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MICROGRAVITY FLUID MANAGEMENT IN TWO-PHASE THERMAL SYSTEMS

A NASA-JSC PERSPECTIVE

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Initial trade studies by NASA Phase B Space Station contractors have indicated that in comparison to an all liquid single phase system, a two-phase liquid/vapor thermal control system requires significantly lower pumping power, demonstrates more isothermal control characteristics, and allows greater operational flexibility in heat load placement.

Subsequently, as a function of JSC's Work Package responsibility for thermal management of Space Station equipment external to the pressurized modules, prototype development programs were initiated on the Two-Phase Thermal Bus System (TBS) and the Space Erectable Radiator System (SERS). Proposed use of these biphasic fluid systems has made it necessary for NASA and contractor engineers to better understand liquid/vapor dynamics and heat transfer characteristics during fluid change of phase in the microgravity environment.

JSC currently has several programs underway to enhance the understanding of two-phase fluid flow characteristics. The objective of one of these programs (sponsored by the Microgravity Science and Applications Division at NASA-Headquarters) is to design, fabricate, and fly a two-phase flow regime mapping experiment in the Shuttle vehicle mid-deck. Another program, sponsored by OAST, will involve the testing of a two-phase thermal transport loop aboard the KC-135 reduced gravity aircraft to identify system implications of pressure drop variation as a function of the flow quality and flow regime present in a representative thermal system. Information from each of these experiments will be used in designing a flight test article of the Prototype TBS which is to be scheduled to fly as a payload aboard the Shuttle vehicle. These experiment results will ultimately allow the Space Station Thermal Management System to be designed with engineering confidence and with increased operational efficiency.

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During the last five years, NASA-JSC has taken an active role in the development of thermal technology for spacecraft temperature control using heat pipes and two-phase fluid heat transport. This activity has highlighted the potential benefits to be realized by the utilization of two-phase fluid technology and has helped to establish thermal management as a major spacecraft design parameter. JSC's accomplishments in the thermal area were recognized by NASA and the Space Station Program by the delegation of significant responsibilities for Thermal Management of the Space Station. Phase B trade studies have substantiated the initial conclusions of NASA engineers and have emphasized the importance of developing a viable Two-Phase Thermal Management System (TPTMS) for the Space Station vehicle.

SPACE STATION THERMAL MANAGEMENT

- 0 JSC SPACE STATION WORK PACKAGE (WP 2) THERMAL RESPONSIBILITIES AS OF AUG. '86
 - OVERALL THERMAL SYSTEM ARCHITECTURE AND END-TO-END VERIFICATION
 - PRODUCTION OF FUNCTIONAL COMPONENTS FOR "OUTSIDE ELEMENTS"
 - PLATFORM THERMAL CONTROL SYSTEM (IN COOPERATION WITH NASA-GSFC)

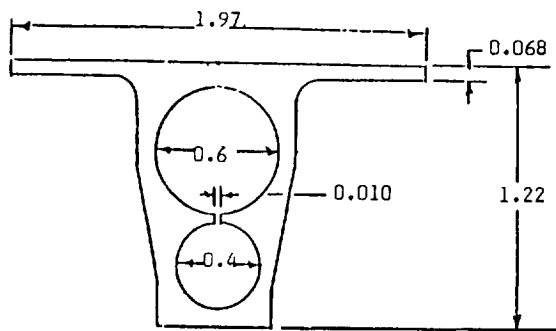
- 0 WP2 PHASE B TRADE STUDY RESULTS INDICATE TWO-PHASE THERMAL SYSTEMS OFFER ADVANTAGES OVER SINGLE-PHASE SYSTEMS:
 - REDUCED PUMP POWER
 - ISOTHERMAL CHARACTERISTICS
 - FLEXIBLE HEAT LOAD PLACEMENT

Figure 1

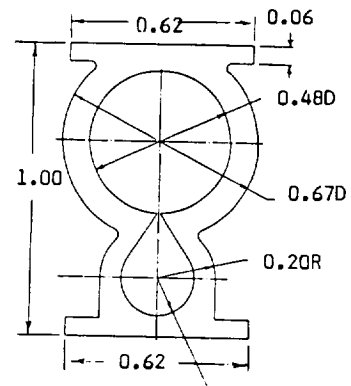
In an effort to bring the technology forward from the point of "proof-of-concept," development contracts were initiated to establish "prototype" systems concepts and to focus the hardware designs on the Space Station specifically. Parallel contracts were awarded to Grumman and LTV (with Lockheed as a subcontractor) to define space erectable radiator designs and to Grumman and Boeing (with Sundstrand as a subcontractor) to define two-phase thermal transport system designs. Although both the heat pipe radiators and thermal bus will utilize ammonia in liquid and vapor states, microgravity effects will be more significantly manifested in the thermal bus system. Therefore, the thermal transport system will be the focus of this discussion.

