N93-12459

# ADVANCED TWO-PHASE HEAT TRANSFER SYSTEMS

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Future large spacecraft, such as the EOS platforms, will require a significantly more capable thermal control system than is possible with current "passive" technology. Temperatures must be controlled much more tightly over a larger surface area. Numerous heat load sources will often be located inside the body of the spacecraft without a good view to space. Power levels and flux densities may be higher than can be accommodated with traditional technology. Integration and ground testing will almost certainly be much more difficult with such larger, more complex spacecraft. For these and similar reasons the Goddard Space Flight Center (GSFC) has been developing a new, more capable thermal control technology called capillary pumped loops (CPLs). CPLs represent an evolutionary improvement over heat pipes; they can transport much greater quantities of heat over much longer distances and can serve numerous heat load sources. In addition, CPLs can be fabricated into large cold plates that can be held to tight thermal gradients. Development of this technology began in the early 1980's and is now reaching maturity. CLPs have recently been baselined for the EOS-AM platform (1997 launch) and the COMET spacecraft (1992 launch). This presentation describes this new technology and its applications. Most of the viewgraphs are self descriptive. For those that are less clear additional comments are provided.

## OBJECTIVES

- SUMMARIZE HISTORY OF TWO-PHASE TECHNOLOGY DEVELOPMENT AT GSFC
- DETAIL STATUS OF CURRENT TWO-PHASE THERMAL CONTROL TECHNOLOGY
- BRIEFLY DESCRIBE GSFC TEST AND DEVELOPMENT PROGRAM WHICH WILL MATURE THE TECHNOLOGY

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# TWO-PHASE THERMAL TECHNOLOGY

## WHAT IS A CPL?

A CAPILLARY PUMP LOOP (CPL) IS A TWO-PHASE THERMAL CONTROL SYSTEM WHICH USES CAPILLARY FORCES TO

- TRANSFER HIGH HEAT LOADS OVER LONG DISTANCES
- OPERATE WITH SMALL TEMPERATURE DIFFERENTIALS BETWEEN HEAT SOURCES AND HEAT SINKS
- PROVIDE TIGHT TEMPERATURE CONTROL FOR HEAT SOURCES

A CPL SYSTEM CONSISTS OF

- EVAPORATOR ZONES
- A VAPOR TRANSPORT LINE
- CONDENSER (RADIATOR) ZONES
- A LIQUID TRANSPORT LINE
- A TWO PHASE ACCUMULATOR/RESERVOIR

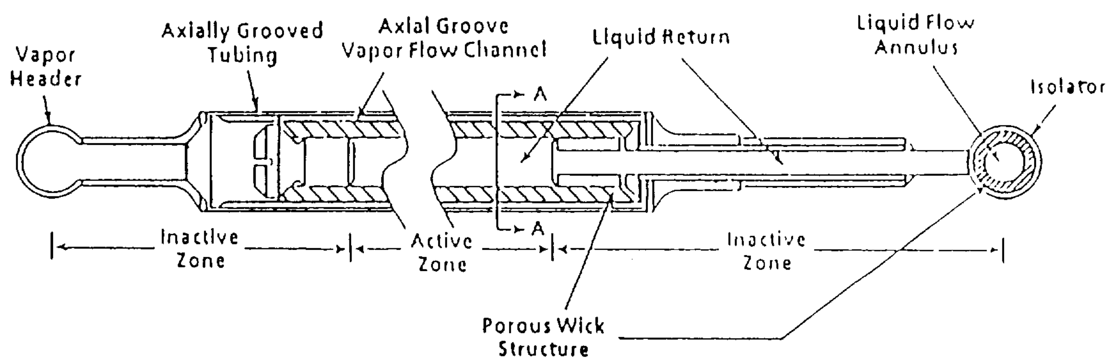
## HOW DOES A CAPILLARY PUMP WORK?

