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THERMAL CONTROL

OAST Summer Workshop

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Vol VIII of X

NOTICE

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VOL II SENSING AND DATA ACQUISITION

VOL III NAVIGATION, GUIDANCE, AND CONTROL

VOL IV POWER

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VOL VI STRUCTURE AND DYNAMICS

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Office of Aeronautics and Space Technology

Summer Workshop

August 3 through 16, 1975

Conducted at Madison College, Harrisonburg, Virginia

Final Report

THERMAL CONTROL PANEL

Volume VIII of XI

OAST Space Technology Workshop

THERMAL CONTROL PANEL

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SUMMARY

Since the Thermal Control Working Group had just recently completed a near term assessment of their technology needs [Ref. 1], the group was able to concentrate on long range identification of technology requirements. The Outlook for Space, Forecast for Technology [Ref. 2], was used as a primary reference for identifying anticipated long range technology deficiencies. Furthermore, the overriding themes which were apparent during the workshop were large structures and cold controlled environments. The Thermal Control Group has attempted to address its technology forecast in the perspective of these guidelines.

Thermal Control technology was divided into eleven categories: Thermal Control Surfaces; Heat Pipes; Mechanisms; Testing; Instrumentation; Contamination; Cryogenics; Analysis; Thermal Properties; Insulation; and Design Techniques. These categories include both technology requirements and tools. Particular long range needs were identified under these categories and finally, relevant flight experiments were identified and documented.

Three major thrusts, besides reduction of costs, were identified as major directions for thermal control technology development and space experiments.

1. Extend the useful lifetime of cryogenic systems for space
2. Reduce temperature gradients

3. Improve temperature stability

The cryogenic objective is interpreted to include such elements as methods for achieving temperatures approaching 0°K, cryogen management, passive radiation and refrigeration systems for replacing expendable cryogens, and technology for cryogen replenishment as well as devices and systems designs to extend lifetime directly by reducing losses.

Reduction of a macro-gradients (tens of degrees) in very large structures and micro-gradients (degrees and fractions of degrees) in instruments and optical systems or the effects of such gradients will be achieved by combinations of new technology in thermal control surfaces, material properties and design approaches as well as active devices such as heat pipes. For example, thermal distortion of an antenna might be reduced by use of low coefficient of expansion material for construction, thermal expansion compensated configuration or heat pipes as ribs.

Improved temperature "stability" includes improved ability to achieve a required absolute temperature, accurate prediction of equilibrium operating temperature in space, controlled transient temperatures as well as ability to maintain acceptable temperatures under varying load and lifetime conditions. Technology requirements include active devices and systems, design approaches as well as long term properties and stability of coatings, insulation, etc.

A consensus of the five key flight experiments was not taken by the group. However, the chairman has identified four key experiments and the fifth experiment will depend on whether space processing and power experiments, or earth resources and earth science experiments are given priority. The key experiments are:

(1.) Shuttle Contamination Effects on Thermal Control Surfaces

(2.) Stored Cryogen System Evaluation

(3.) He^{II} Storage and Utilization

(4.) Ultra-high Conductance Heat Pipe Development for very Large Structures

For space processing and/or power experiments, the fifth experiment should be:

(5.) Development of Large, Variable Heat-rejection Radiators

For earth resources and earth science experiments, the fifth experiment should be:

(5.) Development of a Deployable, Controlled Orientation Radiator

REFERENCES

1. "Report of the Space Transportation Systems Technology Working Group for Thermal Control" Internal Report to Paul Herr, Program Manager, Advanced Systems Technology, OAST, February, 1975.

2. "Outlook for Space Reference Volume: A Forecast of Space Technology 1980-2000", Final Draft, NASA Special Publication, July, 1975.

INTRODUCTION

I. Introduction

The technology recommendations in this report were developed during the two week NASA/OAST 1975 summer workshop, based on the background information provided and the expertise of the working group members. The supporting text and technology descriptions are intended to contain sufficient information to permit assessment as required.

The technology requirements (Section II) are not intended to be a complete listing, and the relative scope of Sections II and III (flight experiments) should not be construed to indicate the relative importance of ground based technology versus space experiments. Identification of technology requirements was an essential and accomplished step in defining meaningful space experiments. Since the primary objective of the workshop was the identification of space experiments, priority was given to their documentation for this report. In many cases, the included information was extracted from Reference 1.

For the purposes of dealing with the total of thermal control technology, several technology categories were identified. These categories included both the requirements as well as specific tools or means to meet these requirements. The sequence has no relation to relative importance, but merely provided a convenient means of organization.

In defining flight experiments, the primary criterion was the need for space (i.e., low-g, vacuum, etc.). The question of relative cost of space vs. ground testing could not be addressed due to the constraints of time. Some technology items not included here may become candidates for space experiment, if cost effectiveness can be shown.

The working group undertook to define its scope, starting with the Outlook for Space (OFS) matrix [Ref. 2]. Thermal control has been defined by OFS as Management of Matter (maintenance of state). During the initial establishment of an approach, some technology items were not clearly identified. These included *contamination*, *radiation* and *micrometeorites*. The containment of pressurized fluids dealt only with thermal control materials (cryogens and phase change materials) aspects of the problem. In the area of contamination, the working group considered only the effects of contamination on the properties of thermal surfaces and some of the effects of temperature profile on contaminant transport.

Technology related to radiation effects on thermal surfaces was included. All other aspects of radiation (i.e., model definitions, other effects, etc.) were deleted from consideration. Micrometeroid technology was omitted. The potential significance of the above omissions is discussed in more detail in Appendix C.

Thermal control design requirements and constraints are derived from the specifics of mission, system, and subsystem design. These design drivers are typically not well defined for advanced missions, with the result that the associated requirements for thermal technology which are interactive with other features of spacecraft design, have consequently been omitted from the Thermal Group's considerations. This omission was the undesirable but unavoidable result of not being able to define part of the required input data; the process of identifying candidate technology developments and flight experiments can be expected to proceed as these data become available. The recommendations herein should therefore be understood to be incomplete in this important area.

APPROACH

The general approach used by the TC working group is illustrated in Figure I-1.

Since near term Thermal Control Technology requirements have been developed during the past year [Ref. 1], the working group chose to approach this workshop from a long range point of view, starting with Outlook for Space (OFS). Section II of the OFS, "Forecast of Space Technology" [Ref. 3] and the detail breakdown of that section in Reference 4, were reviewed in parallel to identify anticipated deficiencies and issues in thermal control technology to meet the overall objectives of the indicated areas of NASA emphasis in Reference 3 and in space environment opportunities to support OFS [Ref. 4]. The subdivisions or categories of thermal control in the matrix (Figure I-2) are a convenient means of organizing the approach and were subsequently carried over into organization of the report. These categories contain both the requirements that TC must meet and the tools used to meet these requirements.

Other source documents, '73 NASA Payload Model, OFS Illustrative Missions (Vol. 2), Opportunities and Choices in Space Science, '74 (National Academy of Science) etc., were reviewed to identify gaps within each technology category.

In developing the matrix (Figure I-2), considerable selectivity was inherent in identifying the need for additional technology. Subsequently each category was reviewed as indicated in Figure I-3. This analysis identified the need for ground based technology, flight experiments for technology development and space experiments for demonstration or verification of equipment or systems.

Flight experiment narrative (Section III) and payload descriptions (forms, Appendix B) were prepared. Each flight experiment was assigned to a primary technology category although many encompass more than one category. The report has been organized in accordance with this assignment. The organization of technology requirements narratives (Section II) and definitions (Appendix A) follow the flight experiment assignment.

CONCLUSIONS

Among the wide variety of requirements that drive Thermal Control Technology, the two outstanding themes for the next 25 years are COLD and LARGE.

Low temperatures (cryogenics) will be required for many of the proposed sensors, optics and experiments. New and improved technology will be required to permit achievement and practical (economical) implementation of proposed equipment and experiments.

Shuttle will make possible and viable, the launch, erection and/or assembly of structures, instruments and equipment very much larger than in the past. Practical utilization of this large equipment will require thermal control approaches significantly different than those used in the first two decades of space exploration.

Most of the technology and space experiments identified during the Workshop can be summarized in three key directions or objectives of thermal control technology development:

1. Extend the useful lifetime of cryogenic systems in space.
2. Reduce temperature gradients.
3. Improve temperature stability.

A major subelement of each of these three as well as of other objectives is REDUCTION OF THERMALLY RELATED SYSTEM COST.

The cryogenic objective is interpreted to include such elements as methods for achieving temperatures approaching

0°K, cryogen management, passive radiation and refrigeration systems for replacing expendable cryogens, and technology for cryogen replenishment as well as devices and systems designs to extend lifetime directly by reducing losses.

Reduction of a macro-gradients (tens of degrees) in very large structures and micro-gradients (degrees and fractions of degrees) in instruments and optical systems or the effects of such gradients will be achieved by combinations of new technology in thermal control surfaces, material properties and design approaches as well as active devices such as heat pipes. For example, thermal distortion of an antenna might be reduced by use of low coefficient of expansion material for construction, thermal expansion compensated configuration or heat pipes as ribs.

Improved temperature "stability" includes improved ability to achieve a required absolute temperature, accurate prediction of equilibrium operating temperature in space, controlled transient temperatures as well as ability to maintain acceptable temperatures under varying load and lifetime conditions. Technology requirements include active devices and systems, design approaches as well as long term properties and stability of coatings, insulation, etc.

The COST objectives are primarily the thermally defined or constrained system cost per unit of science information or space operation time rather than a lower cost can of paint, heat pipe or square foot of insulation.

THERMAL CONTROL APPROACH

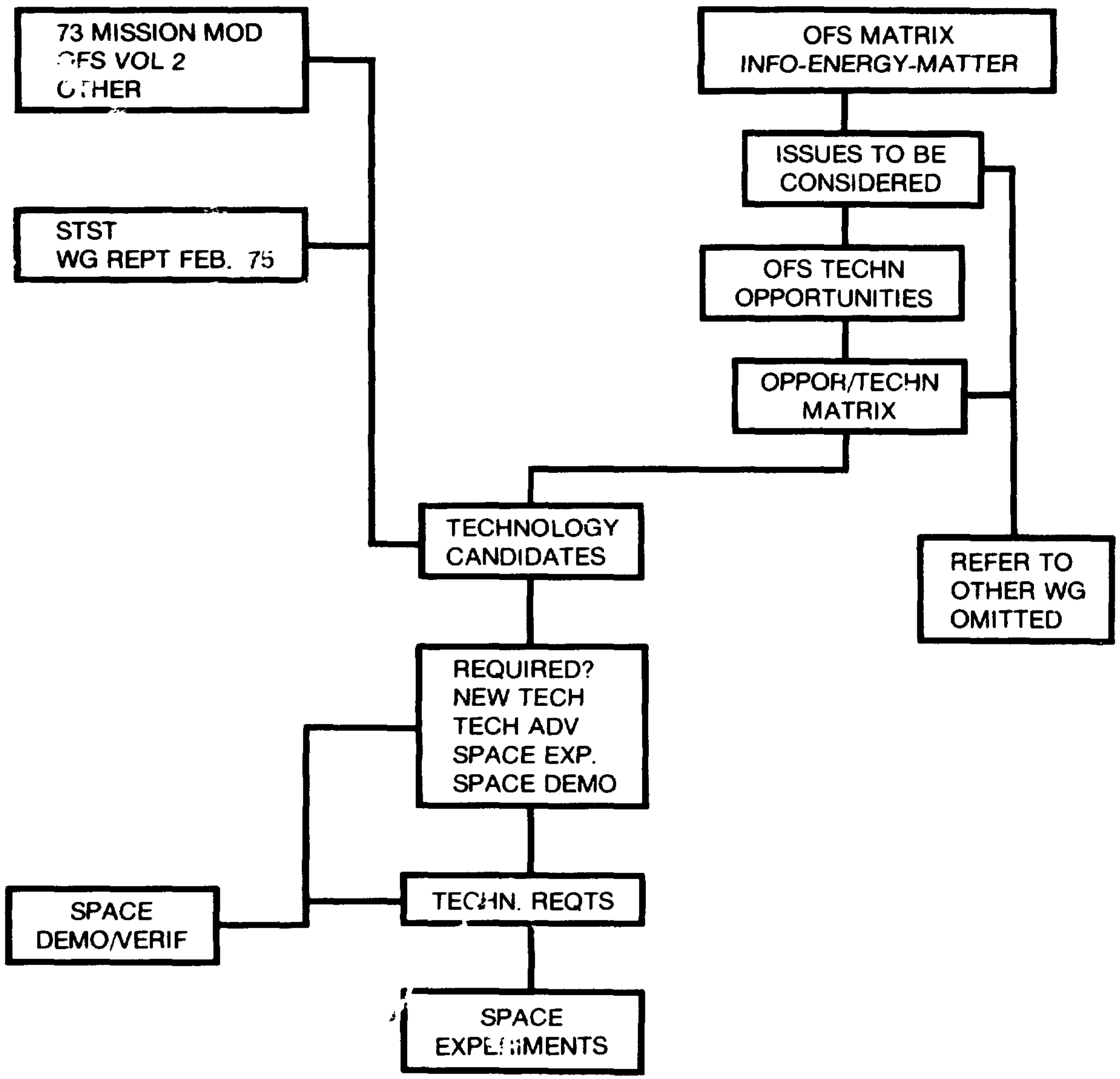


Fig. I-1

TCWG-3

THERMAL CONTROL MATRIX

OPPORTUNITY - TECHNOLOGY

KEY EXP OPP		T.C. SURF	INSUL	HEAT PIPE	DEVICE & SYST	TEST	INST	CON TAM	CRYO	ANAL CAP	OTHER
EARTH TO ORB. LOW COST TRANS	1.1	X									
	1.2		X								
	1.3			X	X						X
	1.4		X	X	X	X	X				
	1.5					X					
	1.6		X					X			
STRUCT BIG, LITE-WT	2.0	X	X	X	X	X	X	X		X	X
	2.1									X	X
	2.2			X	X		X				
	2.3	X	X	X	X	X	X	X		X	X
	2.4									X	
SPACE ENERGY CONV.	3.2	X	X	X	X	X	X	X		X	X
	3.3										X
DATA MGM'T CRYO HI-PW'R	4.1		X	X	X	X	X	X	X	X	X
	4.2			X	X				X		

TCWG-5

Fig. I-2

THERMAL CONTROL MATRIX

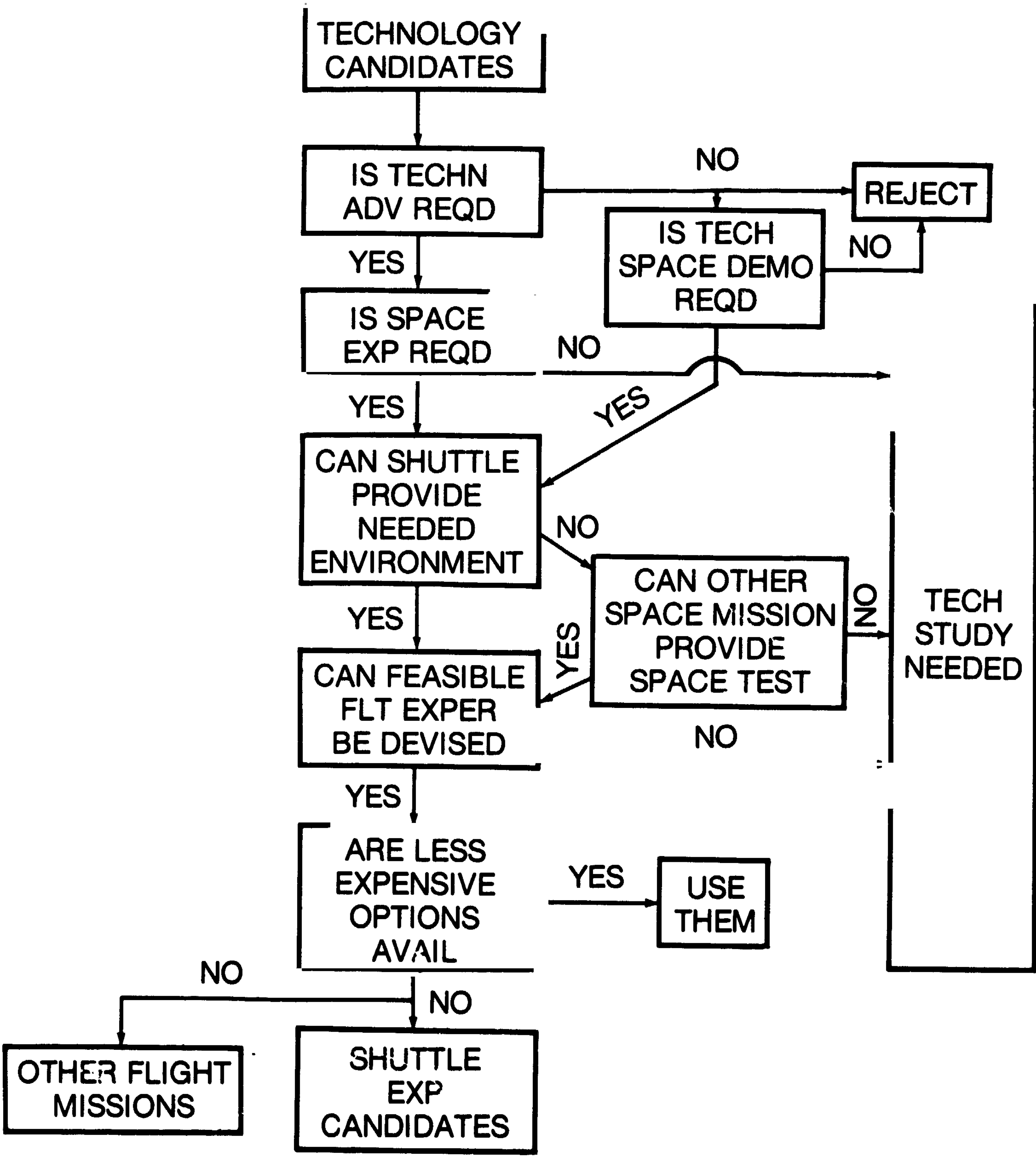
OPPORTUNITY - TECHNOLOGY

KEY EXP OPP		T.C. SURF	INSUL	HEAT PIPE	DEVICE & SYST	TEST	INST	CON TAM	CRYO	ANAL CAP	OTHER
COMMUNICATION	5.3			X	X						
COMPONENTS RELIABILITY LIFE TIME	6.1 7	X	X	X X	X X				 X		
S. CRAFT & ROVER	8	X	X	X	X	X				X	X
PRECI NAV.	9	X	X	X	X	X	X	X		X	X
INSTRU. SENS. & DATA	10.1 11		X	X	X	X	X	X	X	X	X X
NUC PWR & PROP	12 13		X X	X X	X X			X X			X X
ENVIR. PLAN. & LUNAR	16 17	X	X X	X X	X X	X X	X X	 X	 X	 X	X X

TCWG-6

Fig. I-2 (continued)

THERMAL CONTROL SPACE EXPERIMENT EVALUATION



NOTE: FLOW DOES NOT INDICATE NEED OR IMPORTANCE OF SUPPORTING TECHNOLOGY REQUIRED PRIOR TO SPACE EXPERIMENTS

TECHNOLOGY REQUIREMENTS

II. Technology Requirements

Introduction

Technology requirements (Section II and Appendix A) as described in this report are incomplete. The emphasis at the workshop was identification and documentation of space experiments. As a result, many required technology developments discussed during the workshop were not repeated in this report since they have been previously documented [Ref. 2].

Furthermore, although the experiment descriptions in Section III and Appendix B may not specifically indicate, the preparation for and implementation of each experiment must result from, and be supported by, a sound technology program.

a. Thermal Control Surfaces

Even in an era of active thermal control systems, the ultimate regulation of absorbed solar energy and radiated thermal energy will remain dependent on surface properties. Past SR & T has provided a good base of materials, with required characteristics, methods for measurement and test, and design properties data. Additional development in several areas will be required to meet future demands for coatings.