PROTOTYPE THERMAL MANAGEMENT SYSTEMS

- 0 SPACE ERECTABLE RADIATORS UTILIZING HEAT PIPES
 - GRUMMAN MONOGROOVE
 - LTV/LOCKHEED TAPERED ARTERY



GRUMMAN HEAT PIPE



LTV/LOCKHEED HEAT PIPE

- 0 TWO-PHASE THERMAL BUS
 - GRUMMAN SEPARATED PHASE, PUMPED ASSISTED CAPILLARY SYSTEM
 - BOEING/SUNDSTRAND INTEGRATED LIQUID/VAPOR PHASE SYSTEM

Figure 2

The Boeing Prototype Thermal Bus concept utilizes a Sundstrand Rotary Fluid Management Device (RFMD), accumulator, and back-pressure regulator valve (BPRV) to control liquid inventory to the evaporators. Varying quality liquid/vapor mixtures (changing as a function of heat load) exit from the evaporators and are returned to the RFMD pump. There, the rotating drum of the pump separates liquid from vapor by centrifugal forces. This causes liquid to be located at the wall of the drum, enabling a pressure head at a pitot pump intake probe. The separated liquid is again pumped to the evaporator sites. Vapor, located in the center core of the drum, exits through the BPRV to be condensed at the radiator interface using shear flow control of the condensed liquid layer thickness. The condensate is returned to the pump and regenerated to saturation temperature. The unique features of this system are the absence of active flow control hardware for the evaporators and the presence of two-phase fluid flow in the "wet" return line.

BOEING PROTOTYPE THERMAL BUS SYSTEM SCHEMATIC

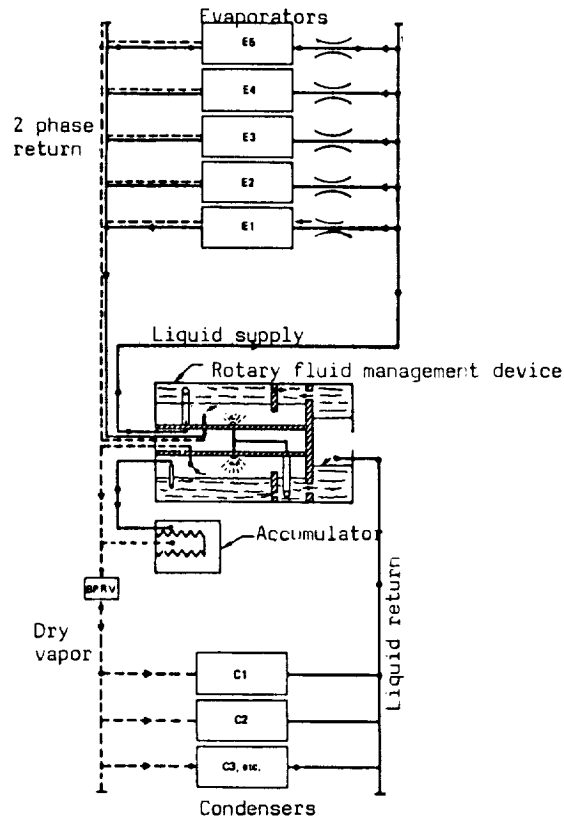


Figure 3

Grumman eludes potential problems of fluid management in two-phase transport lines by controlling flow into the evaporators, causing only high quality vapor to be emitted. Liquid is admitted by solenoid valves to reservoirs upstream of the evaporators and is wicked by capillary forces from the reservoirs into the evaporator plates. The "dry" vapor exits the evaporators, condenses at the radiator interface, is drained by capillary action, and exits as sub-cooled liquid. The amount of sub-cooling that is required is a function of pump and system characteristics. A pump which is insensitive to cavitation will not require as much sub-cooling (to prevent vapor formation at the pump inlet). The sub-cooled liquid exiting the pump will enter a regenerator to bring the fluid back up to the saturation temperature before being admitted to the evaporator reservoirs. In actual practice the regenerator function may not be required or may be de-tuned to maintain sub-cooling for proper valve functioning. The advantages of this system are predictability (due to single phase liquid and vapor transport lines), high evaporative heat transfer coefficients, and small pump power requirements.