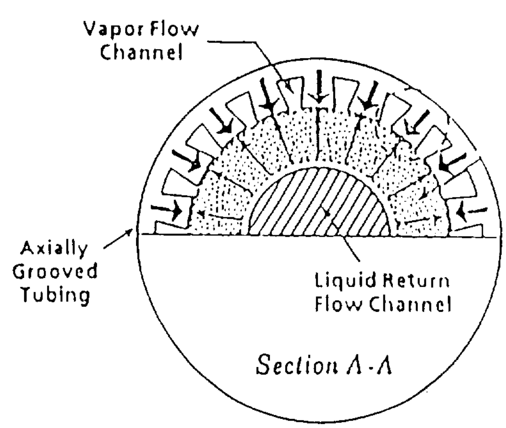
- A POROUS WICK MATERIAL IS USED TO MAINTAIN THE WORKING FLUID AT THE HEAT TRANSFER SURFACE
- AS THE WORKING FLUID EVAPORATES, SURFACE TENSION FORCES CREATE A PRESSURE HEAD IN THE WICK, WHICH IN TURN DRIVES THE WORKING FLUID AROUND THE SYSTEM

$$\text{PRESSURE HEAD} = \frac{2 \times \text{SURFACE TENSION}}{\text{EFFECTIVE RADIUS}}$$

- EVAPORATION OF THE WORKING FLUID COOLS WHATEVER IS ATTACHED TO THE CAPILLARY PUMP

## CAPILLARY PUMP

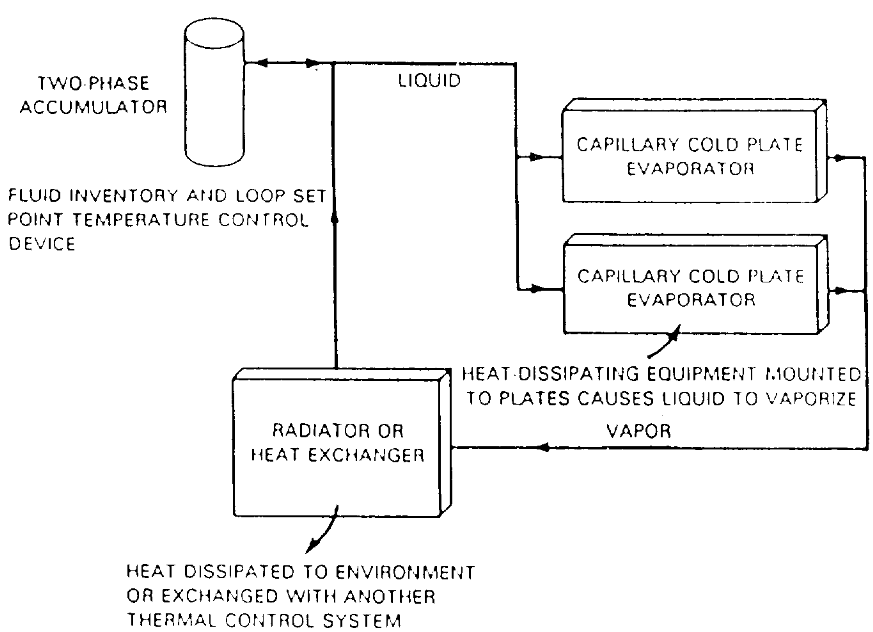


# HOW DOES A CPL SYSTEM WORK?

- HEAT DISSIPATING COMPONENTS ARE ATTACHED TO COLD PLATES WHICH CONTAIN A NUMBER OF CAPILLARY PUMPS
- COMPONENTS ARE KEPT COOL THROUGH EVAPORATION OF THE WORKING FLUID
- THE VAPOR GENERATED IN THE COLD PLATES IS TRANSPORTED TO A HEAT EXCHANGER OR RADIATOR, WHERE IT IS CONDENSED. IN THIS WAY, THE HEAT IS DISSIPATED TO ANOTHER SYSTEM OR TO SPACE
- THE CONDENSED FLUID IS RETURNED TO THE COLD PLATES BY THE CAPILLARY PUMPING IN THE COLD PLATES AND THE CYCLE CONTINUES
- A TWO-PHASE RESERVOIR IS USED TO CONTROL THE TEMPERATURE AT WHICH EVAPORATION TAKES PLACE (AND THUS THE TEMPERATURE OF THE COMPONENTS BEING COOLED)