Low α/ε paint. White paints with controlled optical characteristics, offer the most convenient reference surfaces for a long-term space vehicle, which requires heat rejection from the sun input (i.e., cold running surfaces). Such a coating has been used on most satellites flown to date. Application is by normal paint spray gun on properly prepared substrate (which substrate can be a wide variety of materials, both metallic and non-metallic). The paint surface as presently applied is somewhat elastomeric and not subject to coasting. It meets the outgas standards as proposed by Sidenburg at GSFC testing. Because of a great number of flights in which the coatings have been used, and extensive measurements of the coatings thereon, the expected variation in properties is of narrow latitude. Advantages are:

(1) Weight economical

(2) Easy to apply

(3) Extensive lab and limited space data on degradation rate

(4) Very high emissivity (above 0.92)

(5) Methyl silicones can be easily cleaned before launch and easily repaired if necessary

(6) Passive system

(7) Application to any size and configuration of substrate by normal spray gun

Disadvantages are:

(1) Subject to soiling in handling and assembly

(2) While not a probable source of contamination, the surface can be contaminated, with subsequent degradation of optical properties

(3) Cleaning system for space not presently known

(4) Repair system for space not presently developed

(5) Thermophototrophic system of wide range not known, so variation depends on mechanical louvers or the like

Current status of development and available data indicates the feasibility of extending development to achieve a solar absorptance of approximately .08 with 1-2 years of additional work on five orthotitanate systems.

Diffuse SSM. Conventional second-surface mirrors (SSM) are specular reflectors with 85 to 90% of their total solar reflectance being specular. Since the SSM coatings are the most space stable low α/ε systems for spacecraft temperature control, their current and projected use includes all types of spacecraft both manned and unmanned. Therefore, diffuse counterparts of current SSM's are required to: provide for more effective thermal analysis; eliminate concentrations of reflected energy; and provide safety for manned operations. Current OAST efforts are concentrated on providing a low cost 90 to 95% diffuse, flexible SSM of silvered FEP Teflon for possible use as the Shuttle orbiter crew systems radiator coatings and as a substitute for currently used flexible SSM coatings.

Composite. Vapor deposited composite $Ag/SiO/A_2O_3$ coatings have low α's, controllable moderate ε's have demonstrated space stability and are non-contaminating and low weight. Improvements are required in scaling of application to large area radiators.

Thin film. High modulus, radiation resistant polymeric films are currently being used to provide temperature control for large aperture spacecraft instruments, i.e., x-ray spectrometers. Current investigators are requesting these films to be approximately 0.1 mils in thickness to provide maximum resolution for their instruments. Polymide films, such as "Kapton", are not commercially available in thickness below 0.3 mils, therefore these films must be produced in the laboratory. Currently the thin polymeric films are produced by casting on an optical glass plate, oven curing to 300° C on this glass plate, and then floating the cured film off the glass in a water bath. This is a time-consuming, expensive process, giving only 50% good films; and it (this process) is limited by the flatness of the glass plates and the size (length and width) of these glass plates. Films of approximately 8 inches by 12 inches can currently be produced by this technique, but requirements for film as large as 14 inches by 18 inches are forecast for the near future.

Long-term data. Extended term laboratory tests, correlated with space flight data, of coating degradation is essential for reliable thermal design of future vehicles.

A number of other potential coatings tasks have been identified as shown in Table I of the STST TC WG Report Feb 1975 [Ref. 1].

Thermal control materials compatible with the space plasma/charging environment. Current typical spacecraft flexible solar array and thermal control system designs include a large number of dielectric materials facing the space environment. These materials include: silvered Teflon, Kapton (bare and aluminized), silvered quartz, and paints. Until recently, these materials and designs have appeared acceptable. There is increasing evidence, however, that there may be significant adverse interactions of these materials with the space plasma/ charging environment. A large number of spacecraft electrical anomalies are attributed to such interactions. Spacecraft thermal control dielectric materials and applications techniques do not exist which are compatible with the space plasma/charging environment. Conductive coatings with low α/ε must be developed to accomplish this.

Accordingly a technology program is needed to help solve this very important space plasma/charging problem. By evaluating data from the ATS-5 and ATS-6 satellites, a model of the charging environment can be postulated. An attempt will be made to define the space environment, model the spacecraft interaction with this environment, and to simulate the environment in ground based facilities. There will be an experimental effort to determine the response of spacecraft materials to this environment and to develop new or modified materials. Later on there will be flight programs to obtain space environment data, to evaluate materials in the actual environment, and to provide a calibration for ground simulation.

All spacecraft that have missions to geosynchronous orbit will benefit from this technology effort.

Improved temperature control coatings for very large space structures including solar collectors. This major thrust will require inputs from all the base technology being done on thermal control coatings and surfaces. Primary emphasis will be on integrating the thermal control coating with structural elements. For example, light-weight laminates with integral thermal control surfaces will have to be developed. High α/ϵ (values of 30 to 50) coatings for use on solar collectors must be developed. In addition this technology will be driven by the need for light weight, high efficiency, low cost, and increased performance in future very large space structures such as a space photovoltaic.

Evaluation of long-life stability of spacecraft thermal control surfaces. Long-term missions are planned in energetic radiation environments but little or no flight data is available in these environments on coatings developed in the 70's. Other coatings with greater potential are currently being developed. Laboratory testing has been shown to be only an approximation of space tests. Therefore, actual space tests are required and in the specific environment where missions are planned.

b. Heat Pipes

Heat pipes have a demonstrated capability to transport large quantities of thermal energy over long distances at minimum temperature drop and weight. This characteristic allows remote heat rejection, thus permitting equipment location compatible with structure, configuration, orientation, etc., with minimized thermal control constraints. The high thermal efficiency also makes it possible for heat pipes to isothermalize surfaces which have concentrated heat inputs. Additionally, several mechanisms inherent in the heat pipe process can be used to self-regulate the amount of heat transferred and, thus, provide temperature control.

When compared to fluid loops for some applications, heat pipes inherently offer the following advantages:

(1) Absence of mechanical and electrical interference from pumps and moving fluid (e.g., vibration of finely pointed telescopes).

(2) No moving mechanical parts.

(3) Simple for parallel redundancy (e.g., minimizes effect of meteroid penetrations).

(4) No power required (e.g., passive).

Heat pipes have already been used on several spacecraft currently operating in space.

The following is a summary of critical factors which require new or continuing technology. These are reflected, where applicable, in flight experiments.

Hydrodynamics. Assuming proper selection of materials and processes, hydrodynamic behavior generally becomes the limiting factor in the performance and reliability of heat pipes operating at temperatures below those of the liquid metals. The need to increase the capillary pressure (implies small capillary pores) without increasing flow resistance (implies larger effective pore sizes) to improve the heat pipe's hydrodynamic capacity beyond that of the simple screen wicking system. Each of these more complex wicking systems have unique problems which remain to be understood completely and then circumvented. For example, axial grooves are attractive because they can be extruded inexpensively and provide sufficient 0-g performance for many spacecraft applications. However, they have poor ability to pump liquid against gravity, making ground testing difficult and confusing the extrapolation from one to 0-g performance. Composite wicks use a variety of methods to achieve small effective pores for pumping, while maintaining a large effective pore size to reduce liquid flow resistance. It is still difficult, however, to fabricate composite wicks to achieve a predicted performance. Arterial wick systems offer the greatest hydrodynamic capacities, but have difficulty in priming reliably, especially in low pressure heat pipes. Better analytical performance predictions, fabrication techniques, and reliable arterial priming methods are required. (See Flt. Exp. b-2, Section III.)

Cryogenic. A significant future application of heat pipes appears to be in cooling various types in the range 2 to 150K. Two factors complicate cryogenic heat pipe designs. The first is the cryogenic fluids which increase the complexity of the wicking system and ground testing. The other is the fact that at room temperature the fluids become supercritical and may cause extremely high pressures. Considerable work remains in extrapolating room temperature heat pipe technology into the cryogenic temperature range. (See Flt. Exp. b-2, b-3, Section III.)

Electrohydrodynamic (EHD). EHD offers the potential to control heat transfer by varying electrical voltage. In addition the use of EHD flow structures to replace or augment capillary pumping in a heat pipe, may result in higher performance (ability to carry heat over long distances). Although the feasibility of EHD heat pipes has been proven in the laboratory, much work remains to develop a practical system. The potential capabilities of EHD heat pipes are sufficiently great that work should be continued, even though no specific application has been identified. The same principle may also be applicable to other fluid (i.e., propellant) acquisition and control. (See Flt. Exp. b-2, Section III.)

Vapor control. Variable conductance heat pipes have already found application on several spacecraft. These pipes, however, have used the compression and expansion of a non-condensing gas to block condensation over varying lengths of the condenser to control the rate of heat transfer. This control mechanism is very sensitive to changes in temperature at the condenser and gas storage reservoir. In cases where temperatures at these locations are high and widely varying, a new control mechanism (vapor control) offers several advantages: better control characteristics, direct control of heat source, and possibilities for standardization. Efforts are required to develop this concept into a useful, standardized controllable heat pipe for large variable heat rejection radiators. (See Flt. Exp. b-5, Section III.)

Diode. The heat pipe process inherently offers mechanisms by which heat can be transferred very efficiently in one direction, and very inefficiently in the reverse direction. A major application for heat pipe diodes is the coupling of a sensitive heat source to a space radiator. The diode will protect the source by not allowing heat to be transferred to it if the radiator should become warmer than the source due to spacecraft orientation, atmospheric entry, etc. A diode which uses excess liquid to block heat transfer in the reverse direction was flown as part of the Advanced Thermal Control Flight Experiment on ATS-F. Several other techniques exist and offer unique advantages, as well as disadvantages. These techniques require further development and understanding, especially for use in the cryogenic temperature range where the fluid properties which control heat pipe performance are less effective than at room temperature and initial start-up is from a supercritical state. (See Flt. Exp. b-1, Section III.)

High temperature. Heat pipe technology received much of its early impetus from potential applications at temperatures requiring liquid metal working fluids (e.g., Thermionic energy conversion). Problems of materials compatibility processing, and fabrication still exist. High-temperature heat pipes may have significant applications for aircraft leading edge cooling, and other nuclear applications. (See Flt. Exp. d-3, Section III.)

** Effects of heat pipes on s/c performance. As pointing systems become more sophisticated and requirements for stability enter the .01 arc sec regime, the small disturbances caused by heat pipe fluid dynamics must be ascertained. In order to quantify these values experimentally, sufficient analysis and testing is required. (See Flt. Exp. d-2, Section III.)

** Intermediate temperature range. Where it is required to raise the heat retention temperature of radiators, in order to reduce weight, heat pipes will have to be developed in the 300 to 800K range. Water-copper heat pipes have been used in radiator designs in this range; however, their efficiency falls off rapidly above 400K. (See Flt. Exp. b-5, Section III.) It may be noted that heat pipes in this temperature range can be used in many terrestrial applications such as solar collectors, heat recovery systems, etc.

** New Technology requirements not identified in report of STS Technology working group for thermal control Technology Report Feb 75

c. Mechanisms and Systems

The thermal group reviewed earlier recommendations [Ref. 2] on the types of devices which might be required for future missions. The classification by type is given in Table I, together with some potential areas of application. The design requirements and constraints which seemed of importance to the thermal group are listed in Table II, as deduced from the broad considerations of the Outlook for Space and what was known of nearer term mission requirements. As noted earlier, the specifics of mission and system design will dictate the types of devices which must be developed. Some technology development recommendations for devices were given in the Report of the STS Technology Group for Thermal Control Technology (February, 1975); the working group expects that additional candidates will be identified as improved definitions of mission and system design are obtained.

A technology development leading to a flight experiment of deployable/orientable radiator systems and components is contained in Appendix A (C-3).

TABLE I

THERMAL CONTROL DEVICES

I. Thermal Energy Generation/Acquisition
   - Radioisotope
   - Solar

II. Thermal Energy Storage
   - Phase change

III. Thermal Energy Transport
   a. Input
   b. Removal
      - high flux
      - high temperature
   c. Transfer
      - ultra-high conductance
      - variable
      - long distance

IV. Rejection
   - Controllable
   - Radiators

V. Systems
   - Gradient control
   - Thermostatic
   - Expendable heat sink

TABLE II

DESIGN REQUIREMENTS & CONSTRAINTS

1. Low weight
2. Low cost
3. Long life
4. Reliability
5. Standardized
6. Precision (allowable temperature range)
7. Reusable
8. Cryogenic
9. High temperature
10. Articulating
11. System compatible

d. Testing

No new technology requirements beyond those previously established [Ref. 2] were identified.

e. Instrumentation

No new technology requirements beyond those previously established [Ref. 2] were identified.

f. Contamination

Skylab photos indicate significant, as yet unexplained, differences in the sensitivity of low α/ϵ systems to contamination. The relative sensitivity and data on effects of contaminants on properties will be essential coating selection criteria for Shuttle payloads. In addition, the data may prove to be useful in establishing cleanliness requirements of Shuttle. Analysis of Skylab experiments and hardware will provide basis of probable contaminants for evaluation.

Protective coatings. The initial properties and stability of thermal control coatings can be adversely affected by pre-launch contamination. Elaborate procedures, such as handling constraints, protective covers and immediate pre-launch cleaning or recoating will be impractical or not cost effective for future vehicles.

Effects of shuttle induced contamination on thermal control surfaces. Current thermal control surfaces are dielectrics with ability to accept and hold charges which may attract contaminants. Many contaminants are also dielectric which may interfere with conductive coatings applied over these surfaces. Skylab DO-24 experiment has shown that significant contamination can change a low α/ϵ coating to a gray or relatively high α/ϵ coating. The possibility of this type of contamination on Shuttle is high and results could be highly significant to temperature control of Shuttle launched S/C.

A better understanding of contamination effects on optical properties of surfaces must be obtained. Criteria for coating selection for Shuttle launched spacecraft must be developed.

Techniques for contamination protection. Advanced techniques are required for protection of optical, x-ray, and solar physics telescopes as well as thermal control surfaces.

g. Cryogenics

A growing number of scientific and applications payloads are being proposed which require temperatures from 200°K to less than 1°K. For example, the "Outlook for Space Study" and the subsequent "Forecast of Space Technology" identified potential missions which require technology based on the devices described in Table g I. Based on the 1973 mission model, the "Future Payload Technology Requirements Study" identified the missions shown in Table g II. Additional proposed payloads are listed in Table g III.

Growing emphasis must, therefore, be placed on what appears to be a major, emerging area of thermal control cryogenics. Various techniques for achieving cryogenic temperatures are shown in Table g IV. These techniques can be divided into three general categories: (1) passive radiative coolers, (2) storable cryogens, and (3) closed cycle refrigerators. Technology development required in each of these categories will be discussed below.

Passive radiative coolers. Passive coolers have been used on several spacecraft, but have been designed for each particular application with no common data base. Design details, performance, operational experience, and in-flight contamination data need to be consolidated as an aid to future designers. In-flight contamination of the optical train remains a problem.

The AFFDL (Dayton, Ohio) currently plans to develop larger capacity, lower temperature (3-5 watts @ 70-90°K) radiators. Using heat pipe technology, passive coolers may be used to reduce parasitic heat leaks and/or provide auxiliary cooling for other methods of producing cryogenic temperatures (see Experiments b-1 and b-3 in Section III).

Storable cryogens. Cryogens may be stored in three basic states: supercritical (gas), subcritical (liquid), and solid. In the special case of helium, a superfluid state is achieved below a transition temperature of approximately 2.2°K. Each state offers unique technology problems which are illustrated by the technology requirements described below:

Supercritical: Since they avoid the phase separation problems of subcritical fluids, supercritical cryogens have been used reliably in low-g to produce temperatures as low as about 5°K. One method of reaching temperatures below about 5°K is by the Joule-Thomson (J-T) expansion of supercritical helium (SHe). Although SHe avoids problems of phase separation in low-g, the J-T expansion may induce thermal and acoustic noise in sensitive detectors. Theoretical predictions need to be refined and experimentally verified, and suitable expanders developed and tested in low-g (Experiment g-3, Section III).

Subcritical: The major difficulty in using subcritical cryogens in space is the lack of gravity to separate the liquid from its vapor, and to serve as a means of liquid acquisition. Ground based facilities have provided a wealth of information on reduced gravity fluid behavior, multilayer insulation systems, fluid acquisition and transfer, propellant thermal conditioning, and propellant reorientation. This information is the best that can be obtained within the limitations of ground based test facilities. Sounding rockets and aircraft flying low-g trajectories also provide insufficient low-g time for cryogenic fluids to stabilize and come to steady-state conditions. The application of these results to a long term reduced gravity environment is frequently inconclusive and, at best, hypothetical.

Space flight experiments are required to provide the type of data to both designers and users which show that the systems being advocated for spacecraft can indeed perform as intended and expected.

The specific areas of technology to be advanced by flight demonstration are described in Appendix A (Ag-1 and Ag-2). Two flight experiments (g-1 and g-2, Section III) are proposed to obtain the necessary data.

For applications involving large amounts of cryogens and gimballed instruments, it may be necessary to transfer the cryogen from a bulk storage tank across the gimbal to the instrument. Transfer methods which minimize impact on pointing and stabilization performance while minimizing heat leaks, need to be developed. (Experiment g-4, Section III.)

Superfluid helium (He^{II}) has several attractive properties for cooling detectors below 2°K. These include nearly infinite thermal conductivity, nearly zero viscosity, and the "fountain" effect. To take advantage of these characteristics, the behavior of bulk He^{II}, film coefficients, and porous plug venting need to be determined in low-g. A rocket experiment scheduled for launch in late 1975 will be the first step; more detailed analysis and longer duration orbital flight should follow. In addition to its storage and venting capabilities, distribution of He^{II} to complex experiments and/or multiple instruments needs to be developed and flight tested. Promising techniques include temperature modulated porous plugs and He^{II} heat pipes (Experiment g-5, Section III).

Solid: Solid cryogens are compact, lightweight, and don't "slosh". Lifetimes, however, are difficult to accurately predict and dewars can become mechanically complex. The difficulty in using solid cryogens to cool large instruments, maintain venting and pressure control, and to dump excess cryogens prior to reentry (for Shuttle payloads using hazardous cryogens) needs to be assessed. In addition, the use of integrated heat pipe/passive radiative cooler systems to reduce parasitic heat leaks offers extended lifetime capability (Experiment b-3, Section III).

Closed cycle refrigerators. Closed cycle refrigerators are required for long term missions (>1 yr.) which require temperatures below those achievable (~100K) by passive radiators. A technology requirement of 1-4°K for up to 3 years has been identified in the "Future Payload Technology Requirements" (Ag-8, Appendix A) and has been proposed for flight testing (Experiment g-8, Section III). Vuilleumeir and rotary-reciprocating refrigerators which potentially have 3 years lifetime are currently being tested by the AFFDL. Minimum temperatures, however, are about 10°K. Extreme inefficiencies will be encountered in attempts to lower this minimum temperature.

Another potential closed cycle system is the demagnetization of rare earth salts. Laboratory tests have produced temperature differences of 27°K near room temperature. Work is continuing to investigate materials with Curie points approaching 4-20°K. Such a magnetic refrigerator needs to be "cascaded" or to have a cryogenic heat sink (e.g., LH^2) available. The technique, however, potentially offers near-Carnot efficiencies and should be flight demonstrated (Experiment g-7, Section III).

A refrigerator capable of producing mK temperatures for periods up to 30 days is also required for several future observations and experiments. A $^3He/^4He$ dilution refrigerator appears to be the only technique for producing mK continuously. Existing dilution refrigerators rely on gravity to separate the ^3He and ^4He in the mixing chamber and still. Technology needs to be developed to permit operation in low-g (See Ag-6, Appendix A) and then proven in space (Experiment g-6, Section III).