GRUMMAN PROTOTYPE THERMAL BUS SYSTEM SCHEMATIC

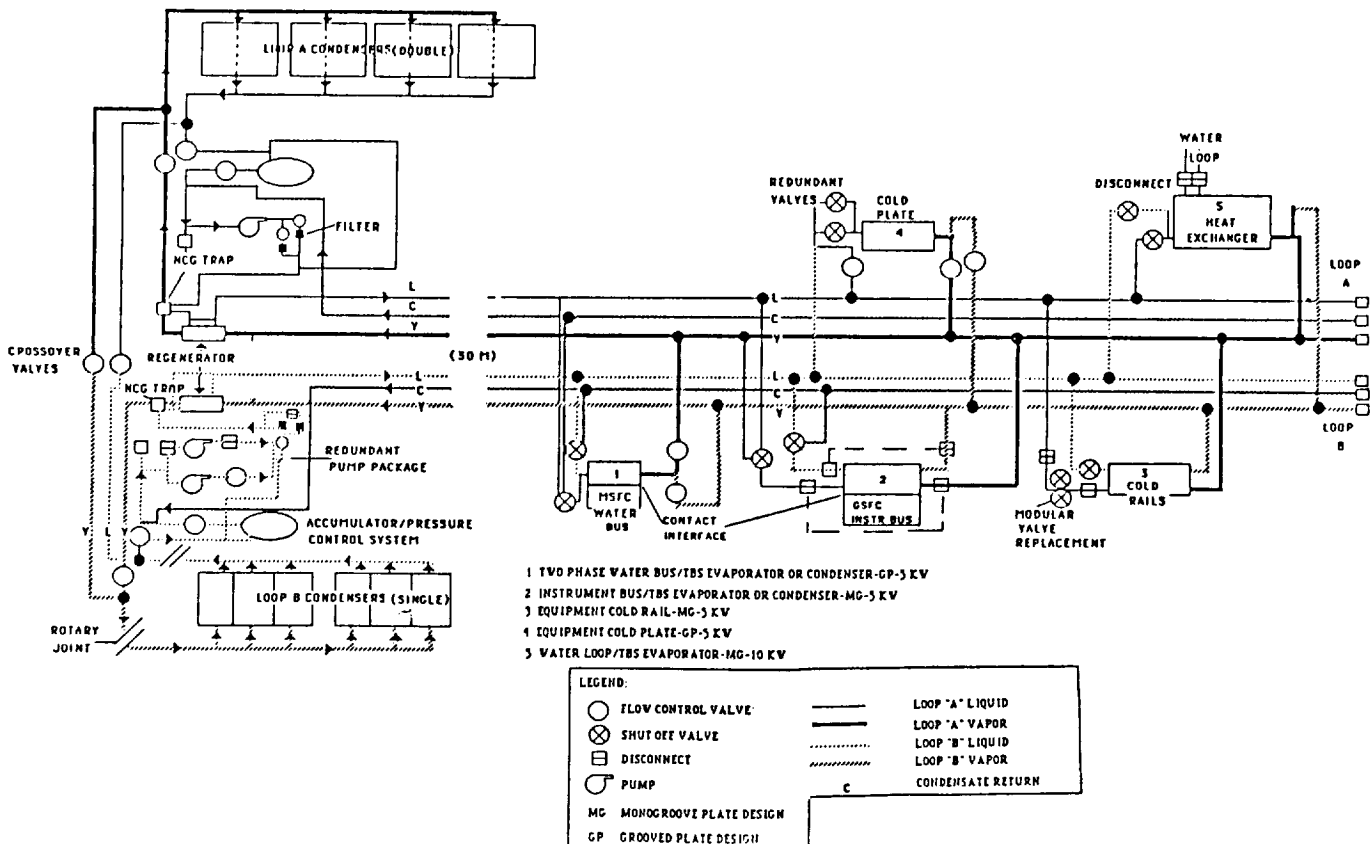


Figure 4

The design of the two-phase heat acquisition and transport system for the Space Station will be accomplished while trying to minimize the effects of gravity (or the absence thereof) on system performance. There are, however, certain aspects of fluid behavior which must be well understood to ensure adequate and efficient hardware design. Although several of these areas have been addressed in previous investigations, none has been sufficiently researched in the microgravity environment to establish a credible data base. Therefore, a continued and vigorous research program must be established so that fundamental knowledge keeps pace with, and conceivably precedes, technology development.