# CAPILLARY PUMPED SYSTEMS




UNIQUE EVAPORATOR DESIGN ALLOWS FOR HEAT ACQUISITION AND FLUID PUMPING WITHOUT MOVING PARTS

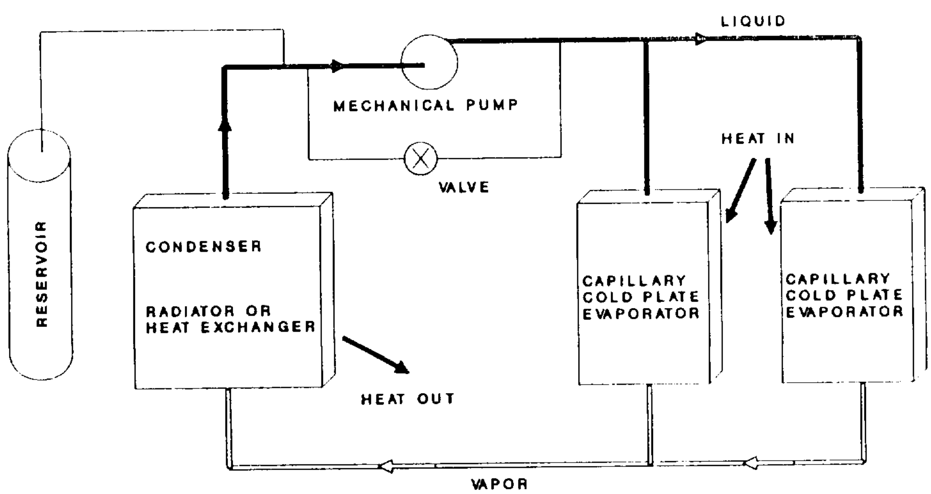
BENEFITS:

- VIBRATION FREE
- HIGH RELIABILITY
- NO EMI

# WHAT IS A HYBRID CPL?

- A HYBRID CPL CONTAINS A MECHANICAL PUMP IN SERIES WITH THE CAPILLARY COLD PLATES
- THE MECHANICAL PUMP CAN BE USED TO:
  - ALLOW GROUND TESTING IN MOST ORIENTATIONS
  - ALLOW THE USE OF HIGHER PRESSURE DROP COMPONENTS IN THE SYSTEM
  - INCREASE THE HEAT TRANSFER CAPACITY OF A CAPILLARY SYSTEM
  - ASSIST IN START-UP AND REPRIMING OF A CAPILLARY SYSTEM

# CAPILLARY/MECHANICALLY PUMPED (HYBRID) LOOP




- CAN OPERATE AS A PURE CAPILLARY PUMP LOOP (CPL), A MECHANICAL-PUMP-ASSISTED CPL, OR AS A MECHANICALLY PUMPED SYSTEM
- INCREASED HEAT TRANSPORT CAPACITY ABOVE THAT FOR A CPL
- MAINTAINS BENEFITS OF PARENT SYSTEM IN EACH OPERATING RANGE
- ALLOWS ONE-G TESTING OF CPL SYSTEMS WITH HIGH TILTS

# CAPILLARY PUMP LOOP
## HISTORY

| DATE | EVENT/SYSTEM |
|---|---|
| LATE 1960'S | - CONCEPT DEVELOPED BY STENGER FOR WATER (LeRC) |
| LATE 1970'S | - REDISCOVERED BY BIENERT<br>- SMALL SCALE CONCEPT DEMONSTRATION DEVELOPED |
| 1982 | - CPL-1: 10 METER TRANSPORT LENGTH USING AMMONIA; 7 kW CAPACITY |
| 1985 | - CPL/GAS FLIGHT EXPERIMENT |
| 1986 | - CPL/HITCHHIKER FLIGHT EXP. |
| 1986 | - CPL-2: SIMILAR IN SIZE TO CPL-1; TESTED AT JSC |
| 1987 | - HIGH POWER SPACECRAFT THERMAL MANAGEMENT SYSTEM: 25-52 kW, 10 METER LENGTH |
| 1990 | - INSTRUMENT THERMAL TEST BED (100W - 10 kW+) |
| 1993 | - CAPL FLIGHT EXPERIMENT |