TABLE g I

Cryogenically Cooled Devices Likely To Be Used In Fulfilling The Recommendations Of The Outlook For Space Study *

Temperature Range: 0.1 to $10^{o}K$

Far IR Detectors--Bolometric and Superconducting

Superconducting Magnets, Galvanometers, and Voltmeters

Superconducting Magnets for High Energy Detections and Identification

Superconducting Computers--Based on Josephson effects

Maser and Parametric Amplifiers

* Outlook for Space--A Forecast of Space Technology
Final Draft, July 15, 1975

TABLE g II

Payload Cryogenic Requirements *
Based on 1973 Payload Model

PAYLOAD	NAME	TEMPERATURE REQUIREMENTS (DETECTORS OR MAGNETS)	LIFE	(LOAD WATTS)
AS-03-A	COSMIC BACKGROUND EXPLORER	$3^{o} \pm 1.2^{o}K$	1 YEAR	<1
AS-07-A	3-M AMBIENT TEMP IR TELESCOPE	$1-4^{o}K$	1-3 YEARS	1
AS-11-A	1.5-M IR TELESCOPE	$1-4^{o}K$; $20 \pm 1^{o}K$ (TELESCOPE)	3 YEARS	1
HE-09-A	LARGE HIGH-ENERGY OBSERVATORY B	$4^{o}K$	1-2 YEARS	0.2
AS-01-S	1-M COOLED IR TELESCOPE	$2 \pm 0.5^{o}K$; 20 ± 1^{o}(TELESCOPE)	7 DAYS	1
AS-14-S	1-M UNCOOLED IR TELESCOPE	UNKNOWN	7 DAYS	1
AS-15-S	3-M AMBIENT TEMP IR TELESCOPE	$2 \pm 1.5^{o}K$	7 DAYS	1
AS-20-S	2.5-M CRYO COOLED IR TELESCOPE	$2 \pm 0.5^{o}K$; $20 \pm 1^{o}K$(TELESCOPE)	7 DAYS	1
HE-15-S	MAGNETIC SPECTROMETER	$3 \pm 1^{o}K$	7 DAYS	1

* Future Payload Technology Requirements Study
Final Report No. CASD-NAS-75-004, Contract NAS-2-8272, June 1975

TABLE g III

Payload Cryogenic Requirements

Based on Proposed Experiments Not Included in 1973 Mission Model

Name	Temperature, °K
Infrared Astronomy Satellite (IRAS)	2.2
Gyroscopic Test of General Relativity (GTGR)	2.2
LST/Infrared Science Package	2.2
Shuttle Infrared Telescope Facility (SIRTF)	0.1 to 20.
Cosmic IR Background	0.3 to 2.2
Gravitational Radiation Detection	0.01
Equivalence Principle of General Relativity	>1.0
Experiments on Quantum Fluids	>1.0
Earth Observation Satellite (EOS) A,B,C: HRPI	100.-200.
Landsat-D: Thermatic Mappes	120
Airsat: LACATE	65.
MAPS II	100.
HRIR	100.-200.
CIMATS	195

TABLE g IV

PAYLOAD COOLING TECHNIQUES

Technique		Temperature, °K	Comments
* **Passive Radiative Coolers:**		>90	* $90^{o}K$ achievable at sync. alt. * $120^{o}K$ achievable in low earth orbit * Power dissipation 100mw. * Requires radiative shielding from sun, earth, and spacecraft
* **Storable Liquids and Solids:**			
(Name)	(Normal Building Pt.)	(Operational Solid Range)	
Ammonia	--	150.0-195.4	* Temperature achieved depends on cryogen used
Carbon Dioxide	--	125.0-217.5	
Methane	111.7	59.8-90.7	* Total cooling capacity and lifetime depends on dewar design--open cycle
Oxygen	90.2	- - - - - -	
Nitrogen	77.4	43.4-63.1	* Liquid cryogens require methods for phase separation in 0-g
Neon	27.2	13.5-24.5	
Hydrogen	20.4	8.3-13.8	* Fluids may also be stored supercritically to avoid 0-g problems
Helium (normal)	4.2	- - - - - -	
Helium (Super-fluid)	2.2	- - - - - -	* J-T expansion and pumping can be used to achieve temperatures below the normal boiling point
* **Closed Cycle Refrigerators:**			
Vuilleumeir (VM)		>10	* $0.3w@12^{o}K$, $10w@33^{o}K$, and $12w@75^{o}K$ system being life tested by AFFDL * A $0.25w@65^{o}K$ and a $5w@75^{o}K$ system being tested by GSFC
Rotary-Reciprocating (R^2)		>10	* $1.5w@12^{o}K$, $40w@60^{o}K$ system being tested by AFFDL * Both VM and R^2 became highly inefficient below $10^{o}K$

TABLE g IV

PAYLOAD COOLING TECHNIQUES

Technique	Temperature, ^{o}K	Comments
Demagnetization of rare earth salts	4–20	Temperature differential of 27°K demonstrated at room temp. Potentially useful and highly efficient with different materials and heat sinks down to about 4°K.
Adiabatic demagnetization of paramagnetic salts	mK	Currently limited to non-continuous operation. Requires helium heat sink.
$^{3}He/^{4}He$ dilution refrigerator	mK	Systems currently in ground use, but depend on gravity for phase separation in mixing chamber and still. Requires He^{II} reservoir.

h. Analysis

No new technology requirements identified.

j. Thermal Properties

No new technology requirements identified.

k. Insulation

Space Vehicle Requirements

Reusable space vehicles using cryogenic propellants place severe requirements on cryogenic storage and transfer systems. The insulation systems for the various cryogenic propellant tanks on a reusable space vehicle must operate during extended ground hold, launch, ascent through the atmosphere, space coast and re-entry. In addition, the systems must be reusable. The ability of such cryogenic thermal protection systems to perform effectively after cyclic exposure to air and moisture is a new and severe requirement. Important design factors will be reliable and predictable performance under repeated thermal and environmental cycling, ease of system inspection, and ease of repair or replacement--all at low cost. Two approaches are available for meeting these cryogenic insulation system requirements: a purged multilayer system and a lightweight vacuum jacket with a load-bearing insulation system. The purged MLI system is relatively heavy and complex and has need of additional technology to provide effective purge procedures and evaluate inspection, validation, and reuse. However, it offers promise as the best system now available. The lightweight vacuum jacket with load-bearing insulation system offers promise of being lightest in weight and having the advantages of consistent insulation performance, reusability, and simplicity.

Launch Vehicle Requirements

Single stage to orbit (SSTO) vehicles that are presently being evaluated as part of an advanced earth-to-orbit transportation system have a requirement for reusable hydrogen tanks. This means that a need for a reusable insulation system for this particular use has been identified. Some past work on insulations that are internal to the tank, such as the 3-D form on the S-IVB stage has been done. Since SSTO vehicles are especially sensitive to both weight and cost, any advancements in this technology should be addressed to these requirements. As part of the system cost, special attention must be given to ruggedness and ease of repair.

1. Design Techniques

This area was not reviewed in detail by the thermal group. It was recognized that the thermal design features and devices must be compatible with the system and subsystem design. Too often instruments and detectors are developed independent of the thermal design only to find that when they are finally enjoined one or the other has degraded in its performance. A technology requirement which addresses this issue for the thermal control of detector systems is given in Appendix A (c-4). Other candidate technology developments are contained in the STS Technology Group Report.

FLIGHT

EXPERIMENTS

III. Flight Experiments

a. Thermal Control Surfaces

There are significant limitations to simulation of the space environments in laboratories. For evaluation of thermal control surfaces, simplifying energy distribution and rates, compromises must be made. These limitations inhibit the acceptance of new coating technology for vehicle design. Flight experiments related to thermal control fall into two general categories:

(1) Measure performance of coatings in space to generate dependable design data and to verify or modify laboratory simulation methods.

(2) Demonstrate coating readiness by actual performance in space.

A variety of coating experiments have been utilized on past missions. Reuse of designs and hardware as well as new approaches (including spectral measurements in space and sample return) have been proposed for the future. An assessment of available designs and hardware, future opportunities and data requirements is essential to effective implementation of required future experiments.

In the past, coating experiments have been approved, designed and implemented on an individual project or vehicle basis. A systematic, over-all policy and plan is required to implement experiments on vehicles in various types of orbits to obtain necessary performance data.

More frequently than not, the thermal analysis and coating technology specialists are assigned to other tasks by the time a vehicle is operational in space. With few exceptions there has been neither adequate motivation nor resources available to attempt to obtain coating data from thermal performance history of space vehicles. While much past data may be irretrievably lost, a systematic limited assessment should be made in search of useful data. Perhaps most important is the need for a systematic plan to encourage potentially useful engineering temperature measurements and provide resources and motivation to obtain data from current and future vehicles.

The second-surface mirror (SSM) coatings are the most stable space verified, low α/ε systems for spacecraft. The SSM's are purchased commercially and applied to the spacecraft by the use of an adhesive. Since any delamination or release of this coating from the spacecraft will result in an increase in the spacecraft operating temperature, low outgassing, long-life adhesives capable of operating at temperatures from 100 to 480K must be provided for use with these coatings. Current OAST efforts are evaluating commercially available and modified adhesives for bonding silvered FEP Teflon flexible SSM to aluminum.

Potential Flight Experiments

(See Appendix B for definition of Flight Experiments.)

(1) Thermal Control Materials Compatible with the Space Plasma/Charging Environment

Space testing is required to support the technology efforts being advanced in an effort to solve spacecraft charging anomalies that have developed. This testing will expose candidate spacecraft thermal control materials to the space plasma/charging environment and then evaluate their compatability with the environment. Analysis and ground tests will be performed in support of the flight experiment.

Since the space plasma environment is difficult to simulate and insufficient analytical, experimental, and flight data exists to precisely define either the space plasma/ charging environment or the behavior of dielectric materials in this environment, ground tests are of little value. Space flight tests are required.

The missions that will benefit from this flight test are the communications and Synchronous Weather Satellites.

(2) Improved Temperature Control Coatings for Very Large Space Structures Including Solar Collectors

A major thrust of future space opportunities will be the development of very large space structures; for example, solar collectors and their flight applications in space. It will be necessary to integrate thermal control coatings and surfaces with the structural elements. This will include light-weight laminates, conductive high α/ε coatings for solar collectors (α/ε values of 30 to 50), and stable anodized coatings. Flight testing will be required for verification of ground testing and confirmation of coatings test data.

(3) Evaluation of Long-life Stability of Spacecraft Thermal Control Surfaces

The need to obtain flight operational data on the performance of s/c thermal control surfaces in long-term missions is of major concern. Long-term missions in particulate (e^-,p^+) radiation environments are planned but data on coatings developed in 1970's is not available. Flight tests will be required in the following environments: Near-earth polar orbit; Geosynchronous; Interplanetary-Venus, Mercury, Jupiter. Shuttle - LDEF payload will satisfy near-earth data requirements.

(4) Repair/Refurbishment of Thermal Control Surface in Space

Techniques for in space repair and/or refurbishment of malfunctioning of spacecraft thermal control surfaces must be assessed. Such techniques can be evaluated in ATL or SPACELAB missions.

(5) Adhesives for Attachable Thermal Control Surfaces

The performance of attachable thermal control surfaces (i.e., second-surface mirror coatings) depends upon the integrity of their adhesive. Although laboratory tests have demonstrated good performance, earlier adhesives have demonstrated anomalous behavior under different flight conditions. Therefore, space flight tests are necessary since several radiation environments are needed. The following flight tests are required: shuttle launched - LDEF, polar orbiter; geosynchronous; and/or Scout-polar orbiter.

b. Heat Pipes

(1) Cryogenic Heat Pipe Technology Flight Experiments

Experiment b-3: Improved Solid Cryogenic Lifetime

In order to cool detectors in the 65-120K region, solid cryogen coolers using such materials as methane, CO_2, and ammonia will be required. These coolers are usually multi-stage devices which are subjected to high spacecraft parasitic heat loads which limit lifetime (e.g., Nimbus-F had a 6 month expected life, but was designed for 1-2 years). It has been shown analytically that lifetime can be increased (by a factor of 2 or 3) or, conversely, weight decreased (by a factor of 2) by subcooling the outer container to reduce parasitic heat leaks. This can be accomplished by coupling the container thermally via a heat pipe to a passive radiator which views cold space. By flying a conventional solid cryogenic cooler and one with a heat pipe and radiator, a comparison can be made as to loss of solid cryogen with time. (See Experiment b-3, Appendix B.)

Experiment b-1: Cryogenic Heat Pipe/Radiative Cooler

Many sensors and telescopes will be operating in the cryogenic temperature range (100 to 150K, see Table g3) and will require heat pipes for heat management. Large multiple arrays of detectors (5-10 watts) will be remotely located from their optics and will require heat pipes to transfer thermal energy. Telescopes and sensors will have large radiators operating at cryogenic temperature which will make use of heat pipes.

Varying environments will require variable heat rejection in the form of variable conductance heat pipes and diodes. For operating in sunlight conditions or at constant temperature, phase change materials will be required. All the above elements can be incorporated into a single flight experiment wherein each can be exercised thermally to gather data on performance. (See Experiment b-1, Appendix B.)

(2) Ambient Heat Pipe Technology Flight Experiments

Experiment b-2: Ultra High Thermal Conductance Heat Pipes

In order to isothermalize very large structures (i.e., antennae, solar collectors, etc.) to achieve levels of acceptable distortion, ultra high thermal conductance will be required. Both high and low flux densities must be transferred with extremely small temperature gradients over long lengths (T's between 0.1 and 1°C over lengths from 10 to 100m). State-of-the-art heat pipes are hydrodynamically limited to lengths of 5 to 10 meters. New concepts must be developed to extend the hydrodynamic limit and to improve heat transfer coefficients. Since ground testing is difficult to interpret due to the negating effects of gravity, a flight experiment of reasonable size (20m) must be devised. (See Experiment b-2, Appendix B.)

Experiment b-5: Large Variable Heat Rejection Radiators

Radiators will be needed to accommodate a variety of instruments, each with different power levels, temperature levels, and gradient requirements. These radiators will be required to handle power levels in the kilowatts range, be able to vary their heat rejection in order to maintain narrow temperature limits, and be adjustable to hold a variety of temperature levels. Heat pipes with variable conductance capability will permit handling of a wide variety of payloads using a standardized radiator. This universal concept will reduce analysis and manpower and ultimately result in a highly reliable radiator with no moving parts. Current designs are able to dissipate 100-200 watts at room temperature. In addition to room temperature radiators, large capacity radiators operating up to 1500K for nuclear, and space processing applications will be needed. These radiators should be flown as flight experiments in order to demonstrate performance. (See Experiment b-5, Appendix B.)

Experiment b-4: Precision Temperature Control

Many instruments, structures, and gyros, which are required to hold extremely tight temperature control (±.1°C), may require techniques involving feedback or cascaded gas controlled heat pipes. These units will either directly or indirectly sense a change in the instrument temperature and adjust their heat rejection to achieve this tight temperature control. This will ultimately minimize temperature excursions and permit fine pointing, relative low drift, and aligned stable structures. Present technology using large amounts of heater power and sophisticated electronics is currently limited to ±1-2°C. A flight experiment utilizing one or more heat pipes may be flown to demonstrate this technique. (See Experiment b-4, Appendix B.)

c. Mechanisms and Systems

The three devices which passed the screening criteria for space test were phase change thermal storage systems, expendable material heat rejection systems and deployable/orientable radiator systems; these tests are described in Appendix B (c-1, c-2, and c-3, respectively).

The first two tests are needed because of uncertainties in fluid behavior in low-g. The latter test is intended to demonstrate adequate performance in the space environment. The rationale for this test is given below.

Shuttle and spacelab experiments and payloads have large heat rejection requirements (>2KW) and require solar or earth orientation which will require "deep space" radiator tracking. This capability is not within the currently demonstrated technology, since it requires radiators which can be deployed from the payload bay to a position beyond interference with the orbiter, and can be oriented in a continuously varying attitude relative to the orbiter for maximum efficiency. The technologies involved include the mechanical and fluid flow components of the deployment boom, which must be leakfree under repeated, long term use.

Since the development of thermal devices is driven by mission and system design factors, we should expect that additional flight test requirements will be identified as these factors are established and updated.

d. Test Facilities

(1) Heat Pipe Test Facilities

Experiment d-1: Temperature Control Device Test Facility (Ambient Regime)

Various heat pipe performance phenomena must be studied in O-G because of the negative influence of gravity. Such parameters as liquid distribution, gas/vapor interfaces, and wetting are strongly affected. Improvements in heat transfer coefficients to achieve low temperature gradients at low fluxes and at high fluxes can only be measured and observed in space. Diffusion of vapors, liquids and gases in controllable heat pipes can be studied, as well as distribution of phase change material in a metallic matrix. By flying a "work bench" type facility (either automated or manually operated), these parameters can be varied in real time. Present limits on spacecraft and sounding rockets for weight, power, telemetry and operations preclude data acquisition which permits separation and study of all variables sensitive to the effects of gravity.

Experiment d-2: Zero-G Measurement of Heat Pipe Disturbances

(Introduction and Summary)

The use of heat pipes for thermal control (e.g., isothermalization), of delicate experiments or sensors which require knowledge of the forces imposed by operation of these heat pipes. Limited acceleration data on experimental heat pipe installations have been obtained; however, quantitative force data are required for design analysis of proposed applications. Because of the small values of these forces relative to one-g forces, these measurements would best be made in the space environment. The proposed experiment would include a variety of heat pipe sizes, configurations and types, a range of heat loads with controllable heat sources, with measurements made of forces, accelerations, and temperatures. From these data, parametric relationships of operating conditions to forces for various heat pipes will be obtained.

Experiment d-3: Facility for High Power - High Temperature Device Testing

The required technology advancement is a scalable shuttle-launched, free-flying facility for experimentation and demonstration of high-power-density devices and phenomena. The facility includes a high-power-density source, normally a radioisotope, cooled by a metallic-fluid heat pipe which heats the emitter of a thermionic converter having a collector cooled by a heat-pipe radiator. Some evaluations may require several thermionic-converter heat-pipe modules which feed their electric outputs to a power processing system that energizes instrumentation, control data-handling, and transmission equipment needed for the experimentation or demonstration.

Replacing a standard component of this facility during fabrication with an experimental element allows testing or demonstration of thermal-energy acquisition, transmission, conversion, rejection, or electric processing--each at high power densities.

For example, such replacements would enable tests of solar-concentrator modules, new heat pipes, improved thermionic converters, radiator modules, or the latest processing developments for low-voltage, high-current power.

e. Instrumentation

No flight experiments identified.

f. Contamination

The fact that initial coating properties and stability are adversely affected by contamination has been recognized for many years, and has been dramatically illustrated by the returned Surveyor III equipment and by Skylab photos. While the most dramatic and most significant effects are on low α coatings, changes in mechanical properties and increased ε for low ε surfaces are possible. Work in Germany (DFVLR) has shown contamination degradation of surface conductance of conductively coated second-surface mirrors.

It would seem impractical, if not impossible, to provide a contaminant-free environment for Shuttle. Thus, experiments and equipment aboard or launched from Shuttle must be contaminant tolerant.

FLIGHT EXPERIMENTS

(1) Effects of Shuttle Induced Contamination on Thermal Control Surfaces

The need for contamination monitoring experiments on the early Shuttle missions is recognized. As a part of these experiments, it is mandatory that the effects of this contamination on S/C temperature control surfaces be determined. Flight experiments are required on LDEF (mission 3) and LDEF (mission 4), as well as integration into the design flight instrumentation package for other flights. A statistical average is necessary for proper data interpretation.

(2) Techniques for Contamination Protection

Advanced techniques are required for protection of optical, x-ray, and solar physics telescopes as well as thermal control surfaces. Referenced Convair experiment is limited in scope for techniques of accomplishing this protection.

Spacelab or ATL can provide excellent flight test conditions.

g. Cryogenics

As described in Section II g and Tables g I-IV, a growing number of scientific and application payloads are being proposed which require that increasing emphasis be given to the development of cryogenic technology. Detailed technology requirements were discussed in Section II. Therefore, only a brief description of each experiment proposed in support of these requirements is presented below. "Future Payload Technology Testing and Development Requirement" forms for each experiment are included in Appendix Bg. Each experiment can be traced back to its driving opportunity (Table g I) and/or mission (Table g II, g III) by correlating the temperature and lifetime required with that being developed and tested.