TWO-PHASE FLUID TECHNOLOGY REQUIREMENTS IN MICROGRAVITY

- 0 FLOW BEHAVIOR (LIQUID/VAPOR DYNAMICS)

- 0 PRESSURE DROP IN TWO-PHASE FLOWS OF VARYING QUALITIES

- 0 CONDENSATION/BOILING HEAT TRANSFER COEFFICIENTS

- 0 CHARACTERISTICS OF PHASE SEPARATION

Figure 5

An initial step in the direction of establishing a significant data base for fluid flow behavior has been accomplished by NASA-JSC in conjunction with NASA-LeRC. These two NASA centers have undertaken tentative efforts to define liquid/vapor flow regimes in the microgravity environment and to identify accompanying flow characteristics, such as pressure drop. LeRC has begun drop tower experiments to this end, and JSC has undertaken an effort to define a potential Shuttle mid-deck flight experiment. This latter activity has been funded by the Microgravity Science and Research Division at NASA-Headquarters, but due to the structure of that program, further progress may be delayed.

MULTI-PHASE FLUID BEHAVIOR IN THE MICROGRAVITY ENVIRONMENT

- O CURRENT TASK: TWO PHASE FLOW REGIME MAPPING
 - ACCOMPLISH MAPPING OF FLUID FLOW REGIMES IN REDUCED GRAVITY ENVIRONMENT
 - GRANT WITH DR.'s KESHOCK AND ARIMILLI AT THE UNIVERSITY OF TENNESSEE TO DEFINE SHUTTLE MID DECK FLIGHT EXPERIMENT
 - INITIATED JAN. '86, PRELIMINARY STUDIES HAVE BEEN ACCOMPLISHED
 - FUNDING SOURCE: MICROGRAVITY RESEARCH PROGRAM

- O SUBSEQUENT TASKS:
 - CONDENSATION/BOILING HEAT TRANSFER COEFFICIENTS
 - LIQUID/VAPOR SEPARATION TECHNIQUES

Figure 6

In an effort to obtain near-term information on the operation of two-phase fluid thermal management systems in a reduced gravity environment, JSC has contracted a task with Sundstrand to develop a test stand for incorporation of unique two-phase system components. This test stand will allow ground and KC-135 testing of an integrated advanced thermal control system and will enable photography and measurement of two-phase flow regimes with their associated pressure drops. The objective of the experiment is to confirm the operational characteristics of the unique Rotary Fluid Management Device (RFMD) concept which Sundstrand has refined under contract to JSC. This system has potential for being used in the Space Station TMS, but some uncertainty exists within the technical community as to the behavior of liquid/vapor flow regimes in the reduced gravity environment. NASA-LeRC has added supplemental funds to the effort to gather data on the shear flow controlled condensation of vapor as it would apply to a Sundstrand Organic Rankin Power System.

TWO-PHASE THERMAL MANAGEMENT SYSTEM (TPTMS) COMPONENT DEVELOPMENT

- O OBJECTIVE IS TO DESIGN AND FABRICATE TEST STAND INCORPORATING PROTOTYPE TPTMS COMPONENTS TO BE TESTED IN AMBIENT AND REDUCED GRAVITY ENVIRONMENTS
 - EVALUATE TWO-PHASE FLOW REGIMES AND PRESSURE DROPS
 - EVALUATE VAPOR CONDENSATION PROCESS IN SHEAR FLOW

- O CONTRACT WITH SUNDSTRAND ENERGY SYSTEMS FOR COMPONENT AND TEST STAND DEVELOPMENT
 - DR. KESHOCK ACTING AS CONSULTANT AND ACCOMPLISHING DATA EVALUATION
 - TEST STAND TO BE DELIVERED IN SEPT. '86; KC-135 FLIGHT SCHEDULED FOR NOV.