# CAPILLARY PUMP LOOP
## KNOWN SYSTEMS

- GODDARD -
  - CPL-1
  - CPL-2
  - INSTRUMENT THERMAL TEST BED
  - FLIGHT EXPERIMENTS

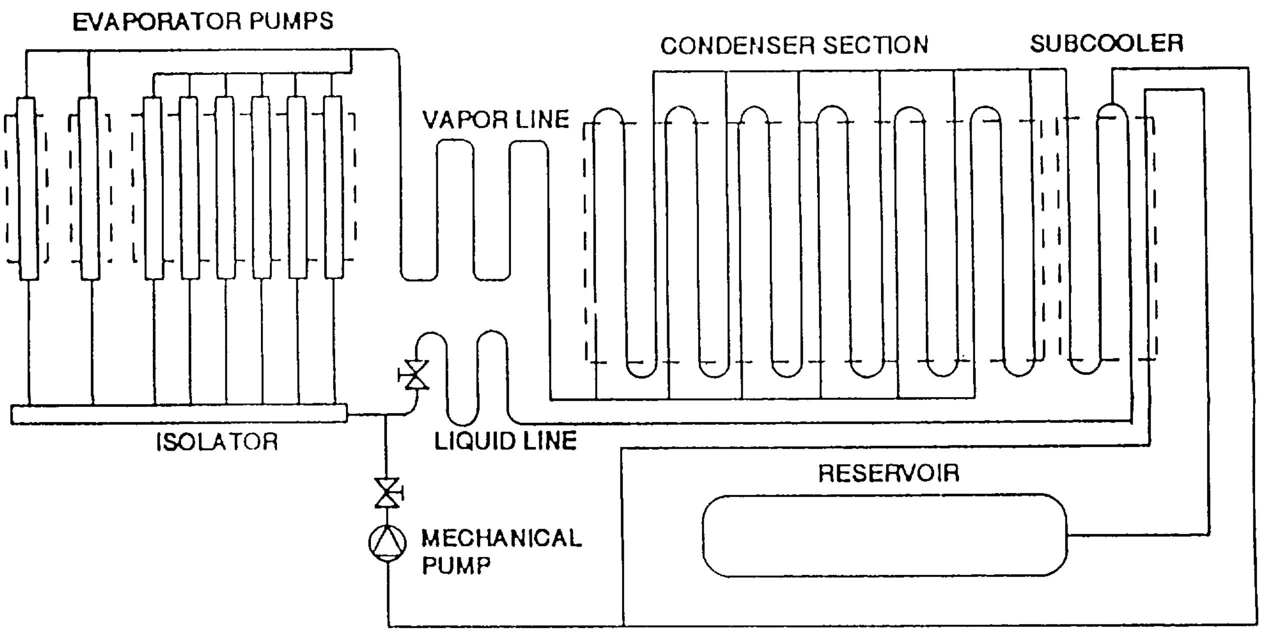
- AIR FORCE
- BOEING
- DYNATHERM CORPORATION
- OAO CORPORATION
- GENERAL ELECTRIC
- MARTIN MARIETTA
- TRW

- ESA - DORNIER SYSTEMS
- UK - BRITISH AEROSPACE
- JAPAN
- USSR

# GSFC GROUND TESTING

## CPL 1 TEST RESULTS
## 1986 - 1989

The CPL I was the first, large scale, operational, ammonia based, two-phase capillary pumped loop. It was initially fabricated in 1984 and was used for a wide variety of testing through 1989. During this time a number of modifications were made, including the addition of a mechanical pump. Use of the mechanical pump creates a "hybrid" mode of operation in which the mechanical pump supplements the capillary pumping of the wicks. This has certain advantages, as are discussed in the following viewgraphs.




CPL-1

# CHARACTERISTICS OF CPL-1
## (CAPILLARY MODE)

- IT WORKED!
- HEAT TRANSPORT LIMIT ABOUT 6.4 KW
- DRYOUT USUAL FAILURE MODE AT 25 C
- DEPRIME USUAL FAILURE MODE AT 45 C
- STARTED-UP RELIABLY IN EARLY LIFE; MORE DIFFICULT AFTER 5 YEARS
- TEMPERATURE OSCILLATIONS RARE

# CPL-2 EVAPORATOR PUMP TESTS

The CPL II represented the second generation design of a capillary pumped loop. Functionally and physically it was very similar to the CPL I. It had the same power capacity (approximately 7 kW), number of evaporator pumps (8), reservoir design (open tank held vertically) and transport length (10 meters). However, the CPL II was less of a brassboard and more of a prototype. It was hard plumbed and made vacuum compatible. In addition, certain design details were changed in the hopes of improving performance.

