas and an antenna switching system may have to be implemented.

5.4.1.4 Interface, Support and Performance Requirements

5.4.1.4.1 Crew Support. During the initial flight experiment, one crewman will be needed to operate the master station for a total of 16 hours. Thirty-two additional hours of crew support will be required which will include time for T/O servicing, data evaluation, etc. An important part of the evaluation of the teleoperator system will be crew reports on system performance.

5.4.1.4.2 Data Requirements. During the 16-hour experiment duration, the digital data described in the measurement section will be recorded for transmittal to ground. The total data requirement is 2.8×10^7 bits plus the video recordings. The total video recording time will be about 12 hours; the other four hours will be the T/O transit time during the navigational/guidance test.

5.4.1.4.3 Power. Power requirements for the experiment are:

Control Station - 160 W, 24 hr

Battery recharge - 300 W, 20 hr

5.4.1.4.4 Data Return. Experiment data return will consist of the digital data and video data telemetered to earth and the crew reports of system performance.

5.4.1.4.5 Resupply Requirements. Battery recharging and cold gas resupply of 42 kg (90 lb) will be required.

5.4.1.5 Potential Role of Man. Man plays a multiple role in the conduct of this experiment. He prepares the T/O spacecraft prior to deployment, controls flight and manipulative functions from the master control station, services the T/O to replenish propellant and electrical energy, provides repairs and adjustments as required and evaluates T/O performance and determines the need for design changes.

Man is also a subject of this experiment in that the man-machine relationship between the human controller and the flight control characteristics of the T/O system will be evaluated.

5.4.2 FUNCTIONAL MANIPULATION EXPERIMENT

5.4.2.1 Technical Objective. The objective of this experiment is to perform a series of functional exercises with the teleoperator system which will provide the data needed to evaluate the manipulative ability of the system. These exercises will be accomplished on the task board (functional manipulation target) mounted on the airlock door and on the task board of the Task Board Subsatellite. The results of these exercises will be compared to a duplicate EVA task that has been accomplished by an EVA crewman.

In addition, the ability of the T/O to perform translation and rendezvous maneuvers while docked to the subsatellite will be evaluated.

5.4.2.2 Description. The first series of task board exercises will be performed using the airlock door task board. After release from the docking platform, the T/O will visually acquire the task board, identify the docking points, perform a rendezvous maneuver, and dock to the task board. At this point an initial series of video system and manipulator exercises will be accomplished. Typical exercises include studies of binocular TV presentation versus monocular TV presentations, and placement and utilization of the close up camera. The TV system will be evaluated in several operational modes, under varying conditions of natural and artificial lighting. Depth preception as a function of shades of grey will be investigated using prepared test samples mounted on the task board.

The dynamics of the manipulator system will be studied using various amounts of force feedback, various filtering bandwidths, and various control loop gains.

Following this, a series of task-oriented exercises will be accomplished. The following are typical tasks which will be carried out on the airlock door task board:

a. Replacement of thermal insulation.

b. Replacement of film packs.

c. Replacement of a thruster assembly.

d. Assembly and disassembly of mechanical components.

    1. Satellite skin panels.

    2. Electrical connectors.

    3. Fuel transfer lines.

    4. Adjustment/alignment stops.

    5. Structural fasteners and jury structure.

e. Replacement of electronic modules.

f. Actuation of fluid valves.

g. Interchange and operation of manipulator tools and end-effectors.

The second series of task board exercises will be performed using the Task Board Subsatellite.

The T/O will initially deploy the Task Board Subsatellite as described in Section 5.2. Using its manipulators, the T/O will grasp the subsatellite, the subsatellite will be released from its airlock or holding receptacle, and the T/O thrusters will be used to acquire a small velocity away from the parent spacecraft. When the T/O and taskboard subsatellite are about 15 m (50 ft) from the parent spacecraft, the subsatellite will be released. Maximum subsatellite velocity should not exceed 0.03 m/sec (0.1 ft/sec) relative to the parent spacecraft upon release.

At this point, the T/O will begin a visual inspection of the task board. This inspection will again exercise the T/O video subsystem primarily. The lighting conditions will be varied, including specular and diffused natural (sunlight and starlight) and artificial light. Automatic light control shutters on the video camera and other light control schemes (automatic beam control and anti-comet tail) will be employed to investigate task board detail resolution as a function of target distance, power requirements, lighting, markings, and communications parameters. The directivity of the camera line of sight (through its pan and tilt axes) and lighting also will be investigated.