- O FUNDING SOURCE: OAST AND LERC SPACE STATION ADVANCED DEVELOPMENT

Figure 7

The Sundstrand TPTMS test stand will consist of the RFMD pump, accumulator, BPRV, swirl flow evaporator, and shear flow controlled condenser. An approximately 20-foot-long section of clear two-phase fluid transport line will enable high speed photography to be accomplished during ground and reduced gravity testing. The transparent line will include a 180° bend to assess its affect on fluid flow characteristics. Additionally, the condenser will have a clear outer housing to allow photography of the condensation process. Monitoring of the numerous measurement locations will be accomplished using a 14-channel analog recorder and a 50-channel desk-top type computer, which will be loaded into equipment racks for the KC-135 flight. Three flight days are planned, each of 2 1/2 to 3 hours of duration. Results of the testing are intended to confirm Sundstrand performance predictions of their TMS concept, provide insight into liquid/vapor interactions under varying flow conditions, and verify performance of shear flow controlled condensation.

SUNDSTRAND KC-135 TPTMS TEST STAND SCHEMATIC

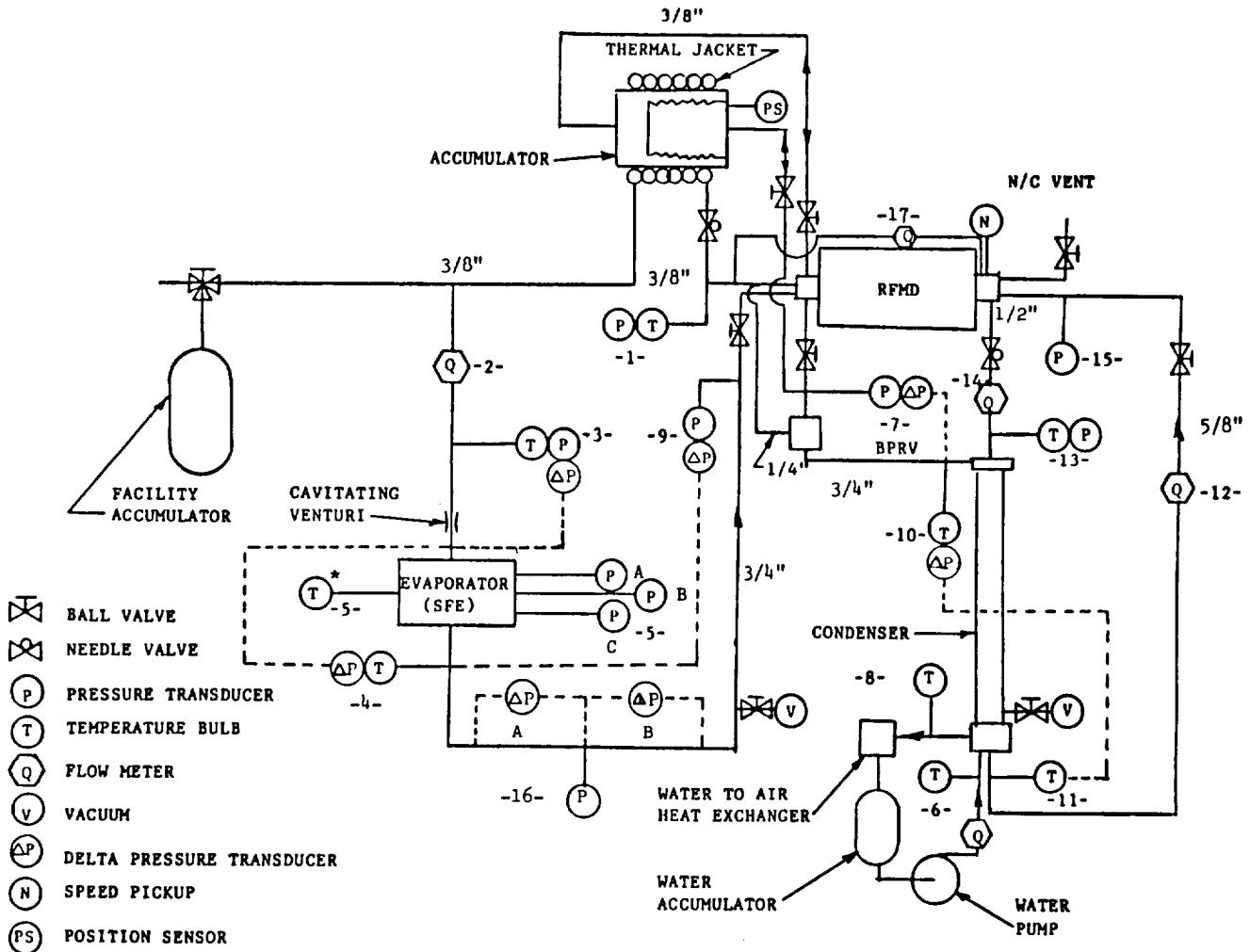


Figure 8

The ultimate step in demonstration and verification of the two-phase TMS will be accomplished through flight testing aboard the Shuttle vehicle. NASA-JSC currently has a three-phase approach to the flight experiment program demonstrating thermal performance and assembly techniques of heat pipe radiator elements and verifying thermal bus operational performance. NASA-GSFC had originally planned a TEMP 2C flight experiment to evaluate operation of either a capillary pumped Loop (CPL) or pumped two-phase (PTP) loop to be used for thermal control of the payloads and attached equipment on the Space Station. This experiment has subsequently been integrated with the TEMP 3C experiment to fly as a single payload aboard the Shuttle vehicle. Furthermore, there is currently a study being accomplished at JSC to assess the benefits or detriments of combining TEMP 3B and TEMP 2C/3C. Successful completion of these flight experiments will insure confidence in the design of hardware to be used by the Space Station.

JSC THERMAL ENERGY MANAGEMENT PROCESSES (TEMP3) SHUTTLE FLIGHT EXPERIMENTS

- O DEMONSTRATE TWO-PHASE THERMAL TECHNOLOGIES IN A SPACE ENVIRONMENT