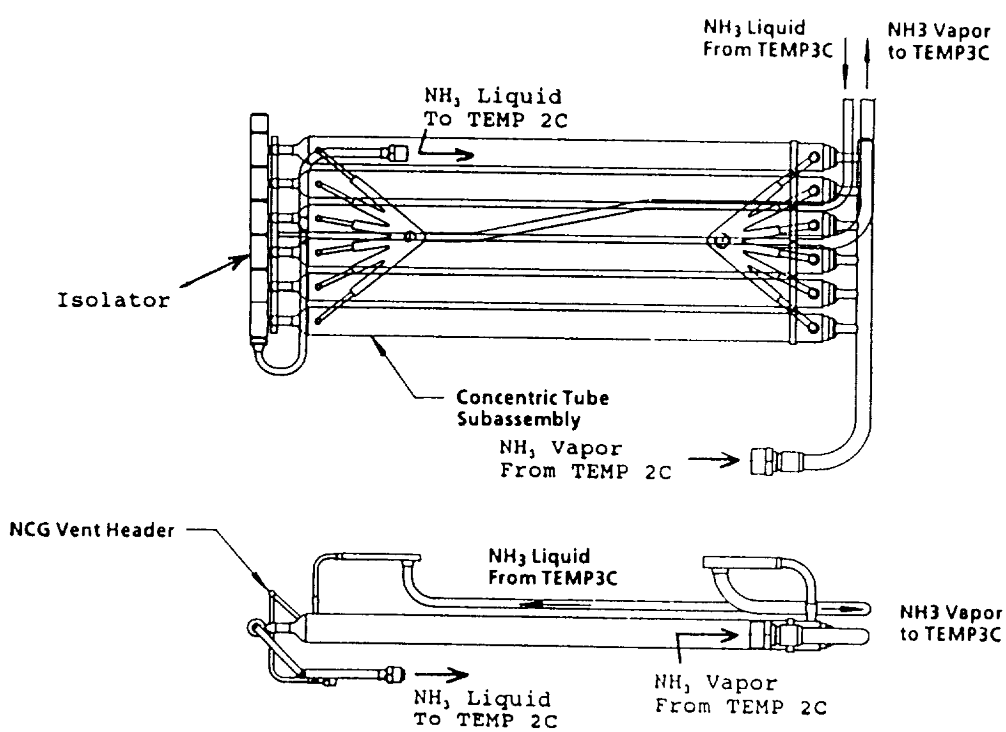
# CHARACTERISTICS OF CPL-11 (CAPILLARY MODE)

- HEAT TRANSPORT LIMIT ABOUT 8.0 KW
- DEPRIMES USUAL FAILURE MODE
- NO DRYOUT EVER SEEN
- TEMPERATURE OSCILLATIONS OCCUR AT LOW POWERS IN SOME PUMPS
- OSCILLATIONS OCCASIONALLY LEAD TO DEPRIMES