(1) Liquid Cryogen Storage and Supply (Bg-1)

This experiment will evaluate the effects of surface tension devices and thermodynamic vents on the storage, acquisition, venting, and withdrawal of a cryogenic liquid in low-g. This experiment also has direct application to those systems currently using supercritical gas storage for life support and fuel cells. In addition, data will be obtained that can be applied to other low temperature fluids that are used in many other space applications. Not the least of these is LHe which is proposed on a variety of future scientific payloads for cooling detectors, telescope optics, and superconducting magnets. Also, by proper instrumentation, the performance of a high performance insulation can be verified in a low-g environment.

(2) Liquid Cryogen Transfer (Bg-2)

This experiment will evaluate the process of cryogenic fluid transfer in a low-g environment. This experiment will evaluate specifically propellant inflow and outflow dynamics, pressurization gas requirements, pressurization diffuser design, and insulation performance. This experiment has direct application to the potential resupply of propulsion stages in orbit and to scientific payloads that could be provided extended lifetimes if these cryogenic fluids could be replaced.

In addition, the data obtained can be related directly to the fluid parameters of all cryogenic liquids and could in turn provide size scaling data when related to the Liquid Cryogenic Storage and Supply experiment described above.

(3) Joule-Thomson Expansion of Supercritical Helium (Bg-3)

This experiment will determine a Joule-Thomson expander with integral heat exchanger (JTX) can be used in low-g to produce temperatures below 2°K without inducing excessive noise in sensitive detectors. Although the JTX can be initially optimized on the ground, the behavior of the He^{II} produced during the expansion process needs to be determined in low-g. It is possible that the creep of He^{II}, with its negligible viscosity, into the high pressure side of the heat exchanger could cause a serious flow instability. The flight test of the JTX should be performed in a system which includes an operational detector, such as an Advanced IR Radiometer (Sensor and Data Acquisition Panel Report). Successful flight tests of the JTX would permit cooling of detectors requiring temperatures below 2.2°K, without the necessity of storing and handling LHe or He^{II} in low-g.

(4) Transfer of Cryogens Across Gimbals (Bg-4)

This experiment will demonstrate a rotary joint which is capable of transfering cryogens, such as LHe, across a gimbal with acceptable heat losses and disturbances to the pointing system. To be an effective demonstration, the flight test should be conducted in conjunction with an operational system, such as the Modular Instrument Pointing Technology Laboratory (Navigation, Guidance, and Control Panel Report).

A successful demonstration w-uld permit the cryogen tanks to be located off the gimballed platform for longer duration, higher heat load missions, thus reducing the mass to be pointed and potential disturbances due to cryogen movement.

(5) He^{II} Storage and Utilization (Bg-5)

This experiment will demonstrate the capability to store, vent, withdraw, and distribute He^{II} in low-g. The proposed experiment goes beyond basic research on the behavior of He^{II} to the task of distributing He^{II} from a central dewar to one or more instruments or experiments. The Thermomechanical and/or mechano-caloric effects offer a potential solution. Another approach is to use helium heat pipes to transfer energy from the instruments to the dewar.

He^{II} is required by a large number of observations and experiments, including IR astronomy, general relativity, high energy astrophysics, and experiments involving superconductivity and quantum fluids.

(6) $^3He/^4He$ Dilution Refrigerators (Bg-6)

This experiment will determine if a dilution refrigerator can be successfully operated in low-g to provide temperatures less than 1°K (mK). Current dilution refrigerators depend on gravity for the separation of ^3He and ^4He. Alternate separation techniques, such as spinning to produce artificial gravity or the use of "superleaks" will be developed in the laboratory. Ultimate independence from gravity, however, must be demonstrated in low-g.

Several observations and experiments require continuous mK temperatures which only the dilution refrigerator can produce. Adiabatic demagnetization of paramagnetic salts can produce mK temperatures, but is basically a single cycle process.

(7) Magnetic Refrigeration (Bg-7)

This experiment will demonstrate in space the capability of the demagnetization of rare earth salts to achieve temperatures from 4 to 20°K. Laboratory tests are being conducted on materials of increasingly lower Curie points. A flight test demonstration will eventually be needed to demonstrate the use of single stage magnetic refrigerator using a storable cryogen (e.g., LH_2) heat sink, or a cascaded system of several rare earth salts using a room temperature heat sink.

As previously mentioned, several future experiments exist for temperatures in the 4-20°K range. The potential for near Carnot efficiency makes further development and flight testing of magnetic refrigerator look attractive.

(8) Closed Cycle Helium Refrigeration (Bg-8)

This experiment will demonstrate in space the capability of a closed-cycle refrigerator to produce temperatures between 1 and 40°K for long term missions. As described in Section II g, Vuilleumier and rotary-reciprocating refrigerators currently under development will produce temperatures only as low as about 10°K. Further development of these or other refrigeration cycles will be required before a flight test can be described in detail.

Long term missions requiring cooling for up to 3 years at temperatures from 1 to 4°K are beyond the lifetime of storable cryogens and must, by necessity, seek a closed-cycle solution.

APPENDIX A

DEFINITION OF TECHNOLOGY REQUIREMENT FORMS

DEFINITION OF TECHNOLOGY REQUIREMENT NO. Aa-1

1. TECHNOLOGY REQUIREMENT (TITLE): Thermal Control Materials Compatible with the Space Plasma/Charging Environment PAGE 1 OF ___

2. TECHNOLOGY CATEGORY: 10 Environmental Control; 11 Environmental Protection

3. OBJECTIVE/ADVANCEMENT REQUIRED: Spacecraft thermal control dielectric materials and applications techniques are needed which are compatible with the space plasma/charging environment.

4. CURRENT STATE OF ART: Existing materials are incompatible. Many serious spacecraft anomalies are attributed to space plasma/charging effects.

HAS BEEN CARRIED TO LEVEL 2

5. DESCRIPTION OF TECHNOLOGY

Current typical spacecraft flexible solar array and thermal control system designs include a large number of dielectric materials facing the space environment. These materials include: silvered teflon, kapton (bare and aluminized), silvered quartz, and paints, for example. Until recently, these materials and designs have appeared acceptable. There is increasing evidence, however, that there may be significant adverse interactions of these materials with the space plasma/charging environment. A large number of spacecraft electrical anomalies are attributed to such interactions. Spacecraft thermal control dielectric materials and applications techniques do not exist which are compatible with the space plasma/charging environment.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

Space system designs have evolved and improved as the knowledge of the space environment improved. Significant recent information and of the space plasma/charging environment has resulted from analyses, flight experiments and analyses of flight anomalies. Future spacecraft failures can be avoided with the development of spacecraft thermal control materials and application techniques which are compatible with the space plasma/charging environment.

The projects benefiting from this technology are identified in CFS Future Payload Technology Requirements Study Report No. CASD-NAS-75-004 - Technology Categories 5.0, 11.0, and 13.0. Also the inputs to the 1975 NASA OAST Workshop (OSS) identifies a requirement for this technology.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. Aa-1

1. **TECHNOLOGY REQUIREMENT(TITLE):** Thermal Control Materials Compatible with the Space Plasma/Charging Environment. **PAGE 2 OF** __

7. **TECHNOLOGY OPTIONS:**

a. Add electronic circuitry/complexity to desensitize spacecraft electrical system to effects of charging/discharging of dielectric surfaces.

b. Prohibit use of dielectric materials on spacecraft external surfaces. This option is not presently compatible with spacecraft thermal design constraints.

8. **TECHNICAL PROBLEMS:**

Insufficient analytical, experimental, and flight data exists to precisely define either the space plasma/charging environment or behavior of dielectric materials in this environment. Until such data exists, spacecraft must be designed using the best available information. Until materials, techniques and environments have been proven, designs may be ultraconservative, or result in future failures. The space plasma is difficult to simulate

(Cont'd. See Attached Form)

9. **POTENTIAL ALTERNATIVES:**

There is no practical way to change the space environment. Thereby it appears absolutely necessary to pursue the stated objective of developing spacecraft thermal control dielectric materials and application techniques which are compatible with the space plasma/charging environment.

10. **PLANNFD PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

RTOP 506-16-39 is a co-operative AF-NASA effort which makes use of existing orbiting spacecraft in an effort to define the space environment. Correlation in ground based facilities are to be made with a planned Air Force Satellite (SCATHA)

EXPECTED UNPERTURBED LEVEL 3

11. **RELATED TECHNOLOGY REQUIREMENTS:**

a. Flight experiments and ayalyses to establish space plasma/charging environment.

b. Analyses, ground tests, and flight experiments to develop spacecraft thermal control dielectric materials compatible with the space plasma/charging environment.

DEFINITION OF TECHNOLOGY REQUIREMENT **NO.** Aa-1

1. TECHNOLOGY REQUIREMENT (TITLE): Thermal Control **PAGE** **OF**
Materials Compatible with the Space Plasma/Charging Environment

8. TECHNICAL PROBLEMS: (Continued)

in a ground test (even if it were known with precision) because of unavoidable interactions with any practical container. Results of materials and applications technique tests made on the ground are therefore clouded with uncertainties. Definitive flight experiment tests are necessary but also difficult to achieve on a near term basis.

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. Aa-1

1. TECHNOLOGY REQUIREMENT (TITLE): Thermal Control — PAGE 3 OF __
Materials Compatible with the Space Plasma/Charging Environment

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Define Environment	---	---	---	---	---														
2. Ground Simulation		---	---	---	---														
3. Analytical Model		---	---	---	---														
4. Develop Materials and Devices		---	---	---	---														
5. Flight Experiment				---	---	---	---	---											
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES:

See Paragraph 6.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. Aa-3

1. TECHNOLOGY REQUIREMENT (TITLE): Evaluation of Long-Life Stability of S/C Thermal Control Surfaces — PAGE 1 OF 2

2. TECHNOLOGY CATEGORY: 10 or 11

3. OBJECTIVE/ADVANCEMENT REQUIRED: Develop flight data in various space radiation environments to help thermal designers select proper coatings for each mission.

4. CURRENT STATE OF ART: Little flight data available on current coatings and coatings under development.

HAS BEEN CARRIED TO LEVEL 5

5. DESCRIPTION OF TECHNOLOGY

Long-term missions are planned in energetic radiation environments but little or no flight data is available in these environments on coatings developed in the 70's. Other coatings with greater potential are currently being developed. Laboratory testing has been shown to be only an approximation of space tests. Therefore, actual space tests are required and in the specific environment where missions are planned.

P/L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

Space tests have given a substantial increase in the confidence level associated with the use of coatings on spacecraft. Predictions of degradation in specific environments are always required for proper thermal design. With flight data available, thermal design is simplified and more reliable.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. Aa-3

1. **TECHNOLOGY REQUIREMENT(TITLE):** Evaluation of Long-Life Stability of S/C Thermal Control Surfaces

PAGE 2 OF 2

7. **TECHNOLOGY OPTIONS:**

   a. use of complex thermal control devices

8. **TECHNICAL PROBLEMS:**

   Other thermal devices are often prohibited due to right or size restrictions. Without knowledge of coating performance most S/C managers will not accept the coatings for their S/C. Ground test simulation is only an approximation of flight performance.

9. **POTENTIAL ALTERNATIVES:**

   None without excessive cost and time penalties.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

EXPECTED UNPERTURBED LEVEL ___

11. **RELATED TECHNOLOGY REQUIREMENTS:**

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. Ab-5

1. TECHNOLOGY REQUIREMENT (TITLE): ______ PAGE 1 OF __

Intermediate Temperature Range Heat Pipes

2. TECHNOLOGY CATEGORY: Environmental Control

3. OBJECTIVE/ADVANCEMENT REQUIRED:

Develop Heat Pipes in the Intermediate Temperature Range

300 to 800K for Large Low Weight Radiators

4. CURRENT STATE OF ART:

Present temperature range 200-300K or 800 to 1100K

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

Develop a family of heat pipes in the temperature range 300 to 800K range with capabilities in the 1-10 KW of heat carrying range.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

Where it is required to raise the heat rejection temperature of radiators, in order to reduce weight, heat pipes will be needed in the 300-800K range. Water-copper heat pipes have been used in radiator designs in this range; however, their efficiency falls off rapidly above 400K.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. Ac-3

1. TECHNOLOGY REQUIREMENT (TITLE): Deployable, Orientable Radiator Systems and Components PAGE 1 OF 2

2. TECHNOLOGY CATEGORY:

3. OBJECTIVE/ADVANCEMENT REQUIRED: To develop and demonstrate space environment compatibility of deployable, orientable radiator systems and components, including low temperature radiators, leak-free gimbals, and deep space tracking systems.

4. CURRENT STATE OF ART: Current demonstrated capability is fixed or limited-deployment radiators. Deployable, orientable system concepts and components are available and have been ground-tested to a limited extent as components. No system has been designed, or components tested in space environment. HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

A complete radiator system would be designed capable of handling representative Spacelab experiment heat loads in earth-oriented or solar-oriented modes. The radiators would be required to deploy from the Shuttle cargo bay to minimize interference with or by orbiter systems, and to track "deep space" in a continuous or near-continuous mode.

5A. REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a.

b. Shuttle payloads such as solar physics which have high heat rejection requirements. #68, #36, #35, #33, #34

c. Would provide more weight- and cost-effective radiator systems, or would permit fewer thermal constraints on mission performance (durations, attitudes).

d. A complete working model tested in space environment.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. c-3

1. TECHNOLOGY REQUIREMENT(TITLE): ____________ PAGE 2 OF 2

7. TECHNOLOGY OPTIONS:

8. TECHNICAL PROBLEMS:

Difficulties with fluid loop components under continuous or repeated gimbal motions at operational temperatures and pressures.

9. POTENTIAL ALTERNATIVES:

Limit experiment durations, orientations.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

EXPECTED UNPERTURBED LEVEL ___

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. Ac-4

PAGE 1 OF 2

1. TECHNOLOGY REQUIREMENT (TITLE): Integrated Sensor/Thermal Control System

2. TECHNOLOGY CATEGORY: Environmental Control

3. OBJECTIVE/ADVANCEMENT REQUIRED: Determining sensor performance when tying a thermal control system to a detector system

4. CURRENT STATE OF ART: Sensor performance has not been mapped with T.C. System

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

Develop a series of integrated sensor/thermal control systems which will demonstrate whether sensor performance is degraded by virtue of elements of thermal system. Such things, in the case of heat pipes and fluid loops, as container materials, fluids, flow rates should be studied.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

Current sensors and instruments are being developed independent of how they will be thermally controlled in orbit. The question arises as to whether or not the sensor performance will be degraded when mated to an active or passive thermal control system.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT **NO.** c-4

1. **TECHNOLOGY REQUIREMENT(TITLE):** Sensor/T.C. System **PAGE 2 OF 2**

7. **TECHNOLOGY OPTIONS:**

8. **TECHNICAL PROBLEMS:**

Develop integrated system which will fit geometric, weight, power constraints without affecting sensor performance.

9. **POTENTIAL ALTERNATIVES:**

Cool sensors using passive techniques which will not control temperature level or gradients and accept sensor performance degradation.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

EXPECTED UNPERTURBED LEVEL ___

11. **RELATED TECHNOLOGY REQUIREMENTS:**

Sensors and thermal system must be integrated early in development.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. Ad-2

1. TECHNOLOGY REQUIREMENT (TITLE): Zero-G Measurement of Heat-Pipe Disturbance Forces PAGE 1 OF ___

2. TECHNOLOGY CATEGORY: ___

3. OBJECTIVE/ADVANCEMENT REQUIRED: To quantify experimentally in a zero-G environment the disturbing forces induced by various types of heat pipes under a range of heat transfer rates, and to evaluate concepts and configurations which would minimize these forces.

4. CURRENT STATE OF ART: Disturbance sources have been observed, but magnitudes of forces have not been determined. No quantitative data exist which would permit analytical determination of where heat pipes can or cannot be applied because of distrubance effects. HAS BEEN CARRIED TO LEVEL ___

5. DESCRIPTION OF TECHNOLOGY

A variety of heat pipe installations, with controlled heat sources and sinks would be instrumented thermally and mechanically to measure the very small magnitudes of disturbance effects, fluid mass shifts, etc., as a function of thermal conditions and configurations.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a.

b. Payloads such as optical experiments and others requiring precise pointing or quiescent conditions. #26, #12, #30

c. Would permit reliable application of heat pipes instead of other less efficient passive control methods, providing weight and cost savings.

d. Models tested in space environment with sufficient data obtained to determine relationships described in 5 above.

TO BE CARRIED TO LEVEL ___

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT(TITLE): ________________ PAGE 2 OF __

7. TECHNOLOGY OPTIONS:

8. TECHNICAL PROBLEMS:

Difficulty in designing experiment mounting system and instrumenting to measure very small forces.

9. POTENTIAL ALTERNATIVES:

Ignore heat pipe disturbance effects. Do not apply heat pipes to sensitive experiments.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT NO. Ad-3

1. TECHNOLOGY REQUIREMENT (TITLE): Metallic-Fluid Heat Pipes PAGE 1 OF ___

2. TECHNOLOGY CATEGORY: Thermal Control

3. OBJECTIVE/ADVANCEMENT REQUIRED: Acquire the technology for production and space application of economical, durable, effective metallic-fluid heat pipes.

4. CURRENT STATE OF ART: Metallic-fluid heat pipes are self-contained, self-pumped systems that can transport great thermal power densities (to 15 KW.cm^2 or more) at high temperatures (to 1800K or higher) with small thermal gradients (order of 0.1°/cm). But contaminant-accelerated corrosion and solution can be troublesome. And economical fabrication and processing are essential.

HAS BEEN CARRIED TO LEVEL ___

5. DESCRIPTION OF TECHNOLOGY

Metallic-fluid heat pipes have potentialities to transport thermal pow r densities up to two orders of magnitude greater than those of their ammonia counterparts. For example, a lithium heat pipe operating at 1500°C can transport 15,000 W/cm^2 with a 0.1/cm gradient. However, these reactive heat-pipe fluids combined with tenacious low-concentration contaminants like oxygen, that accelerate corrosion and solution particularly at high operating temperatures, can cause serious material problems. Effective, economical processing must be established to minimize contaminant effects and maximize lifetimes. Simple high-performance wick, envelope configurations must be developed to reduce costs, ease processing, and decrease contamination. Special application problems such as those of the head-pipe-cooked reactor and of the thermionic-converter, heat-pipe module must be solved.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Nuclear electric power and propulsion for over 100 kWe missions near the end of the twentieth century need light-weight thermal-transport systems that handle great power densities at high temperatures with small thermal gradients. Metallic-fluid heat pipes can meet these requirements.

b. Beginning in the 1990's, nuclear electric power and propulsion should provide for planetary, earth-orbit, and nuclear waste-disposal propulsion and for large-space-station and lunar-base power.

c. Simple effective configurations and processing of metallic-fluid heat pipes can make these high-performance therm transport systems economical, light-weight, and long-lived. And their capability to carry great thermal energy densities in thin-walled tubes with relatively low pressures at high temperatures and small thermal gradients is unparalleled.

d. The technology advancement requires establishment of simple, effective, ext udable configurations; compatible, economical materials and fabrication techniques; efficient, low-cost processing; and demonstration of performances and life times with space-flight verification. Nuclear electric power and propulsion demand special integration developments and evaluations.

TO BE CARRIED TO LEVEL ___

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. **TECHNOLOGY REQUIREMENT(TITLE):** Metallic-Fluid Heat Pipes **PAGE** 2 **OF** 3

7. **TECHNOLOGY OPTIONS:**

Because the heat pipe is a thermal-transport system other heat transfer systems are competitors. Previous sections contain heat-pipe advantages.

8. **TECHNICAL PROBLEMS:**

Technical problems appear in 5 and 6d.