The T/O will then rendezvous to within approximately 10 feet of the subsatellite where it will identify docking points, advance, and dock to the task-board. Once docked, the T/O will stabilize the motion and optimize the attitude of this docked configuration.

The T/O will then reposition itself on the task board in several positions, each time orienting the docked configuration with respect to the parent spacecraft to establish the optimum work stance with regard to manipulator reach/dexterity, vision, lighting, and communications. The second series of investigations of basic manipulator performance (both working arms and docking legs) will then commence including end effectors' grip strength, manipulator strength/deflection, force feedback feel, manipulator traverse rates, and both end effector and tool exchange rates. Various deflection gages, spring scales, and timing devices will be used in these investigations.

Power consumption and temperatures of the various joint motors of the manipulators will be recorded along with subsystem power requirements, temperatures, etc.

The two series of manipulative task studies will require eight flights of the T/O of four hours duration each.

The next phase of the experiment will be the re-docking of the T/O to the subsatellite and delivery of the subsatellite back to the parent spacecraft. This experiment will evaluate the ability of the T/O to dynamically stabilize an unsymetric load and, using its thrusters, translate this load over a specified course to the parent spacecraft. This phase of the experiment will require two flights of the T/O of four hours duration each.

The final phase of the experiment will be conducted using the maintainable attitude control propulsion system described in Section 4.4.6. A series of exercises will be performed which involve the replacement of propulsion system components by the teleoperator system. These components will already have been replaced by an EVA astronaut so that time line data will be available to compare the two methods of task accomplishment. This phase of the experiment will require 4 flights of the T/O of two hours duration each.

5.4.2.3 Measurement Program. During the entire functional manipulator experiment the performance of the T/O system will be recorded. A partial list of T/O system parameters to be recorded is given below.

a. Power and fuel consumption rates.

b. Subsystem power consumption.

c. Temperatures.

d. Manipulator forces and torques.

e. Attitude, velocity, and accelerations.

f. Manipulator and camera positions.

g. Docking legs positions and forces.

h. Video data.

During the test program described, the data load to the parent spacecraft will be:

Video data, 2 channels - 8.4 Mhz

Digital data - 1.5 kbits/sec

Command and control - 3.4 kbits/sec

A total impulse of about 3600 N/sec (8250 lb/sec) would be required, for a cold gas supply of about 61 kg (135 lb).

5.4.2.4 Interface, Support and Performance Requirements

5.4.2.4.1 Crew Support. A crewman will be needed to operate the control station during the entire 48-hour experiment period. Ninety-six additional hours of crew support will be required for T/O servicing, data evaluation, etc.

5.4.2.4.2 Data Requirements. All of the data will be recorded onboard the parent spacecraft and telemetered to the ground. The total data requirements are 85 x 10^6 bits and 48 hours of video data recording. Some real time relay to the ground would be desirable to prepare for the following experiment.

5.4.2.4.3 Power. Power requirements for this experiment are:

Control station - 160 watts for 72 hours.

Battery recharge - 300 watts for 60 hours.

5.4.2.4.4 Data Return. Experimental data returned will consist of the digital data and video data telemetered to Earth and crew reports of system performance.

5.4.2.4.5 Resupply Requirements. Battery recharging and cold gas resupply of 61 kg (135 lb) will be required.

5.4.2.5 Potential Role of Man. In addition to the functions described in Section 5.4.1.5, this experiment will study the interaction between the T/O controller and the effective performance of specified manipulative tasks. Of particular interest will be the ease in which the crewman can adapt to changing lighting conditions and the desirability of binocular vision.

The data obtained from this experiment will become baseline data for the ground based control experiment.

5.4.3 GROUND CONTROL EXPERIMENT

5.4.3.1 Technical Objective. The object of this experiment is to evaluate the effects of the radio link transit time on the remote operation of the T/O as it is used to perform several specified tasks.