 - TEMP 3A: HEAT PIPE RADIATOR ELEMENT THERMAL PERFORMANCE
 - TEMP 3B: HEAT PIPE RADIATOR ASSEMBLY
 - TEMP 3C: TWO-PHASE THERMAL SYSTEM PERFORMANCE

- O UTILIZE JSC CONTRACTED HARDWARE DEVELOPED UNDER SPACE STATION ADVANCED DEVELOPMENT PROGRAMS

- O VERIFY HEAT TRANSFER/TRANSPORT CAPABILITIES ON-ORBIT

- O STATUS:
 - TEMP 3A MANIFESTED FOR FLIGHT
 - TEMP 3B HARDWARE AND INTEGRATION EFFORT IN PROGRESS
 - TEMP 3C EXPERIMENT DEFINED AND CONTRACT INITIATED

- O FUNDING SOURCE: SPACE STATION PROGRAM

Figure 9

SUMMARY

Utilization of multiphase fluids (liquid/vapor) in the Thermal Management System for Space Station has numerous potential benefits. Reduced pumping power requirements, isothermal control characteristics, and flexibility in placement of heat loads are the most attractive of these benefits. Although the technology has been demonstrated in ground testing, numerous questions remain as to fluid behavior in the microgravity environment. These uncertainties include: a) fluid flow regimes and associated pressure drops; and b) evaporation, boiling, and condensation heat transfer coefficients. Systems can be designed conservatively to compensate for these uncertainties; however, for optimization of components, more detailed knowledge is required.

Activities have been initiated by NASA to obtain the required design information by utilizing the JSC reduced gravity aircraft and flight experiments aboard the Shuttle. These activities should markedly increase the data base for future design endeavors but a wealth of information on multiphase fluid behavior is still required to ensure adequate understanding of phenomena unique to the microgravity environment. It is suggested and recommended that increased activity in the area be initiated to further substantiate this technology for spacecraft thermal control.

- O TWO-PHASE FLUID FOR SPACECRAFT THERMAL MANAGEMENT IS TECHNICALLY ADVISABLE

- O TECHNOLOGY REQUIREMENTS HAVE BEEN IDENTIFIED

- O PRELIMINARY STEPS HAVE BEEN TAKEN TO OBTAIN REQUIRED INFORMATION
 - MICROGRAVITY FLOW REGIME DEFINITION
 - KC-135 FLIGHT EXPERIMENTS
 - TEMP SHUTTLE FLIGHT EXPERIMENTS

- O MICROGRAVITY INFORMATION STILL REQUIRED IN GREATER DEPTH/DETAIL
 - FUNDAMENTAL TWO-PHASE FLUID BEHAVIOR
 - HEAT TRANSFER COEFFICIENTS
 - PHASE-SEPARATION TECHNIQUES

Figure 10