9. **POTENTIAL ALTERNATIVES:**

Section 7 indicates alternatives while 4, 5, and 6c give heat-pipe gains.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

RTOP: 506-16-31

EXPECTED UNPERTURBED LEVEL __

11. **RELATED TECHNOLOGY REQUIREMENTS:**

a. Select and evaluate materials (compatibility and strength).

b. Develop simple, efficient, extrudable heat-pipe designs (general heat-pipe problem).

c. Establish economical, effective processing and fabrication to assure long lifetimes (general heat-pipe problem).

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. Ad-3
1. TECHNOLOGY REQUIREMENT (TITLE): Metallic-Fluid Heat Pipes	PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Select, screen, test metallic-fluid heat-pipe materials and components	---	---	---	---	---														
2. Performance- and life-test metallic-fluid heat-pipes				---	---	---													
3. Provide space-flight verification				---	---	---													
APPLICATION (Example: Nuclear Electric Power and Propulsion)																			
1. Design (Ph. C)			---	---	---	---	---												
2. Devl/Fab (Ph. D)						---	---	---	---	---	---	---	---	---					
3. Operations													---	---	---	---			
4. > 100 kWe missions																---	---	---	---

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES:

Outlook for Space
Future Payload Technology Requirements
RTOP's 506-16-31 and 506-24-21
NASA, ERDA Thermionic-Conversion Program Reviews

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. Af-1

1. TECHNOLOGY REQUIREMENT (TITLE): Effects of Shuttle Induced Contamination on Thermal Control Surfaces

PAGE 1 OF 2

2. TECHNOLOGY CATEGORY: 10 or 11

3. OBJECTIVE/ADVANCEMENT REQUIRED: Develop understanding of contamination effects and provide selection criterion for thermal control surfaces on shuttle launched S/C.

4. CURRENT STATE OF ART: Data from skylab DO-24 experiment and laboratory testing is available.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

Current thermal control surfaces are dielectrics with ability to accept and hold charges which may attract contaminants. Many contaminants are also dielectric which may interfere with conductive coatings applied over these surfaces. Skylab DO-24 experiment has shown that significant contamination can change a low α/ε coating to a gray or relatively high ε coating. The possibility of this type of contamination on Shuttle is high and results could be highly significant to temperature control of Shuttle launched S/C.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Develop better understanding of contamination effects on optical properties of surfaces.

b. Develop criterion for coating selection for Shuttle launched S/C.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. Af-1

1. TECHNOLOGY REQUIREMENT(TITLE): Shuttle Induced Contamination on Thermal Control Surfaces — PAGE 2 OF 2

7. TECHNOLOGY OPTIONS:

a. Add complex thermal control devices to compensate for changes in α/ε.

b. Eliminate all possible contaminants from Shuttle.

8. TECHNICAL PROBLEMS:

Insufficient analytical, experimental and flight data exist to define problem of contamination, and to predict quantity and type of contamination available from Shuttle. Ground testing can only provide an approximation of actual flight testing.

9. POTENTIAL ALTERNATIVES:

Clean up all possible contaminants from Shuttle by active or passive techniques. This is extremely expensive and technology is not currently available.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

The development of partially conducting coatings will substantially help eliminate this problem. AFML is currently performing laboratory studies on these effects of contamination on coatings.

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

Quantitative and qualitative analysis of contaminants on Shuttle during actual flight conditions.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. Ag-1 Ag-2

1. TECHNOLOGY REQUIREMENT (TITLE): The Storage, Supply and Transfer of Cryogenic Fluids in Space PAGE 1 OF ___

2. TECHNOLOGY CATEGORY: 12 Cryogenic Control

3. OBJECTIVE/ADVANCEMENT REQUIRED: (1) Reusable high performance insulation, (2) behavior of cryogenic fluids in low-g, (3) venting of cryogenic fluids in low-g, (4) control of cryogenic fluids in low-g

4. CURRENT STATE OF ART: Within the limits of ground based facilities, the control of cryogenic fluids have been evaluated in low-g

HAS BEEN CARRIED TO LEVEL 3

5. DESCRIPTION OF TECHNOLOGY

Ground based facilities have provided a wealth of information on reduced gravity fluid behavior, multilayer insulation systems, fluid acquisition and transfer, propellant thermal conditioning, and propellant reorientation. This information is the best that can be obtained within the limitations of ground based test facilities. The application of these results to a long term reduced gravity environment is frequently inconclusive and, at best, hypothetical.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

The specific areas of technology to be advanced by flight demonstration are:

(a) data on the reusability of insulation
(b) data that will allow the determination of the behavior in reduced gravity of LH_2, LF_2, LO_2, LHe, and LAr
(c) pressurization gas and diffuser performance data
(d) outflow and inflow propellant dynamics

Requires a space flight demonstration to provide verification of system designs. Flight program to evaluate the necessary fluid parameters to establish the level of assurance required by spacecraft designers.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. Ag-1 Ag-2

1. TECHNOLOGY REQUIREMENT(TITLE): The Storage, Supply and Transfer of Cryogenic Fluids in Space — PAGE 2 OF __

7. TECHNOLOGY OPTIONS:

The option to using cryogenics as energy sources in space is to use propellants that are identified as earth storable. These propellants are less efficient, cause reductions in payload, and produce environmental pollution.

8. TECHNICAL PROBLEMS:

9. POTENTIAL ALTERNATIVES:

There are no alternatives to obtaining space flight data on cryogenic fluids.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

RTOP 506-21-10 describes work that will carry this technology as far as it can be carried without space flight testing.

EXPECTED UNPERTURBED LEVEL 5

11. RELATED TECHNOLOGY REQUIREMENTS:

High performance insulation development.

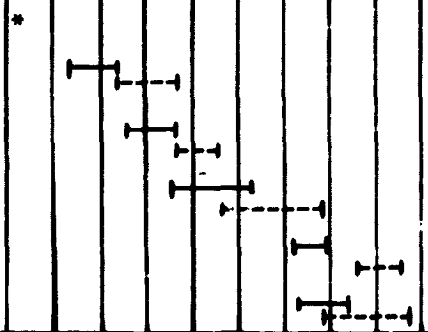
DEFINITION OF TECHNOLOGY REQUIREMENT — NO. Ag-1, Ag-2

1. TECHNOLOGY REQUIREMENT (TITLE): The Storage, Supply and Transfer of Cryogenic Fluids in Space — PAGE 3 OF ___

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY	*																		
1. Conceptual Design																			
2. Detail Design																			
3. Fabrication																			
4. Flight Qualification																			
5. Flight Test																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			



13. USAGE SCHEDULE:

																TOTAL
TECHNOLOGY NEED DATE																
NUMBER OF LAUNCHES																

14. REFERENCES:

*

⊢—⊣ Supply and Storage Exp.

⊢--⊣ Transfer Exp.

(1) "Outlook for Space"
(2) "Future Payload Technology Space Testing and Development Requirements" FT-WP-001
(3) "Future Payload Technology Requirements Study" CASD-75-004
(4) 1975 NASA OAST Summer Workshop

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ____

1. TECHNOLOGY REQUIREMENT (TITLE): LHe Recycling Unit PAGE 1 OF 6

2. TECHNOLOGY CATEGORY: Cryogenic Control

3. OBJECTIVE/ADVANCEMENT REQUIRED: Provide LHe refrigeration machines to cool payload items noted below.

4. CURRENT STATE OF ART: Elements of machine under construction and test. Engineering model will be available for testing by 1-1976.

HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

The DoD has been funding development of low temperature refrigerators. An early investigation was a three-year program to develop a long life 3.6K, one watt load refrigerator for use with a superconducting computer system. The effort by Arthur D. Little, Inc. was terminated after one year.

Three companies have since been funded for development of closed cycle refrigeration systems; they are:

Hughes Aircraft Corp.
North American Phillips, Inc.
Arthur D. Little, Inc.

(continued on page 4)

See Table 1 below

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS: Table 1. Payload Requirements

Payload	Status	Payload	Status	Payload	Status
AS-03-A	Pre Phase A	HE-09-A	Phase B	AS-15-S	Pre Phase A
AS-07-A	Pre Phase A	AS-01-S	Pre Phase A	AS-20-S	Pre Phase A
AS-11-A	Pre Phase A	AS-14-S	Pre Phase A	HE-15-S	Phase B

a. Temperature requirements result from two factors:
   (1) Requirements for superconduction which defines operational temperature of magnets and permits low power measurement of particle energies.
   (2) Requirements for high detectability and high S/N ratio which requires detector cooling and allows detection of faint IR sources.

b. See Table 2

c. The use of LHe closed cycle systems permit long life missions without resupply or large dewar requirements

d. Space flight testing of a prototype model

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO. Ag-6

1. TECHNOLOGY REQUIREMENT (TITLE): $^3He/^4He$ Dilution Refrigerator - Operable in 0-g PAGE 1 OF ___

2. TECHNOLOGY CATEGORY: Cryogenic Temperature Control

3. OBJECTIVE/ADVANCEMENT REQUIRED: Produce mK temperature in the 0-g environment of space.

4. CURRENT STATE OF ART: $^3He/^4He$ dilution refrigerators have been developed for use on the ground, but depend on gravity for the separation.

HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

Develop a $^3He/^4He$ dilution refrigerator which is capable of continuously producing, in 0-g and for periods up to 30 days, temperatures in the mK range.

No other methods exist for continuously producing mK temperatures. For example, the adiabatic demagnetization of paramagnetic salt is basically a single-cycle method of cooling. Pumping on ^4He and ^3He can only produce, at least, 0.5 and 0.3K.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

1. Ultimate sensitivity of some advanced detectors (e.g., IR) depends on their operation at mK temperatures. Some physics experiments, especially quantum fluids, may require mK temperatures.
2. Benefiting payloads include IR telescopes, gravitational radiation detectors and Spacelab physics experiments.
3. Integration time for detectors decreased as the square of the temperature, therefore allowing significantly more data to be gathered during a given mission. Increased sensitivity may also allow the use of smaller telescopes.
4. Since the major thrust of this technology effort is to develop independence from gravity, a space flight test is mandatory.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT(TITLE): ______ PAGE 2 OF __

7. TECHNOLOGY OPTIONS:

In the case of detectors, trade-offs exist between sensitivity, size, mission duration, and temperature. There may be no other option, however, for physics experiments.

8. TECHNICAL PROBLEMS:

Current dilution refrigerators depend on gravity for separation of the ^3He and ^4He phases in the mixing chamber and still. Alternate means of separation must be developed.

9. POTENTIAL ALTERNATIVES:

No other techniques are known to exist which can continuously produce mK temperatures for periods up to 30 days.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Dilution refrigerators have been built for ground and aircraft applications. No program currently exists for a system to be operable in 0-g. However, Ames anticipates initiating such a program in FY '76.

EXPECTED UNPERTURBED LEVEL 4

11. RELATED TECHNOLOGY REQUIREMENTS:

He^{II} storage and utilization

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. Ag-8

1. **TECHNOLOGY REQUIREMENT(TITLE):** LHe Recycling Unit **PAGE 2 OF 6**

7. **TECHNOLOGY OPTIONS:**

Two Brayton cycles and various others should be investigated; they are:

1. Reciprocating Reverse Brayton Cycle
2. Rotary Reverse Brayton Cycle
3. Rotary Claude Cycle
4. Dual Phased Recuperated Vuilleumeir Process
5. Hybrid Systems - which combine mechanical refrigeration with other techniques such as dielectric cooling

8. **TECHNICAL PROBLEMS:**

a. In discussion with Arthur D. Little, Inc., it was determined that primary technical problems are in the area of fabrication of system items and no major problems are foreseen. It can be seen from the scheduled availability of the ADL unit for life testing as of January 1976, that the unit modified to the necessary cooling requirements will not be available by the technology need date. The early payloads may be more suited to using the dewars currently under development until the technology is developed by WPAFB for cooling machines.

b. Maintenance of close tolerances during operation.

9. **POTENTIAL ALTERNATIVES:**

It can be seen from Table 2 that a number of the payloads which are listed as desirable to incorporate closed cycle systems are Shuttle sortie payloads of seven-day duration. The weights of the refrigerators are estimated as:

North American Phillips VM - 130 pounds
Hughes VM - 180 pounds
ADL Rotary Reciprocating - 300 pounds prior to modification for lower temperatures (continued on page 5)

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

The ADL unit will be at the stage for initiating life testing about January 1976; however, the minimum temperature it will be capable of operating to will be 11.5K at 0.3 watts. No modification to lower temperature capabilities required for these payloads is planned.

EXPECTED UNPERTURBED LEVEL 4

11. **RELATED TECHNOLOGY REQUIREMENTS:**

Use of closed cycle systems will require a source of high power. Related technology will be highly efficient large solar arrays, or focusing solar collectors capable of providing thermal power.

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. Ag-8

1. TECHNOLOGY REQUIREMENT (TITLE): LHe Recycling Unit — PAGE 3 OF 6

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY							NOTE: Technology need date seriously impacts required time for development and testing.												
1. Engineering Model Design																			
2. Life Testing																			
3. Development through development testing																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devi/Fab (Ph. D)																			
3. Operations AS-03-A, AS-07-A, AS-11-A																			
4. HE-09-A																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE			▽															
NUMBER OF LAUNCHES					1	4	5	5	8	4	3	2	4	3	5	4	4	52

14. REFERENCES:

1. Conversation between R. W. Breckenridge, Arthur D. Little, Inc., and P. R. Fagen, Rockwell International, Inc., Nov. 27, 1974.
2. Conversation between J. Kirkpatrick, NASA-ARC, and P. R. Fagan, Rockwell International, Inc., Nov. 20, 1974.
3. Development of Rotary Reciprocating Cryogenic Refrigerator for Space Applications, R. W. Breckenridge, Jr., et al, Arthur D. Little, Inc., AFFDL-TR-72-88.
4. Letter from R. S. Hunt, Garrett-Airresearch Co., to H. Ikerd, GDCA, January 6, 1975.
5. Letter from J. Kirkpatrick, NASA-ARC, to H. Ikerd, GDCA, January 6, 1975.
6. Letter from Dr. E. Urban, MSFC, to H. Ikerd, GDCA, January 5, 1975.
7. Letter from C. McCreight, NASA-Arc, to H. Ikerd, GDCA, January 7, 1975.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

Description of Technology (continued)

The Hughes Vuilleumier (VM) cycle refrigerator is the furthest along in the development cycle and is best suited for near-term missions. However, its performance at low temperatures is relatively poor. Unattended operational life on the order of three years is problematic as the dry lubricated Hughes VM has not been able to demonstrate long life, as yet.

Hughes and North American Phillips are both developing VM cycles and the requirements to which they are working are to simultaneously produce:

0.3w at 11.5K
10w at 33K
12w at 75K

Additional requirements are to draw 2700 watts in the all electric mode and in the thermol-electric mode draw 2600w or less of thermal power and 500 watts of electric power.

For missions beyond the near term, the Arthur D. Little (ADL) rotary reciprocating refrigerator offers the greatest potential. It is a positive displacement machine, but because of funding lags the VM in development cycle. The prototype is in the fabrication cycle and complete refrigeration testing is expected about January 1976. The ADL device has the advantage of relatively high performance and long life, by virtue of hydrodynamic lubrication achieved by the pistons stroking motion. The ADL device is capable of simultaneously producing:

1.4w at 12K
40w at 60K

It can be seen from Table 2 that the above minimum temperatures of the three noted companies are too high for detectors or superconducting magnets, although they are suitable for providing internal cooling to the IR telescopes.

In discussions with R. W. Breckenridge, Arthur D. Little, Inc., he stated that the rotary reciprocating unit currently under development and noted above is capable of one watt load at 3.6K at a required input power of 1300 watts. Further extrapolation to 2.5K will result in a requirement for about 1900 watts for a one watt load. This capability could be achieved through the addition of another Joule-Thompson loop which will require another stage compressor and heat exchanger.

VM cycles cannot be operated at temperatures on the order of those required for detectors listed in Table 2.

5. Description of Technology (continued)

The potential availability of an LHe cryogenic machine can be tempered somewhat by:

1. As yet no complete miniature He refrigerator (or liquefier) has demonstrated the capability for providing useful refrigeration at any temperature under 10K.

2. The longest endurance run that has been conducted to date on a cryogenic refrigerator (Vuilleumier device operating at 80K) is slightly in excess of 5000 hours. Demonstrating the capability of operating for periods in excess of one year may prove to be a practical impossibility due to outgassing or the accumulation of wear products irrespective of quantities involved.

3. No tests have been done to confirm the possibility that no LHe cryogenic machine can withstand the launch and space vehicle environmental conditions.

9. Potential Alternatives (continued)

Additionally the machine will require a power input on the order of two to three thousand watts. At least for short term Shuttle sortie missions of 7 days it appears feasible to consider open cycle phase change dewars. The advantages are no or little power requirements and probable operation within the weights defined above. A prototype dewar is presently being prepared for thermal testing at Ball Brothers. It was designed for one year operation at 30 milliwatt heat leak and weight of 200 pounds. The dewar will cool the relativity gyroscope to 1.6K. (See RI, 12.1)

APPENDIX B

FLIGHT EXPERIMENT FORMS

FUTURE PAYLOAD TECHNOLOGY TESTING AND DEVELOPMENT REQUIREMENT

NO. Ba-1
PAGE 1

1. REF. NO. 11 **PREP DATE** 8/8/75 **REV DATE** ____ **LTR** ____
CATEGORY Environmental Protection

2. TITLE Thermal Control Materials Compatible with the Space Plasma/Charging Environment

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
2	3	7

Current typical spacecraft flexible solar array and thermal control system designs include a large number of dielectric materials facing the space environment. There is increasing evidence that there may be significant adverse interactions of these materials with the space plasma/charging environment. Spacecraft thermal control dielectric materials and applications techniques do not exist which are compatible with the space plasma/charging environment. The objective of this experiment is to expose candidate spacecraft thermal control materials to the space plasma/charging environment and then to evaluate their compatibility with the environment. Analyses and ground tests would be performed in support of the (continued on attached form)

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** Earliest available sync. orbit
PAYLOAD DEVELOPMENT LEAD TIME 2 **YEARS. TECHNOLOGY NEED DATE** ASAP

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** All sync. orbit

TECHNICAL BENEFITS In some cases it has been postulated that high potential discharges have destroyed orbiting spacecraft. In those cases where the spacecraft may not be destroyed the gathering of data is interfered with.

POTENTIAL COST BENEFITS Any loss of the spacecraft is a costly failure.

ESTIMATED COST SAVINGS $ ____

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Insufficient analytical experimental and flight data exists to precisely define either the space plasma/charging environment or the behavior of dielectric materials in this environment. The space plasma is difficult to simulate. Ground tests are therefore of dubious value.

REQUIRED SUPPORTING TECHNOLOGIES Spacecraft analytical model, materials characterization, study of charging and discharging mechanisms, development of conductive materials with required surface properties.

7. REFERENCE DOCUMENTS/COMMENTS OFS Future Payload Technology Requirements Study Report No. CASD-NAS-75-004 - Technology Categories 5.0, 11.0, and 13.0. Office of Space science Input document to 1975 NASA OAST Workshop.

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TITLE ______________________________ NO. ________

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: ______________________________

TEST DESCRIPTION: ALT. (max/min) _____/_____ km, INCL. _____ deg, TIME _____ hr

BENEFIT OF SPACE TEST: ______________________________

EQUIPMENT: WEIGHT _____ kg, SIZE _____ X _____ X _____ m, POWER _____ kW

POINTING _____ STABILITY _____ DATA _____

ORIENTATION _____ CREW: NO. _____ OPERATIONS/DURATION _____/_____

SPECIAL GROUND FACILITIES: ______________________________

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE _____

9. GROUND TEST OPTION TEST ARTICLE: ______________________________

TEST DESCRIPTION/REQUIREMENTS: ______________________________

SPECIAL GROUND FACILITIES: ______________________________

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ______________________________

TEST CONFIDENCE _____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ _____ (SUM OF PROGRAM COSTS $ _____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ _____

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FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Ba-1

PAGE 1 (Cont'd)

1. REF. NO. ____ PREP DATE ____ REV DATE ____ LTR ____

CATEGORY ____

2. TITLE ____

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

flight experiment. Guidelines would be issued for materials and application techniques based on the flight data.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE ____

PAYLOAD DEVELOPMENT LEAD TIME ____ YEARS. TECHNOLOGY NEED DATE ____

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ____

TECHNICAL BENEFITS ____

POTENTIAL COST BENEFITS ____

ESTIMATED COST SAVINGS $ ____

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS ____

REQUIRED SUPPORTING TECHNOLOGIES ____

7. REFERENCE DOCUMENTS/COMMENTS ____

FT (TDR-1) 7/75

TITLE Thermal Control Materials Compatible with the Space Plasma/Charging Environment

NO. Ba-1

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Piggyback package

TEST DESCRIPTION: ALT. (max/min) sync. / orbit km, INCL. ______ deg, TIME ______ hr

Evaluate materials exposed to space environments.