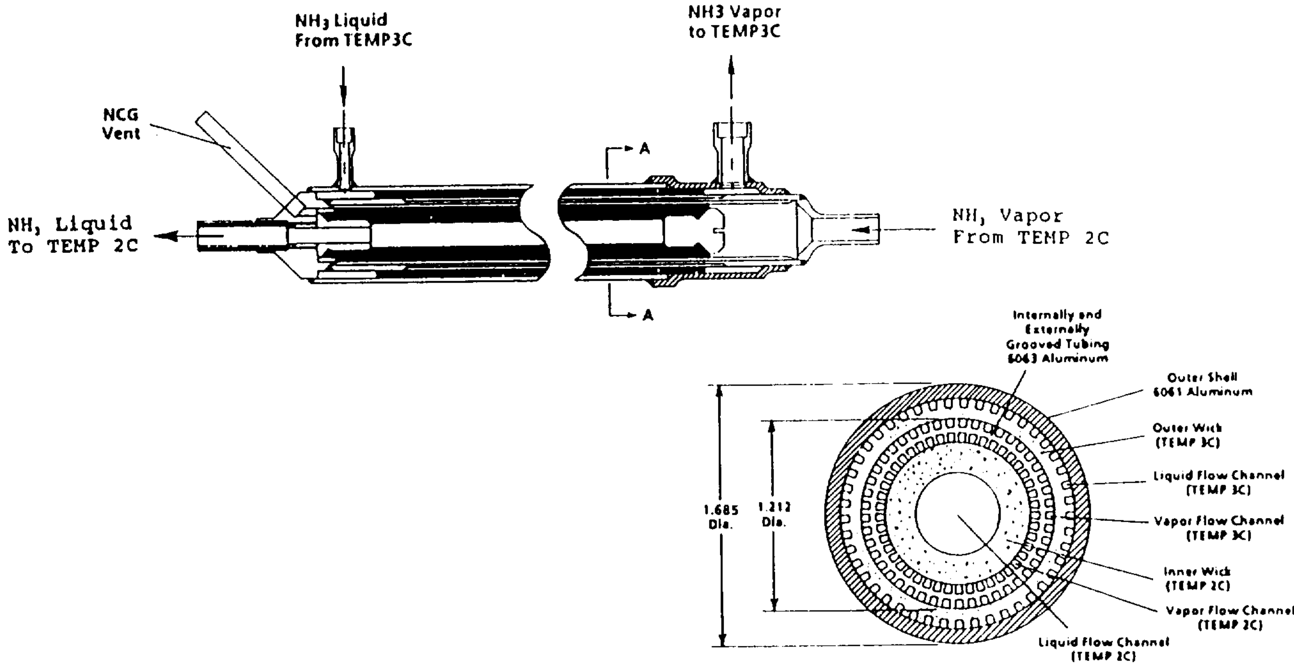
# BI-DIRECTIONAL HEAT EXCHANGER

- DESIGNED TO COUPLE TWO TWO-PHASE HEAT TRANSFER SYSTEMS
- ACTS AS A CONDENSER IN ONE LOOP AND AN EVAPORATOR IN THE SECOND LOOP
- CAN BE OPERATED IN "REVERSE" - CONDENSING IN THE NORMALLY EVAPORATING LOOP AND VICE VERSA
- CONTAINS CAPILLARY WICK MATERIAL TO ALLOW REVERSE OPERATION AND FOR FLOW REGULATION AND DISTRIBUTION
- TRANSFERS 4 KW WITH A LOOP TO LOOP SATURATION TEMPERATURE DIFFERENCE OF LESS THAN 2 C
- COMPATIBLE WITH BOTH CPL AND HYBRID (MECHANICALLY PUMPED) TWO-PHASE HEAT TRANSFER SYSTEMS