5.4.3.2 Description. Using the functional manipulation experiment (Section 5.4.2) data as a baseline, this experiment will be conducted with the T/O at various slant ranges from the ground based control station. These ranges will vary from 185 km (100 n. mi.) to 1650 km (900 n. mi.), (assuming a 185 km orbit), giving two way time delays of the order of 1.2 millisec to 11.0 millisec. If repeater stations are used to obtain beyond-the-horizon distances, the transit delays could go to 0.14 sec for distances of up to 20,000 km (11,000 n. mi.). The use of data relay satellites in synchronous orbit would further increase the delay time.

The experiment will be performed using the airlock door task board. A series of previously specified tasks such as actuation of valves or insertion of components, for example, will be systematically accomplished and the T/O system performance evaluated as a function of varying delay time.

Flight control of the T/O from the docking platform to the task board and back will initially be accomplished by the crewman on the parent spacecraft. If subsequent data reveals no danger, flight control and experiment manipulations will be accomplished by the ground-based controller.

5.4.3.3 Measurement Program. A series of 20 experimental runs will be performed. Each run will be about two hours duration and will consist of repeated manipulative exercises using the airlock door task board, and flight maneuvers in the near vicinity of the parent spacecraft. Time delays will vary from 1.2 millisec to 0.14 sec, assuming the use of repeater stations. Greater delays simulating operation at lunar or interplanetary distances can be introduced by the computer at the ground control station.

In addition to the telemetered data detailed in Section 5.4.2.3 of the functional manipulation experiment, data on power consumption required to complete a specified task with various time delays will be acquired. The data from the functional manipulation experiment will be used as baseline data. In addition, the torques and transient loads imposed on the task board by the T/O manipulators will be measured to establish the "jerkiness" of the manipulator motions during the portion of the experiment using long time delays.

Studies of trained operators will be made to determine man's ability to compensate for the varying delays. In addition, various adaptive control system techniques can be tried in the ground-based equipment to investigate automated methods for coping with the transit time problem.

5.4.3.4 Interface, Support and Performance Requirements

5.4.3.4.1 Crew Support. A crewman will man the T/O control station in the parent spacecraft during the 40-hour experiment duration in case of excessive signal loss or communication system failure. Eighty additional hours of crew support will be required for T/O servicing, data evaluation, etc.

5.4.3.4.2 Data Requirements. During the 40-hour test series, data will be recorded aboard the parent spacecraft and relayed to the ground control station simultaneously. A two-way command and control link with the ground station is required.

5.4.3.4.3 Power. Power requirements imposed on the parent spacecraft are:

Control station - 160 W for 60 hours

Battery recharge - 300 W for 50 hours

5.4.3.4.4 Data Return. All data from this experiment will be recorded at the ground station during the experiment. No additional data from the parent spacecraft will be needed to supplement it.

5.4.3.4.5 Resupply Requirements. Battery recharging and cold gas resupply of about 65 kg (150 lb) will be required.

5.4.3.5 Potential Role of Man. The controller aboard the parent spacecraft is primarily a safety observer during the conduct of this experiment. T/O servicing and data evaluation are also required.

5.5 FPE INTERFACE, SUPPORT, AND PERFORMANCE REQUIREMENTS

The summary data presented in Table 5-3 represents, in the best judgement of NASA scientists, the overall facility and experimental requirements to accomplish a realistic experimental program. The rationale for selection of the summary parameters is arbitrary in some instances but has as a basis the total NASA experience and knowledge of prior flight and experiment definition and integration programs.

Table 5-3. Interface, Support, and Performance Requirements Summary

Mass	670 kg (1500 lb)
Volume	4.4 m^3 (155 ft^3)
Power (from parent spacecraft, worst case)	300 W
Crew Skills	Electromechanical Technician Electronic Engineer Mechanical Engineer
Data Rate	4.9 kbps + 8.4 MHz TV
Logistics Up (Per 30 days)	80 kg (180 lb)
Logistics Down (Per 30 days)	5 kg (11 lb), notes and photographic film
Pointing and Stability	No parent spacecraft maneuvering permissible during T/O docking and undocking
Orbit Altitude and Inclination	N/A
Unique Environmental Requirements	N/A

5.6 POTENTIAL MODE OF OPERATION

The potential modes of operation to be considered are:

Mode A. Limited on-orbit stay time supported by the Space Shuttle

Mode B. Extended on-orbit stay time with a free flying RAM, periodically revisited by a Shuttle.