BENEFIT OF SPACE TEST: Ground simulation difficult and uncertain

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION known or controlled CREW: NO. ______ OPERATIONS/DURATION ______ / ______

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: Samples exposed to simulated environment

TEST DESCRIPTION/REQUIREMENTS: Determine suitability of selected materials to withstand simulated environment.

SPECIAL GROUND FACILITIES: Need to develop special simulation facilities

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: Poor representation of space environment

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

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FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Ba-2
PAGE 1

1. REF. NO. ____ **PREP DATE** 8/9/75 **REV DATE** ____ **LTR** ____
CATEGORY 10 or 11

2. TITLE Improved Temperature Control Coatings For Very Large Space Structures Including Solar Collectors

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Integrate the thermal control coating with the structural elements. Will include light-weight laminates, conductive α/ϵ coatings for solar collectors (α/ϵ values 30 to 50), stable anodized coatings.

Will require flight testing for verification of ground testing and confirmation of coating test data.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** ____
PAYLOAD DEVELOPMENT LEAD TIME ____ **YEARS. TECHNOLOGY NEED DATE** ____

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ____

TECHNICAL BENEFITS Light weight, high efficiency, low cost, increased performance.

POTENTIAL COST BENEFITS ____

ESTIMATED COST SAVINGS $ ____

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS R & D required in coating development

REQUIRED SUPPORTING TECHNOLOGIES ____

7. REFERENCE DOCUMENTS/COMMENTS ____

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TITLE ______________________________ NO. ________

______________________________ PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: ______________________________

TEST DESCRIPTION: ALT. (max/min) ______/______ km, INCL. ______ deg, TIME ______ hr

BENEFIT OF SPACE TEST: ______________________________

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. ______ OPERATIONS/DURATION ______/______

SPECIAL GROUND FACILITIES: ______________________________

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: ______________________________

TEST DESCRIPTION/REQUIREMENTS: ______________________________

SPECIAL GROUND FACILITIES: ______________________________

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ______________________________

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

FT (TDR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Ba-3
PAGE 1

1. REF. NO. ____ **PREP DATE** 8/9/75 **REV DATE** ____ **LTR** ____
CATEGORY 10 or 11

2. TITLE Evaluation of Long-Life Stability of S/C Thermal Control Surfaces

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

The need to obtain flight operational data on the performance of s/c thermal control surfaces in long-term missions is of major concern. Long-term missions in particulate (e^-, p^+) radiation environments are planned but data on coatings developed in 1970's is not available. Flight tests will be required in following environments: Near-earth polar orbit; Geosynchronous; Interplanetary - Venus, Mercury, Jupiter. Shuttle - LDEF payload will satisfy near-earth data - requirements.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** 1981
PAYLOAD DEVELOPMENT LEAD TIME 2 **YEARS. TECHNOLOGY NEED DATE** 1979

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ____
TECHNICAL BENEFITS Better temperature stability through predictable coating performance and coating selection.

POTENTIAL COST BENEFITS ____

ESTIMATED COST SAVINGS $ ____

6. RISK IN TECHNOLOGY ADVANCEMENT
TECHNICAL PROBLEMS None.

REQUIRED SUPPORTING TECHNOLOGIES Thermal control coating development.

7. REFERENCE DOCUMENTS/COMMENTS ____

FT (TDR-1) 7/75

TITLE ______ NO. ______
PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Thermal control surfaces test LDED

only shuttle payload optio., others are Scout (earth polar); Air Force - STP payloads; other s/c.

TEST DESCRIPTION: ALT. (max/min) ____/____ km, INCL. ____ deg, TIME ____ hr

Hardware Available

BENEFIT OF SPACE TEST: Actual Radiation vs Time

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____/____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: ____

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: Radiation testing in lab does not match flight test data.

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

FT (TDR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Ba-4
PAGE 1

1. REF. NO. ______ **PREP DATE** 8/9/75 **REV DATE** ______ **LTR** ______
CATEGORY 10 or 11

2. TITLE Repair/Refurbishment of Thermal Control Surfaces in Space

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Development of techniques for repair/refurbishment of thermal control surfaces in space on malfunctioning s/c are desired. Techniques can be evaluated in ATL or spacelab missions.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** ______
PAYLOAD DEVELOPMENT LEAD TIME ______ **YEARS. TECHNOLOGY NEED DATE** ______

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ______

TECHNICAL BENEFITS Repair and reorbit of spacecraft; provide techniques for emergency repairs; eliminate need for backup spacecraft.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Provide full access to total s/c thermal control surface

REQUIRED SUPPORTING TECHNOLOGIES ______

7. REFERENCE DOCUMENTS/COMMENTS CASD-NAS-75-004
C 9.9

FT (TDR-1) 7/75

TITLE ______ NO. Ba-4
PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: ______

TEST DESCRIPTION: ALT. (max/min) ____/____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: 0-g; VAC; EVA compatibility

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____/____

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: ______

TEST DESCRIPTION/REQUIREMENTS: ______

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: need 0-g

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

F1 (TDR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Ba-5
PAGE 1

1. REF. NO. ____ **PREP DATE** 8/9/75 **REV DATE** ____ **LTR** ____
CATEGORY 10 or 11

2. TITLE Adhesives for Attachable Thermal Control Surfaces

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

The performance of attachable thermal control surfaces (i.e., second surface mirror coatings) depends upon the integrity of their adhesive. Although laboratory tests have demonstrated good performance, earlier adhesives have demonstrated anomalous behavior under different flight conditions; therefore, space flight tests are necessary since several radiation environments are needed, the following flight tests are required: shuttle launched - LDEF, polar orbiter; geosynchronous; and/or Scout-polar orbiter.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** ____
PAYLOAD DEVELOPMENT LEAD TIME ____ **YEARS. TECHNOLOGY NEED DATE** ____

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ____

TECHNICAL BENEFITS Increased reliability of attachable thermal control surfaces in space environments and increased reliability in predicted thermal performance of s/c.

POTENTIAL COST BENEFITS ____

ESTIMATED COST SAVINGS $ ____

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS None.

REQUIRED SUPPORTING TECHNOLOGIES Adhesive development for second surface mirror and other attachable thermal control surfaces.

7. REFERENCE DOCUMENTS/COMMENTS ____

FT (TDR-1) 7/75

TITLE ______________________________________ NO. ________

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: ____________________

TEST DESCRIPTION: ALT. (max/min) ______/______ km, INCL. ______ deg, TIME ______ hr

BENEFIT OF SPACE TEST: ____________________

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW NO. ______ OPERATIONS/DURATION ______/______

SPECIAL GROUND FACILITIES: ____________________

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: ____________________

TEST DESCRIPTION/REQUIREMENTS: ____________________

SPECIAL GROUND FACILITIES: ____________________

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____________________

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK		SPACE TEST OPTION							GROUND TEST OPTION						
	CY							COST ($)							COST ($)
1. ANALYSIS 2. DESIGN 3. MFG & C/O 4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

FT (TDR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Bb-1
PAGE 1

1. REF. NO. ______ **PREP DATE** 8/9/75 **REV DATE** ______ **LTR** ______
CATEGORY Environment Control & Cryogenic Control

2. TITLE Cryogenic Heat Pipe Radiative Coolers

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Many sensors and telescopes will be operating in the cryogenic range (100 to 150K) and will require heat pipes to transport heat. Large multiple arrays of detectors (5-10 watts) will be remotely located from their optics and will require heat pipes to isothermalize them. Telescopes and sensors will have large radiators operating at cryogenic temperature which will make use of heat pipes. Varying environments will require variable heat rejection devices in the form of variable conductance heat pipes and diodes. For operating in sunlight conditions or at constant temperature, change phase materials will be required.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** 1980 EOS (EO,3) Mission 30
PAYLOAD DEVELOPMENT LEAD TIME 3 **YEARS. TECHNOLOGY NEED DATE** 1978 (EOS)

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** 3-5

TECHNICAL BENEFITS Allows for handling large amounts of power at cryo temperatures at varying power and environment conditions.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Present technology is limited to 10-50 Millwatts with detectors and radiators intimately located.

REQUIRED SUPPORTING TECHNOLOGIES Sensors, cryogenics

7. REFERENCE DOCUMENTS/COMMENTS 1) Outlook for Space ("Instruments and Sensors") 2) SFC, LDEF Cry. Heat Pipe Exp. Proposal 3) Outlook - Missions Documents

FT (TDR-1) 7/75

TITLE Cryogenic Heat Pipe Radiative Coolers

NO. Bb-1
PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Flight experiment containing cryo heat pipes, diodes, phase change material, radiators and support equipment

TEST DESCRIPTION: ALT. (max/min) ____/____ km, INCL. ____ deg, TIME ____ hr
Prefer Synch. Alt. (lower alt. acceptable with view of space)
Use solar or electrical power to activate system. Measure temperatures.

BENEFIT OF SPACE TEST: ____

EQUIPMENT: WEIGHT 100 kg, SIZE 1.25 X 1.0 X .5 m, POWER 600 watt hours kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. 500 OPERATIONS/DURATION 4 hr. /

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☒

TEST CONFIDENCE High (2 S/C and sounding rocket exp. flown)

9. GROUND TEST OPTION TEST ARTICLE: ____
Cannot be adequately tested in 1-g due to effects on hydro-dynamics

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY 75	76	77	78	79	80	81	SPACE TEST OPTION COST ($)	GROUND TEST OPTION COST ($)
1. ANALYSIS								100	
2. DESIGN								85	
3. MFG & C/O								170	
4. TEST & EVAL								145	
TECH NEED DATE									
GRAND TOTAL								500K	

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

FT (TDR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Bb-2
PAGE 1

1. REF. NO. 10 **PREP DATE** 8/8/75 **REV DATE** ____ **LTR** ____
CATEGORY Environmental Control

2. TITLE Ultra-High Thermal Conductance Heat Pipe

3. TECHNOLOGY ADVANCEMENT REQUIRED

In order to isothermalize very large structures, i.e., antennas, solar collectors, etc., to levels of acceptable distortion, ultra-high thermal conductance will be required. Both high and low flux densities will have to be transferred with extremely low temperature gradients (L=10 100M, @ T=0.1 1°C @ q=0.1 50w/cm²)

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** ____
PAYLOAD DEVELOPMENT LEAD TIME ____ **YEARS. TECHNOLOGY NEED DATE** ____

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ____

TECHNICAL BENEFITS Minimizes distortion for accurate pointing and thermal stabilization of large structures.

POTENTIAL COST BENEFITS ____

ESTIMATED COST SAVINGS $ ____

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Present technology is limited to 1-10 w/cm² for 1-10 meters length @ 3-5°c gradient

REQUIRED SUPPORTING TECHNOLOGIES Structures, materials, basic research

7. REFERENCE DOCUMENTS/COMMENTS Outlook for Space ("Large, Controllable Lightweight Structures")

FT (TDR-1) 7/75

TITLE ______________________ NO. Bb-2

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: 20 meter (shuttle bay) Long Heat Pipe

TEST DESCRIPTION: ALT. (max/min) any / ____ km, INCL. ____ deg, TIME ____ hr

Apply power to Heat Pipe and Measure Temperature

BENEFIT OF SPACE TEST: 0-g environment required due to negating gravity effects on hydrodynamics on ground

EQUIPMENT: WEIGHT 25 kg, SIZE .01M X20M(LG) X ____ m, POWER .5-1.0 kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. 10 OPERATIONS/DURATION 2 /1M

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: Cannot be adequately tested in 1-g due to effects on hydrodynamics

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

FT (TDR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Bh-3
PAGE 1

1. REF. NO. ______ PREP DATE 8/9/75 REV DATE ______ LTR ______
CATEGORY Environment Control and Cryogenic Control

2. TITLE Improved Solid Cryogenic Lifetime Experiment

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

In order to cool IR detectors to the 65-120K region, solid cryogenic coolers are used. These usually take the form of multi-stage devices which are bulky, heavy-weight and subject to high parasitic heat loads. These coolers could be greatly enhanced by coupling them to a heat pipe passive radiator which would sub-cool the container and limit parasitic heat loads. This would eliminate the need for multiple staging, which would lower weight, (factor of 2) and extend lifetime (by factor of 2-3).

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1980 (ECS), EO-3, OBJ. 0-24
PAYLOAD DEVELOPMENT LEAD TIME 3 YEARS. TECHNOLOGY NEED DATE 1978

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______
TECHNICAL BENEFITS Lowers Weight (Factor 2), Extends Life (Factor 2-3)

POTENTIAL COST BENEFITS Simpler, more reliable design

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT
TECHNICAL PROBLEMS Present technology (LRIR Nimbus F) is limited to 6-8 mo. expected life (Design 1 yr.).

REQUIRED SUPPORTING TECHNOLOGIES Sensors, Mtls., Struct.

7. REFERENCE DOCUMENTS/COMMENTS NASA 1973 Mission Model, Outlook for Space Missions, AEAA Paper

FT (TDR-1) 7/75

TITLE Improved Solid Cryogeric Lifetime Experiment — NO. Bb-3
PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Solid cryogen cooler with outer shell containing heat pipes and passive cooler

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

Synch Alt. or Low Orbit w/cold view or space simulate detector heat, measure temperature over long time or recover and reweigh system

BENEFIT OF SPACE TEST: 0-G Environment required due to negative gravity effects on heat pipe hydrodynamics

EQUIPMENT: WEIGHT 100 kg, SIZE .5 X .5 X .5 m, POWER 5-50 kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: Heat pipes cannot be adequately tested in 1-g

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

F 1 (TDR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY **NO.** Bb-4

TESTING AND DEVELOPMENT REQUIREMENT **PAGE** 1

1. REF. NO. 10 **PREP DATE** 8/9/75 **REV DATE** ______ **LTR** ____

CATEGORY Environment Control

2. TITLE Precision Temperature Control Techniques Using Heat Pipes

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Many instruments, structures, and gyros which are required to hold extremely tight temperature control (± .1°C) may require techniques involving feedback or cascaded heat pipes. These ... will either directly or indirectly receive an indication from the instrument of changing temperature and adjust its heat rejection in order to hold this tight temperature control.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** Mission 33 (Solar Cluster)

PAYLOAD DEVELOPMENT LEAD TIME 3 **YEARS. TECHNOLOGY NEED DATE** 1979 1981

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ______

TECHNICAL BENEFITS Minimizes temperature excursions which permits fine pointing, low drift and aligned optics through stable structures

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Present technology using large amounts of heat, power and sophisticated electronics to maintain control.

REQUIRED SUPPORTING TECHNOLOGIES GN & C, structures

7. REFERENCE DOCUMENTS/COMMENTS Outlook for Space ("Precision Navigation", Large Controllable Lightweight Structures)

FT (TDR-1) 7/75

TITLE Precision Temperature Control Techniques Using Heat Pipes NO. ______

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: ______

TEST DESCRIPTION: ALT. (max/min) ____/____ km, INCL. ____ deg, TIME ____ hr

Change environment conditions, record response; i.e., drift, align, etc.

BENEFIT OF SPACE TEST: 0-g environment required due to negative effects on hydrodynamics on ground

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____/____

SPECIAL GROUND FACILITIES: ______

EXISTING: 'ES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: ______

TEST DESCRIPTION/REQUIREMENTS: ______

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ______

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	SPACE TEST OPTION CY						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS														
2. DESIGN														
3. MFG & C/O														
4. TEST & EVAL														
TECH NEED DATE														
	GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

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FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Bb-5
PAGE 1

1. REF. NO. 10 **PREP DATE** 8/9/75 **REV DATE** ______ **LTR** ____
CATEGORY Environment Control

2. TITLE Large Variable Heat Rejection Radiators

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

In order to accommodate a variety of very fine pointing instruments, each with different power levels, temperature level and gradient requirements, radiators will be needed. These radiators will be required to handle power levels in the kilowatt range; be able to vary their heat rejection in order to maintain narrow temperature units and be adjustable to hold a variety of temperature level. Heat pipes with variable conductance capability will be the main source of control. A need is also shown at high temperature n 1200°C for nuclear propulsion.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** Mission 33
PAYLOAD DEVELOPMENT LEAD TIME ______ **YEARS. TECHNOLOGY NEED DATE** ______

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ______

TECHNICAL BENEFITS Will allow for a wide variety of payloads to be handled using one type of radiator.

POTENTIAL COST BENEFITS Will reduce analysis and manpower will not require power or contain no moving parts.

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Present technology is limited to 100-200 watt capability at room temperature with wider temperature limits. Large capacity radiators at high temperatures have not been flown.

REQUIRED SUPPORTING TECHNOLOGIES Structures, materials

7. REFERENCE DOCUMENTS/COMMENTS Outlook for Space (advanced propulsion, instruments and sensors). Report to Snowmass Science Meeting, August 1974.

FT (TDR-1) 7/75

TITLE ______ NO. Bb-5

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: 3Mx1m (300w)

Radiator with variable conductance heat pipes. Larger (5-10 kw) radiators 1200^oC

TEST DESCRIPTION: ALT. (max/min) ___/___ km, INCL. ___ deg, TIME ___ hr

Any altitude, including apply variable loads and measure thermal responses

BENEFIT OF SPACE TEST: 0-G environment required due to negating gravity effects

EQUIPMENT: WEIGHT 50 kg, SIZE 3m X 1m X .25 m, POWER ___ kW

POINTING ___ STABILITY ___ DATA ___

ORIENTATION ___ CREW: NO. ___ OPERATIONS/DURATION ___/___

SPECIAL GROUND FACILITIES: ___

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ___

9. GROUND TEST OPTION TEST ARTICLE: ___

TEST DESCRIPTION/REQUIREMENTS: ___

SPECIAL GROUND FACILITIES: ___

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ___

TEST CONFIDENCE ___

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ___ (SUM OF PROGRAM COSTS $ ___)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ___

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FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Bc-1
PAGE 1

1. REF. NO. ____ **PREP DATE** 8/8/75 **REV DATE** ____ **LTR** ____
CATEGORY 10/11 Thermal Control

2. TITLE Phase Change Materials for Thermal Storage

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
2	5	7

a) To identify techniques for the control of the solid, liquid and vapor phases of the working medium in phase-change heat sink devices in order to improve the performance of such devices.
b) To characterize the performance of phase-change devices in the space environment.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** when ready
PAYLOAD DEVELOPMENT LEAD TIME 3 **YEARS. TECHNOLOGY NEED DATE** ASAP

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ____

TECHNICAL BENEFITS Provide basic design data and techniques for more effective phase-change heat-sink devices. These devi s will be used to maintain a nearly constant temperature by absorbing/releasing thermal energy during cyclic or intermittant thermal loading.

POTENTIAL COST BENEFITS May permit avoidance of more costly active control systems.

ESTIMATED COST SAVINGS $ ____

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Material compatibility

REQUIRED SUPPORTING TECHNOLOGIES Material properties and compatibility

7. REFERENCE DOCUMENTS/COMMENTS International Heat Pipe Sounding Rocket Experiment

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TITLE ______________________________ NO. ________

______________________________ PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: ______________________________

____

____

TEST DESCRIPTION: ALT. (max/min) ______ / ______ km, INCL. ______ deg, TIME ______ hr

____

____

BENEFIT OF SPACE TEST: ______________________________

____

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. ______ OPERATIONS/DURATION ______ / ______

SPECIAL GROUND FACILITIES: ______________________________

______________________________ EXISTING: YES ☐ NO ☐

______________________________ TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: ______________________________

____

TEST DESCRIPTION/REQUIREMENTS: ______________________________

____

____

SPECIAL GROUND FACILITIES: ______________________________

____

______________________________ EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ______________________________

____

______________________________ TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION							GROUND TEST OPTION						
								COST ($)							COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

______________________________ ______ ______

______________________________ ______ ______

COST RISK $ ______

I I (I DR 2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Bc-2
PAGE 1

1. REF. NO. ______ **PREP DATE** 8/8/75 **REV DATE** ______ **LTR** ______
CATEGORY 10/11 Thermal Control

2. TITLE Expendable Materials Heat Rejection Systems

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
7	8	9

Performance of boilers/sublimers and other elements of expendable material heat rejection systems must be verified in the flight environment before committing to their use in an actual mission. Representative hardware must be designed and fabricated before performing these verification tests. Limited specific applications using water have been developed in the past.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** 1981
PAYLOAD DEVELOPMENT LEAD TIME 2 **YEARS. TECHNOLOGY NEED DATE** 1979

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ______

TECHNICAL BENEFITS Technology is applicable for short duration or special circumstances where radiative cooling is inadequate or inappropriate. Cooling of shuttle payload radioisotope power sources and EVA crews are typical applications.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Contamination control and venting provisions

REQUIRED SUPPORTING TECHNOLOGIES 1) Contamination studies for fluids used, 2) Boiling of fluids in zero-g

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE Phase Change Material NO. ______

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Assembly of phase-change capsules with various design features

TEST DESCRIPTION: ALT. (max/min) ____/____ km, INCL. ____ deg, TIME 10 hr

Heating/cooling provisions and temperature readouts

BENEFIT OF SPACE TEST: Zero gravity

EQUIPMENT: WEIGHT 20 kg, SIZE ½ X ½ X ½ m, POWER 0.5 kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____/____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: Same as above

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: One-g

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

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FUTURE PAYLOAD TECHNOLOGY NO. ______

TESTING AND DEVELOPMENT REQUIREMENT PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY ______

2. TITLE ______

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE ______
PAYLOAD DEVELOPMENT LEAD TIME ______ YEARS. TECHNOLOGY NEED DATE ______

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______
TECHNICAL BENEFITS ______
POTENTIAL COST BENEFITS ______
ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT
TECHNICAL PROBLEMS ______
REQUIRED SUPPORTING TECHNOLOGIES ______

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE Boilers and Expendable Fluid Heat Rejection Systems NO. Bc-2

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Test model of cooling system

TEST DESCRIPTION: ALT. (max/min) ____/____ km, INCL. ____ deg, TIME 15 hr

BENEFIT OF SPACE TEST: Accurate simulation of flight environment, especially zero-g

EQUIPMENT: WEIGHT 500 kg, SIZE 1 X 1 X 1 m, POWER 0.1 kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____/____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE 95%

9. GROUND TEST OPTION TEST ARTICLE: Test model of cooling system components or system

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: Simulated heat loads; high capacity vacuum pumps

EXISTING: YES ☒ NO ☐

GROUND TEST LIMITATIONS: No simulation of shuttle environment; 1-g field

TEST CONFIDENCE 75%

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

F1 (1DR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY **NO.** Bc-3

TESTING AND DEVELOPMENT REQUIREMENT **PAGE** 1

1. REF. NO. ______ **PREP DATE** 8/8/75 **REV DATE** ______ **LTR** ______

CATEGORY 10 Environmental Control

2. TITLE Deployable Orientable Radiator Systems and Components

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Develop and verify in a space environment deployable orientable radiator systems including low-temperature (<100°K) radiators, leak-free gimbals and connectors, and mechanisms and controls for deep space tracking for long-term space experiments (1 to 6 months). System must be capable of deployment beyond interference regions of shuttle orbiter, out of the payload bay.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** 1981

PAYLOAD DEVELOPMENT LEAD TIME 2 **YEARS. TECHNOLOGY NEED DATE** 1979

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** Many

TECHNICAL BENEFITS Achieve maximum efficiency from radiation systems by permitting continuous or nearly continuous radiation to "deep space".

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Long-term space operation effects on fluid loop components, joints, gimbals, and design of mechanical components.

REQUIRED SUPPORTING TECHNOLOGIES Materials, structural design, thermal control

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE ______________________ NO. Bc-3

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Deployable/orientable radiator with heat source (could be an active experiment or payload)

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: Verify operation of system in space environment - deployment, pointing, performance

EQUIPMENT: WEIGHT 2?0 kg, SIZE 0.2 X 1 X 2 m, POWER ? kW

POINTING yes STABILITY ____ DATA thermal/position

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: ____

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	SPACE TEST OPTION CY						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS														
2. DESIGN														
3. MFG & C/O														
4. TEST & EVAL														
TECH NEED DATE														
	GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

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FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Bd-1
PAGE 1

1. REF. NO. 10 **PREP DATE** 8/8/75 **REV DATE** ______ **LTR** ______
CATEGORY Environmental Control

2. TITLE Temperature Control Device Test Facility (Ambient Regime)

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Various phenomena in heat pipe performance must be studied in 0-G because of the negative influence of gravity on parameters such as liquid distribution gas/vapor interfaces and wetting parameters. Improvements in heat transfer coefficients to accomplish low temperature gradients at low fluxes and at high fluxes, can be measured and observed. Diffusion of vapors, liquids and gases in controllable heat pipes can be studied as well as distribution of phase change materials in a metallic matrix.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** ______
PAYLOAD DEVELOPMENT LEAD TIME ______ **YEARS. TECHNOLOGY NEED DATE** ______

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ______

TECHNICAL BENEFITS Allows for a basic understanding of heat pipe performance so that improvements in state-of-art can be made.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Present limits on spacecraft and sounding rocket experiments as to weight, telemetry power and operations prevent sufficient data from being acquired to separate variables.

REQUIRED SUPPORTING TECHNOLOGIES Materials

7. REFERENCE DOCUMENTS/COMMENTS Spacelab payload accommodations doc., "NASA Objectives on Co-op Spacelab Experiments-Heat Transfer"

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TITLE ______ NO. Bd-1
PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Facility in Pressured Module or Pallet

TEST DESCRIPTION: ALT. (max/min) ___/___ km, INCL. ___ deg, TIME ___ hr

Work bench and rack equipment and pallet support structure and services.

BENEFIT OF SPACE TEST: Cannot be performed w/o zero gravity

EQUIPMENT: WEIGHT 100 kg, SIZE ___ X ___ X ___ m, POWER 1.0 kW

POINTING ___ STABILITY ___ DATA ___

ORIENTATION ___ CREW: NO. ___ OPERATIONS/DURATION ___/___

SPECIAL GROUND FACILITIES: ___

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ___

9. GROUND TEST OPTION TEST ARTICLE: ___

TEST DESCRIPTION/REQUIREMENTS: ___

SPECIAL GROUND FACILITIES: ___

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ___

TEST CONFIDENCE ___

10. SCHEDULE & COST

TASK	SPACE TEST OPTION							GROUND TEST OPTION						
CY							COST ($)							COST ($)
1. ANALYSIS 2. DESIGN 3. MFG & C/O 4. TEST & EVAL														
TECH NEED DATE														
	GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ___ (SUM OF PROGRAM COSTS $ ___)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ___

F1 (TDR 2) 7-75

FUTURE PAYLOAD TECHNOLOGY **NO.** Bd-2

TESTING AND DEVELOPMENT REQUIREMENT **PAGE** 1

1. REF. NO. ______ **PREP DATE** ______ **REV DATE** ______ **LTR** ______

CATEGORY 10 Environmental Control

2. TITLE Zero-G Measurement of Heat-Pipe Disturbances

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
4	5	7

Quantify experimentally in space environment the disturbing forces resulting from performance of a variety of heat pipe configurations and capacities, over a range of heat transfer conditions, and to evaluate concepts and configurations which would minimize these forces.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** 1981

PAYLOAD DEVELOPMENT LEAD TIME 2 **YEARS. TECHNOLOGY NEED DATE** 1979

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ______

TECHNICAL BENEFITS Provide quantitative basis for selection of heat pipes in lieu of less effective passive means of thermal control for experiments requiring extremely quiescent conditions.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Instrumentation difficulty in determining very small forces precisely.

REQUIRED SUPPORTING TECHNOLOGIES ______

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE ______ NO. Bd-2

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Several (15-20) heat pipes and variable heat sources and heat sinks instruments for forces (loads/strains) and accelerations.

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: Only way to accurately measure forces

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: N.A.

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	SPACE TEST OPTION (CY)						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS														
2. DESIGN														
3. MFG & C/O														
4. TEST & EVAL														
TECH NEED DATE														
	GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

FT (TDR 2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Bd-3
PAGE 1

1. REF. NO. ____ **PREP DATE** ____ **REV DATE** ____ **LTR** ____
CATEGORY Electric Power and Thermal Control

2. TITLE Scalable Shuttle-Launched, Free-Flying Facility for High Power Density Testing

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

The required technology advancement is a scalable shuttle-launched, free-flying facility for experimentation and demonstration related to high-power-density devices and phenomena. The facility includes a high-power-density source, normally a radioisotope, cooled by a metallic-fluid heat pipe which heats the emitter of a thermionic converter having a collector cooled by a heat-pipe radiator. Some evaluations may require several thermionic-converter, heat-pipe modules which feed their electric outputs to a power processing system that energizes instrumentation control, data-handling, and transmission equipment needed for the experimentation or demonstration. Replacing a standard component of this facility during fabrication with (cont.)

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** 1980
PAYLOAD DEVELOPMENT LEAD TIME 3 to 4 **YEARS. TECHNOLOGY NEED DATE** now

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ____

TECHNICAL BENEFITS This facility will allow high-power-density testing and verification in space of some essential thermal-control and electric-power components.

POTENTIAL COST BENEFITS The facility enables such testing and verification without large-space-station power.

ESTIMATED COST SAVINGS $ dependent on number of missions

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS a) Radioisotope handling (perhaps manifold heat-pipe cooling)
b) Use of heat pipes and converters not verified in space as standard facility components (but verification of these in such a facility is desirable).
c) Scaling to various power levels (solved by varying the number of thermionic-converter, heat-pipe modules.

REQUIRED SUPPORTING TECHNOLOGIES Thermionic conversion
Metallic-fluid heat pipes
Material selection and evaluation

7. REFERENCE DOCUMENTS/COMMENTS RTOP's 506-24-26 and 506-16-31; NASA, ERDA Thermionic-Conversion Program Reviews; Outlook for Outer Space; Future Payload Technology Requirements Study

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TITLE ______ NO. Bd-3
PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Described in 3

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: Described in 5

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: ____

TEST DESCRIPTION/REQUIREMENTS: Ground evaluation leading to performance-life and verification-testing in space is desirable

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: Ground tests cannot substitute for spaceflight verification

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

F 1 (TDR 2) 7/75

DEFINITION OF TECHNOLOGY REQUIREMENT **NO.** Bd-3

1. TECHNOLOGY REQUIREMENT (TITLE): Scalable Shuttle-Launched, Free-Flying Facility for High Power Density Testing **PAGE** 2 **OF** 1

3. (cont.)

an experimental element allows testing or demonstration of thermal-energy acquisition, transmission, conversion, or rejection or electric processing, each at highpower densities.

For example, such replacements would enable tests of solar-concentrator models, new heat pipes, improved thermionic converters, radiator modules, on the latest processing development for low-voltage, high-current power.

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Bf-1
PAGE 1

1. REF. NO. ______ **PREP DATE** 8/9/75 **REV DATE** ______ **LTR** ______
CATEGORY ______

2. TITLE Effects of Shuttle Induced Contamination on Thermal Control Surfaces

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

The need for contamination monitoring experiments on the early shuttle missions is recognized. As a part of these experiments, it is mandatory that the effects of this contamination on S/C temperature control surfaces be determined. Flight experiments are required on LDEF (mission 3) and LDEF (mission 4) as well as integrated into the design flight instrumentation package for other flights. A statistical average is necessary for proper data interpretation.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** 1979
PAYLOAD DEVELOPMENT LEAD TIME 1.5 **YEARS. TECHNOLOGY NEEL DATE** 1977

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ______

TECHNICAL BENEFITS Provide data for selection of thermal coatings for future shuttle payloads. Direct benefit to all shuttle payloads.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS ______

REQUIRED SUPPORTING TECHNOLOGIES Development of techniques for quantitative and qualitative analysis of contaminants.

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE Effects of Shuttle Induced Contamination on Thermal Control Surfaces
NO. Bf-1
PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Shuttle contamination of thermal control surfaces

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: 0-g, Vacuum, Shuttle induced environment

EQUIPMENT: WEIGHT 5 kg, SIZE 0.3 X 0.3 X 0.1 m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: ____

NOT APPLICABLE

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: Shuttle not available to produce contaminants

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ 800 K (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

F1 (1DR 2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Bf-2
PAGE 1

1. REF. NO. ______ PREP DATE 8/9/75 REV DATE ______ LTR ______
CATEGORY 10 or 11

2. TITLE Techniques for Contamination Protection

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
3	5	7

Advanced techniques are required for protection of optical, x-ray, and solar physics telescopes as well as thermal control surfaces. Referenced convair experiment is limited in scope for techniques of accomplishing this protection. See spacelab or ATL as providing excellent flight test conditions.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE ______
PAYLOAD DEVELOPMENT LEAD TIME ______ YEARS. TECHNOLOGY NEED DATE ______

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______
TECHNICAL BENEFITS Long-life operation, less s/c cleanliness requirements

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT
TECHNICAL PROBLEMS Advanced technology development required, lack of support for contamination studies.

REQUIRED SUPPORTING TECHNOLOGIES ______

7. REFERENCE DOCUMENTS/COMMENTS CASD-NAS-75-004
C 8.4

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TITLE ______________________________ NO. ______

______________________________ PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: ______________________________

____

____

TEST DESCRIPTION: ALT. (max/min) ______ / ______ km, INCL. ______ deg, TIME ______ hr

____

____

BENEFIT OF SPACE TEST: ______________________________

____

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. ______ OPERATIONS/DURATION ______ / ______

SPECIAL GROUND FACILITIES: ______________________________

______________________________ EXISTING: YES ☐ NO ☐

______________________________ TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: ______________________________

____

TEST DESCRIPTION/REQUIREMENTS: ______________________________

____

____

SPECIAL GROUND FACILITIES: ______________________________

____

______________________________ EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ______________________________

____

______________________________ TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION							GROUND TEST OPTION						
								COST ($)							COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

______________________________ ______ ______

______________________________ ______ ______

COST RISK $ ______

F1 (TDR 2) 7/75

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

FUTURE PAYLOAD TECHNOLOGY TESTING AND DEVELOPMENT REQUIREMENT

NO. Bg-1
PAGE 1

1. REF. NO. ______ **PREP DATE** 8/9/75 **REV DATE** ______ **LTR** ______

CATEGORY Cryogenic Control

2. TITLE Liquid Cryogenic Transfer

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Reduced gravity fluid behavior as it pertains to acquisition, thermal control, low-g venting, and transfer have been evaluated to the limits of ground based reduced gravity facilities in experiment scale and time. The final proof of such systems before their adoption rests on an in-space demonstration. The data to be collected will be applied to cryogenic systems containing LH_2, LF_2, LO_2, LHe, and LAr. Design for pressurant diffuser performance and liquid outlet designs will be verified.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** 1984

PAYLOAD DEVELOPMENT LEAD TIME 2 **YEARS. TECHNOLOGY NEED DATE** 1982

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ______

TECHNICAL BENEFITS Space basing of propulsion systems, increased spacecraft lifetime, space station feasibility, increased orbiter lifetime, space rescue, increased spacecraft payload, increased assurance of low-g engine starts.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS ______

REQUIRED SUPPORTING TECHNOLOGIES ______

7. REFERENCE DOCUMENTS/COMMENTS OFS Future Payload Technology Requirements Study Report No. CASD-NAS-75-004 - Technology Categories 1.2, 4.1, 4.2, 7.0, 10.1, 10.2, 13.0, 16.0. "Future Payload Technology Space Testing and Development Requirements"

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Items 1.6, 2.3-1, 2.14-1, 10.1, 12.1, 18.2. 1975 OAST Workshop (OSS)

TITLE ______ NO. Bg-1
PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Package containing insulated receiver tank, insulated supply tank, and all necessary instrumentation

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: Assurance that system works before committing it to an expensive vehicle system

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: ____

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

f 1 (1DR 2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Bg-2
PAGE 1

1. REF. NO. ______ **PREP DATE** 8/9/75 **REV DATE** ______ **LTR** ______
CATEGORY Cryogenic Control

2. TITLE Liquid Cryogen Storage and Supply

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
4	5	7

Reduced gravity fluid behavior as it pertains to acquisition, thermal control and transfer have been evaluated to the limits of ground reduced gravity facilities in experiment scale and time. The final proof of such systems before their adoption rests on an in-space demonstration. The data to be collected will be applied to cryogenic systems containing LH_2, LF_2, LO_2, LHe, and LAr.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** Can be used as soon as available.
PAYLOAD DEVELOPMENT LEAD TIME ______ **YEARS. TECHNOLOGY NEED DATE** ASAP

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** All shuttle flights

TECHNICAL BENEFITS
Supercritical power and life support systems, if converted to subcritical systems utilizing advanced reduced gravity fluid technology, would realize substantial weight savings.

POTENTIAL COST BENEFITS Any increase in vehicle payload results in a decreased cost of payloads in orbit.

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS ______

REQUIRED SUPPORTING TECHNOLOGIES ______

7. REFERENCE DOCUMENTS/COMMENTS OFS Future Payload Technology Requirements Study Report No. CASD-NAS-75-004-Technology Categories 1.2, 4.1, 4.2, 7.0, 10.1, 10.2, 13.0, 16.0 GD/C Rpt. #FT-WP-001, "Future Payload Technology Space Testing and Development Requirement", Ite 1.6, 2.3-1, 2.14-1, 10.1, 12.2, 18.2. 1975 NASA OAST Summer Workshop (Power Working Group)

FT (TDR-1) 7/75

TITLE Cryogen Storage and Supply **NO.** Bg-2
PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION **TEST ARTICLE:** Package containing subcritical tank for storing cryogens and all necessary instruments

TEST DESCRIPTION· ALT. (max/min) ______ / ______ km, INCL. ______ deg, TIME ______ hr

BENEFIT OF SPACE TEST: Assurance that system works before committing it to an expensive vehicle system

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW
POINTING ______ STABILITY ______ DATA ______
ORIENTATION ______ CREW: NO. ______ OPERATIONS/DURATION ______ / ______

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ______

9. GROUND TEST OPTION **TEST ARTICLE:** There is no ground test option.

TEST DESCRIPTION/REQUIREMENTS: ______

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ______

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	SPACE TEST OPTION							GROUND TEST OPTION						
CY							COST ($)							COST ($)
1. ANALYSIS														
2. DESIGN														
3. MFG & C/O														
4. TEST & EVAL														
TECH NEED DATE														
	GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

F1 (TDR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Bg-3
PAGE 1

1. REF. NO. ______ **PREP DATE** ______ **REV DATE** ______ **LTR** ______
CATEGORY ______

2. TITLE Joule-Thomson Expansion of Supercritical Helium

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
3	4	7

Develop a Joule-Thomson expander with an integral heat exchanger which is capable of producing temperatures below 2°K without inducing excessive noise in detectors. Demonstrate its performance in 0-g preferably as part of an operating sensor system.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** 1980
PAYLOAD DEVELOPMENT LEAD TIME 2 **YEARS. TECHNOLOGY NEED DATE** 1978

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ______

TECHNICAL BENEFITS The use of a J-T expander/heat exchanger to produce HeII (T=2°K) allows: (1) supercritical storage of the helium, rather than subcritical storage with its phase separation problems and (2) the production of HeII on demand.