Mode C. Extended on-orbit stay time supported by the Space Station.

Modes A and C are both potential modes of operation for this FPE. Since the communications dead zones which may be encountered would be different for different spacecraft sizes and configurations (i.e., Space Shuttle and Space Station), each potential operating mode of the operational T/O system should be evaluated.

5.7 ROLE OF MAN

The teleoperator is a man-machine system and consequently requires the use of man continuously during the operation. All T/O spacecraft actions are controlled and commanded by man. The preparation of the spacecraft prior to deployment must be supervised by man. The evaluation of system performance must be prepared by man.

Man's qualitative judgement represents a significant portion of the experiment data. Man will also be called upon to evaluate the experimental system design and recommend changes for the operational system.

5.8 SCHEDULE

The schedules for Phases A, B, C, and D of a teleoperator flight experiment are shown in Table 5-4.

Table 5-4. FPE Development and Flight Schedule

FPE/Experiments	Schedule (Years) re. Launch Date									
	n-5	n-4	n-3	n-2	n-1	n	n+1	n+2	---	n+10
FPE Development										
5.4.1 Initial Flight Expt.										
5.4.2 Functional Manipulation Expt.										
5.4.3 Ground Control Expt.										

Legend:

Phase A

Phase B

Phase C

Phase D

5.9 PRELAUNCH SUPPORT REQUIREMENTS AND GSE

Protective containers will be required for shipping, handling, and storing the T/O system equipment.

5.10 SAFETY

5.10.1 TELEOPERATOR EVA. The possibility of damage to the manned spacecraft must be considered whenever the teleoperator is being used. Some potentially hazardous conditions are:

1. Uncontrolled thruster operation
2. Uncontrolled manipulator operation

3. Uncontrolled flight, powered or unpowered.

4. Uncontrolled movement of tools or target satellites.

All of these conditions can cause damage to the manned spacecraft. These conditions can occur by:

1. Loss of command signals.

2. Subsystem failure, or control station malfunction.

3. Erroneous flight or manipulative techniques.

To preclude the possibility of the kinds of accidents previously described, the teleoperator must have a "fail-safe" capability. When a loss of command signal occurs, for example, the T/O angular rates and translation velocities must be reduced to zero.

As a final safeguard, translation velocities within 10 meters (30 feet) of the manned spacecraft will be restricted to some low value, i.e. about 0.3 meter/sec (1 ft/sec).

5.11 AVAILABLE BACKGROUND DATA

Several studies involving space teleoperator systems have been funded by the government and are useful as background data along with several published technical papers.

a. A. Interian and D. A. Kugath, General Electric Company and D. Novik, NASA, Teleoperator Applications in the Manned Space Program, prepared for the Twenty-First Congress of the International Astronautical Federation in October, 1970.

b. A. Interian and R. H. Blackner, General Electric Company, and W. H. Allen, NASA, Remote Manipulator Spacecraft Systems, prepared for the Twentieth Congress of the International Astronautical Federation in October, 1969.

c. R. H. Blackner and A. Interian, General Electric Company and R. G. Clodfelter, United States Air Force, The Role of Space Manipulator Systems for Extravehicular Tasks, prepared for the Second National Conference on Space Maintenance and Extravehicular Activities in August, 1968.

d. A. Interian and D. A. Kugath, General Electric Company, and W. H. Allen, NASA, Satellite Maintenance Using Remote Manipulator Spacecraft, prepared for the AIAA Eighth Conference on Reliability and Maintainability in July, 1969.

e. A. Interian and D. A. Kugath, General Electric Company and W. H. Allen, NASA, A Remote Manipulator System for Space Applications, prepared for the International Symposium on Man-Machine Systems in September, 1969.

f. <u>Remote Manipulators and Mass Transfer</u>, AF-33615-67C-1322 by the General Electric Company for the Air Force Aero Propulsion Laboratory, 1968.

g. <u>Application of Remote Manipulation to Satellite Maintenance</u>, CR-73-338 and CR-73-339, by the General Electric Company for the NASA/OART Mission Analysis Division, 1969.

h. <u>Study of Application of Remote Manipulation to Satellite Maintenance</u>, by General Electric, NAS 2-5072.