POTENTIAL COST BENEFITS A suitable J-T expander/heat exchanger would allow use of supercritical (gaseous) helium, rather than the more complex problem of handling two-phase helium in 0-g.

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS J-T expansion to temperatures below 2°K may induce excessive noise (acoustic and thermal) in sensitive detectors. Behavior of the HeII produced during the expansion is not well known in 0-g and may cause flow instabilities.

REQUIRED SUPPORTING TECHNOLOGIES Cryogenic storage, HeII behavior

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE ______________________________ NO. ______

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: ______________________________

TEST DESCRIPTION: ALT. (max/min) ______/______ km, INCL. ______ deg, TIME ______ hr

BENEFIT OF SPACE TEST: ______________________________

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. ______ OPERATIONS/DURATION ______/______

SPECIAL GROUND FACILITIES: ______________________________

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: ______________________________

TEST DESCRIPTION/REQUIREMENTS: ______________________________

SPECIAL GROUND FACILITIES: ______________________________

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ______________________________

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM	COST IMPACT	PROBABILITY

COST RISK $ ______

F1 (1DR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Bg-4

PAGE 1

1. **REF. NO.** ______ **PREP DATE** ______ **REV DATE** ______ **LTR** ______
CATEGORY ______

2. **TITLE** Transfer of Cryogens Across Gimbals

3. **TECHNOLOGY ADVANCEMENT REQUIRED**

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
3	4	7

Develop a rotary joint capable of transferring helium (T=4° to 10°K) across gimbals with acceptable heat losses and disturbances to the instrument pointing system. Demonstrate in space as part of an operational system.

4. **SCHEDULE REQUIREMENTS** **FIRST PAYLOAD FLIGHT DATE** 1980
PAYLOAD DEVELOPMENT LEAD TIME 1.5 **YEARS. TECHNOLOGY NEED DATE** 1978

5. **BENEFIT OF ADVANCEMENT** **NUMBER OF PAYLOADS** ______

TECHNICAL BENEFITS Many future scientific instruments require both accurate pointing and cryogenic cooling. The development of a suitable rotary joint will permit supply dewars (for long missions) to be located off the gimbals.

POTENTIAL COST BENEFITS Less mass on gimbals would simplify pointing and possibly reduce the size of gimbals required.

ESTIMATED COST SAVINGS $ ______

6. **RISK IN TECHNOLOGY ADVANCEMENT**

TECHNICAL PROBLEMS Low friction, leak-tight cryogenic seals and suitable low thermal conductance interfaces have yet to be developed.

REQUIRED SUPPORTING TECHNOLOGIES Cryogenic Thermal Control

7. **REFERENCE DOCUMENTS/COMMENTS** ______

FT (TDR-1) 7/75

TITLE ______________________________ NO. ________

______________________________ PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: ______________________________

TEST DESCRIPTION : ALT. (max/min) ______ / ______ km, INCL. ______ deg, TIME ______ hr

BENEFIT OF SPACE TEST: ______________________________

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. ______ OPERATIONS/DURATION ______ / ______

SPECIAL GROUND FACILITIES: ______________________________

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: ______________________________

TEST DESCRIPTION/REQUIREMENTS: ______________________________

SPECIAL GROUND FACILITIES: ______________________________

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ______________________________

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	SPACE TEST OPTION							GROUND TEST OPTION						
CY							COST ($)							COST ($)
1. ANALYSIS 2. DESIGN 3. MFG & C/O 4. TEST & EVAL														
TECH NEED DATE														
	GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

F 1 (1DR 2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Bg-5
PAGE 1

1. **REF. NO.** **PREP DATE** **REV DATE** **LTR**
CATEGORY

2. **TITLE** He II Storage and Utilization

3. **TECHNOLOGY ADVANCEMENT REQUIRED**

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
2	2	7

Develop a dewar capable of storing, venting, and withdrawing He II for distribution to a single or combination of scientific intruments or experiments. The withdrawal and distribution system may require the development of temperature-modulated porous plugs and/or helium heat pipes.

4. **SCHEDULE REQUIREMENTS** **FIRST PAYLOAD FLIGHT DATE** 1982
PAYLOAD DEVELOPMENT LEAD TIME 3 **YEARS. TECHNOLOGY NEED DATE** 1979

5. **BENEFIT OF ADVANCEMENT** **NUMBER OF PAYLOADS**

TECHNICAL BENEFITS Many future experiments will require He II cooling (2.2°K), but for a variety of reasons cannot be directly immersed within the dewar of He II.

POTENTIAL COST BENEFITS Distribution from a single dewar eliminates the need for individual dewars with each instrument.

ESTIMATED COST SAVINGS $

6. **RISK IN TECHNOLOGY ADVANCEMENT**

TECHNICAL PROBLEMS He II transfer systems using porous plugs based on the thermo-mechanical and mechano-caloric effects ard helium heat pipes have yet to lie developed and tested in the laboratory.

REQUIRED SUPPORTING TECHNOLOGIES He II behavior in 0-g

7. **REFERENCE DOCUMENTS/COMMENTS**

FT (TDR-1) 7/75

TITLE ____________________ NO. ______

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: ____________________

TEST DESCRIPTION: ALT. (max/min) ______ / ______ km, INCL. ______ deg, TIME ______ hr

BENEFIT OF SPACE TEST: ____________________

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. ______ OPERATIONS/DURATION ______ / ______

SPECIAL GROUND FACILITIES: ____________________

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: ____________________

TEST DESCRIPTION/REQUIREMENTS: ____________________

SPECIAL GROUND FACILITIES: ____________________

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____________________

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS 2. DESIGN 3. MFG & C/O 4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

F1 (1DR 2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Bg-6
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY ______

2. TITLE ^{3}He/^{4}He Dilution Refrigerator - Operable in 0-g

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Develop a ^{3}He/^{4}He dilution refrigerator which is capable of continuously producing, in 0-g for periods up to 30 days, temperatures in the mK range.

No other methods exist for continuously producing mK temperatures. For example, the adiabatic demagnetization of paramagnetic salt is basically a single-cycle method of cooling and pumping and ^{3}He and ^{4}He can only produce, at least, temperatures of 0.5° and 0.3°K.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1981
PAYLOAD DEVELOPMENT LEAD TIME 2 YEARS. TECHNOLOGY NEED DATE 1979

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS Ultimate sensitivity of advanced detectors (e.g., TR, etc.) depends on their operation at mK temperatures. Some physics experiments in space, especially solid-state, may also require mK temperatures.

POTENTIAL COST BENEFITS Integration time for a detector decreases as the square of the sensitivity, therefore allowing significantly more data to be gathered in a single flight.

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Current dilution refrigerators depend on gravity for separation of the ^{3}He and ^{4}He phases in the mixing chamber and still. Alternate means of separation must be developed.

REQUIRED SUPPORTING TECHNOLOGIES He^{II} storage and utilization

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE ______________________________ NO. ________

______________________________ PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: ______________________________

TEST DESCRIPTION: ALT. (max/min) ______ / ______ km, INCL. ______ deg, TIME ______ hr

BENEFIT OF SPACE TEST: ______________________________

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. ______ OPERATIONS/DURATION ______ / ______

SPECIAL GROUND FACILITIES: ______________________________

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: ______________________________

TEST DESCRIPTION/REQUIREMENTS: ______________________________

SPECIAL GROUND FACILITIES: ______________________________

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ______________________________

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION							GROUND TEST OPTION						
								COST ($)							COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

F 1 (1 DR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Bg-7
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY ______

2. TITLE Magnetic Refrigeration - Demagnetization of Rare Earth Salts

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
3	4	7

Magnetic refrigeration techniques, currently being developed in the laboratory for use with superconducting magnets, needs to be developed and demonstrated in 0-g for cooling applications in the 4-20°K temperature range.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1984
PAYLOAD DEVELOPMENT LEAD TIME 2 YEARS. TECHNOLOGY NEED DATE 1982

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS Demagnetization of rare earth salts potentially offer efficiencies approaching Carnot efficiency. Many experiments and detectors require temperatures in the 4-20°K range.

POTENTIAL COST BENEFITS Increased efficiency results in lower power requirements.

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Technique has only been demonstrated in the laboratory near room temperature. Investigation of additional material with Curie Points between room temperature and 4°K must be completed.

REQUIRED SUPPORTING TECHNOLOGIES Venting of fluids in 0-g Cryogenics

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE ______________________________ NO. ________

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: ______________________________

TEST DESCRIPTION : ALT. (max/min) ______ / ______ km, INCL. ______ deg, TIME ______ hr

BENEFIT OF SPACE TEST: ______________________________

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. ______ OPERATIONS/DURATION ______ / ______

SPECIAL GROUND FACILITIES: ______________________________

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: ______________________________

TEST DESCRIPTION/REQUIREMENTS: ______________________________

SPECIAL GROUND FACILITIES: ______________________________

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ______________________________

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION							GROUND TEST OPTION						
								COST ($)							COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

F 1 (1DR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. Bg-8
PAGE 1

1. REF. NO. 12.2 **PREP DATE** 7/23/75 **REV DATE** ____ **LTR** ____
CATEGORY ____

2. TITLE Closed Cycle Helium Refrigeration Unit

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Provide a LHe closed cycle refrigeration unit to produce temperatures of 1 to 4 degrees Kelvin for loads up to one watt and periods from 7 days (sortie payload) to 3 years (automated payloads).

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** ____
PAYLOAD DEVELOPMENT LEAD TIME 1.5 **YEARS. TECHNOLOGY NEED DATE** ____

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** 6

TECHNICAL BENEFITS Closed cycle system will permit long missions without the need for resupply or large dewars. Weight and volume savings will be realized through the use of compact refrigeration units in place of large storage devices.

POTENTIAL COST BENEFITS Savings will be realized through the elimination of resupply missions for automated payloads.

ESTIMATED COST SAVINGS $ 12 M

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS (1) Design, fabrication and quality control to permit high reliability throughout long duration missions; (2) attainment of temperatures below 10K using compact recycling units, and (3) high power consumption.

REQUIRED SUPPORTING TECHNOLOGIES Future Payload Technology Requirements Study, Report #CASD-NAS-75-004, June 1975. (Taken directly from "Future Payload Technology - Space Testing and Development Requirements", Preliminary Report, 5 August 1975.)

7. REFERENCE DOCUMENTS/COMMENTS

FT (TDR-1) 7/75

TITLE Prototype Liquid Helium Refrigeration

NO. Bg-8
PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Prototype Liquid Helium Refrigeration Unit

TEST DESCRIPTION: ALT. (max/min) ANY / ANY km, INCL. ANY deg, TIME 10 hr

Performance check under active orbital operational conditions

BENEFIT OF SPACE TEST: Unit will be tested under actual environmental conditions, particularly the loading during boost phase.

EQUIPMENT: WEIGHT 227 kg, SIZE 1.0 X 0.88 X 0.88 m, POWER 2.0 kW

POINTING N/A STABILITY N/A DATA 600 BPS

ORIENTATION ANY CREW: NO. 1 OPERATIONS/DURATION 2 / 1 hr

SPECIAL GROUND FACILITIES: Acoustical/vibration facility

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE 0.8

9. GROUND TEST OPTION TEST ARTICLE: Prototype Liquid Helium Refrigeration Unit

TEST DESCRIPTION/REQUIREMENTS: Performance and endurance test before and after simulated boost environment

SPECIAL GROUND FACILITIES: Acoustical/vibration test facility, vacuum test chamber

EXISTING: YES ☒ NO ☐

GROUND TEST LIMITATIONS: Dynamic load simulation is an approximation of the environmental conditions; behavior of LHe in space near zero "g" may be different.

TEST CONFIDENCE 0.8

10. SCHEDULE & COST

TASK	SPACE TEST OPTION COST ($)	GROUND TEST OPTION COST ($)
1. ANALYSIS	0.2M	0.2M
2. DESIGN	0.6M	0.4M
3. MFG & C/O	0.8M	0.6M
4. TEST & EVAL	0.3M	0.4M
TECH NEED DATE		
GRAND TOTAL	1.9M	1.6M

11. VALUE OF SPACE TEST $ 16.4 M (SUM OF PROGRAM COSTS $ 334 M)

12. DOMINANT RISK/TECH PROBLEM

DOMINANT RISK/TECH PROBLEM	COST IMPACT	PROBABILITY
Low efficiencies may necessitate high power requirements.	0.5 M	0.5

COST RISK $ 250 K

F1 (1DR 2) 7/75

APPENDIX C

APPENDIX C

RELATED TECHNOLOGIES NOT EVALUATED BY THERMAL WORKING GROUP

The Thermal Control Working Group addressed its considerations to the technology matrix in the Outlook for Space - A Forecast of Space Technology final draft of July 13, 1975. The storing of matter (See Ref. 3 and Figure C-1) in this matrix specifically refers to temperature control, radiation control, meteoroid protection, life support systems and containment of pressurized fluids as parameters of maintenance of state (survival). The Working Group emphasized only the thermal control area since this represented its basic technological capability; however, it did assess other areas, such as radiation, to the extent that they impact thermal control devices (for example, radiation damage to thermal control coatings). In the Working Group's deliberations, cryogenics, contamination, and spacecraft charging were added to the storing of matter matrix block. It was recognized that still other related areas are of importance to NASA although these were not considered in any detail. Included were environmental design, criteria and thermal vacuum testing. This appendix is dedicated to these areas, other than thermal control, which this working group deems important for OAST to consider, particularly in view of currently declining support for such areas.

CONTAMINATION--Contamination technology includes prediction, sources, transport mechanisms, constituent identification, active and passive protection, and effects. An ultimate objective is the development of contamination monitors, etc. Currently contamination monitoring devices are supported by OMSF whereas a logical program fulfilling OAST responsibilities would indicate that OAST have this responsibility.

OAST provided through FY 74, the R & T base for NASA's contamination effort. OAST support has declined in the past three years from a three-center program of substantial magnitude to a very limited effort at MSFC in FY 74. OAST's R & T base program was terminated in FY 75. LDEF is considering several experiments on contamination; however, there is currently no program office to advocate these potential experiments.

RADIATION EFFECTS--Basic R & T on high energy radiation at the Langley Research Center is NASA's only base effort in this area. It supports applied dosimetry and shielding design studies in OMSF relative to shuttle, etc., in aviation safety relative to high flying aircraft, and in the life sciences area. In the area of radiation, there is still need for definition of natural environments (e.g., for Jupiter) and for transport analysis.

FY 76 funding for continuation of this Langley activity on radiation has not been determined. OAST is considering which OAST office will support it, if indeed it is determined that OAST should support it. The Thermal Control Working Group recognized the potential hazards of high energy radiation to thermal control coatings, insulation, etc., but did not consider it within its scope to propose space experiments on basic radiation effects. LDEF is currently assessing radiation experiments; however, an OAST program office will be required to advocate such experiments.

METEOROID PROTECTION--OAST has, in the past decade, conducted extensive R & T on meteoroid environments and structural protection of spacecraft from micro-meteoroid impact. The MTS (Meteoroid Technology Satellite) flight program essentially completed OAST's R & T in this area in FY 74.

For the past two years OAST emphasis has been focused on space debris and its hazards, particularly to earth orbital spacecraft. Because of limitations of ground based radar to resolve the debris population in earth orbital environments, a space flight experiment has been proposed and rejected. It is not now possible to fly such a space debris experiment to provide input for early shuttle flights.

The Thermal Control Working Group did not consider potential shuttle payload experiments on space debris.

The TC Working Group did discuss the need for micrometeoroid studies in the planet Saturn environment but did not address the potential for flight experiments. LDEF is considering experiments on micrometeoroids and space debris.

ENVIRONMENTAL DESIGN CRITERIA--The objective of this program is to provide current and future missions with up-to-date knowledge of the space environment including planetary environment for use in design of spacecraft and missions. The value of this program has been attested to by numerous spacecraft and mission designers.

OAST supported a major program in this area which reached a climax in FY 71. Since that time a three-center activity has declined to a clean-up action by GSFC in FY 75. The program is not being supported in FY 76. Consequently, previous monographs on space environmental design criteria are not being updated and no new monographs are being initiated.

The Thermal Control Working Group considered this subject only briefly, insofar as it refers to the understanding of the natural environment of space. In the future it appears that the collection and evaluation of such data will be the responsibility of each mission project manager.

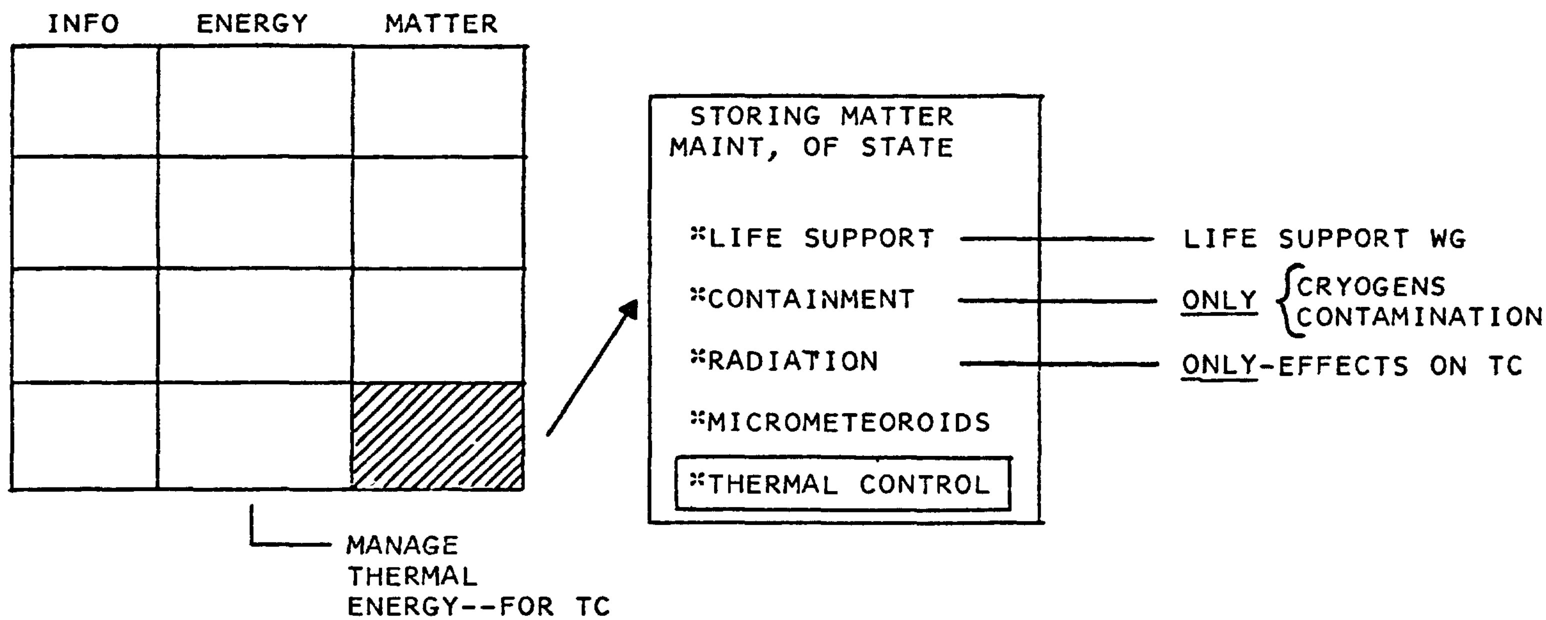
THERMAL VACUUM TESTING--Ground based facilities can provide knowledge of materials and equipment operations in space. These space simulation facilities provide the basis by which decisions requiring space verification are made.

OAST has provided extensive facilities to perform such studies in the past. In FY 72 this major thermal vacuum testing program was terminated. Although most facilities are still intact, the availability of these facilities for studies of materials and devices is uncertain. For one thing, the up-grading of these facilities to meet current requirements is not being done to the knowledge of the Thermal Control Working Group.

If OAST is to provide the NASA R & T needed by OSS, OA, and OMSF, then areas such as those described herein should not be terminated without serious assessment of potential future requirements.

THERMAL CONTROL
SCOPE

(OFS MATRIX)



TCWG-4

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