TWO-PHASE/TWO-PHASE HEAT EXCHANGER



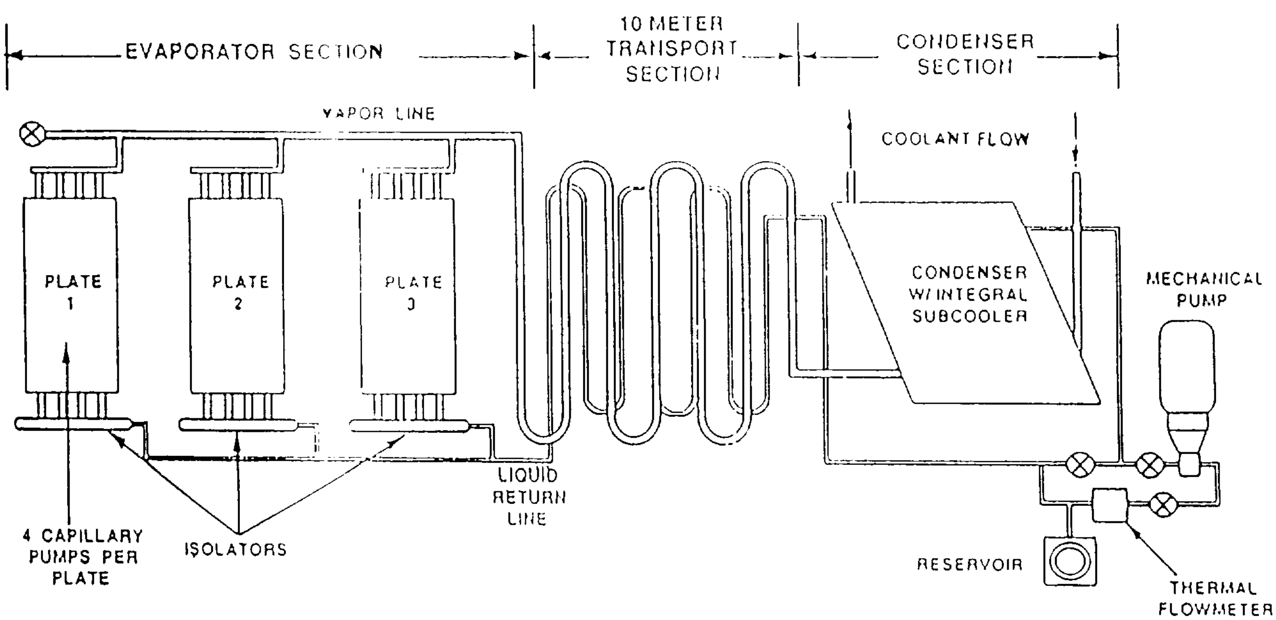
# HEAT EXCHANGER SUBASSEMBLY




*Section A-A*

# HIGH POWER THERMAL MANAGEMENT SYSTEM (HPSTM)

The High Power Thermal Management System (HPSTM) was functionally similar to the CPL II and II, but was larger. The three cold plates were each 2 ft. by 1 ft. (as opposed to the 1 ft. by 1 ft. plates of the CPL I and II) and had four pumps per plate. It also had a 10 meter transport length, an optional mechanical pump for "hybrid" mode operation, and an unwicked reservoir. It was designed for high power, and was able to achieve approximately 25 kW in a capillary mode, and over 50 kW in a hybrid mode. This loop has consistently performed exceptionally well for both startup and continuous operations.




EXPERIMENTAL APPARATUS FOR THE HIGH-POWER HYBRID CPL

# HIGH POWER THERMAL MANAGEMENT SYSTEM

## CAPILLARY MODE RESULTS

- STARTUP
  12 DIFFERENT POWER PROFILES
  NOT A SINGLE STARTUP FAILURE IN TWO YEARS OF TESTING
- LOW SYSTEM POWER LIMIT - 120 WATTS (10 WATTS PER EVAPORATOR
- TRANSPORT LIMIT - 25 KILOWATTS
- LONG TERM STEADY STATE POWER - 20 KILOWATTS (NO HIGHER POWER TESTED)
- SYSTEM OPERATED INTERMITTENTLY FOR ALMOST THREE YEARS
- NO EVIDENCE OF NON CONDENSIBLE GAS

# INSTRUMENT THERMAL TEST BED

The Instrument Thermal Test Bed (ITTB) represents a more modular, generic loop design. The ITTB is basically a skeletal loop which includes the transport plumbing, basic condenser, basic reservoir, a number of valves for quick system reconfiguration, complete instrumentation, cooling lines and control electronics. It is designed to permit both system and component level testing. The system can be quickly arranged for either capillary or "hybrid" mode of operation. Transport lengths can also readily be adjusted. In addition a test component such as a cold plate, reservoir or condenser can be easily "plugged in" to standardized ports and testing commenced within a matter of a few days, rather than the usual weeks. The ITTB is the largest known modular, two-phase test bed in the world. The facility has been operational for over a year and has already been used for a large variety of both system and component level testing.

LARGE SCALE TWO PHASE THERMAL TEST BED

- MODULAR DESIGN FOR EASY RECONFIGURATION
- COMPONENT AND SYSTEM LEVEL TESTING
- TECHNOLOGY DEVELOPMENT AND FLIGHT HARDWARE QUALIFICATION

# INSTRUMENT THERMAL TEST BED (ITTB)

CONFIGURATION

INITIAL OPERATIONS IN NOVEMBER 1990

- CONSTRUCTED TO REFLECT SPACE STATION BASELINE
  - THERMAL CAPACITY 25 kW (CONDENSER LIMIT)
  - SYSTEM VOLUME 7.75 GALLONS + 6.25 GALLON SYSTEM RESERVOIR
  - VARIABLE TRANSPORT LENGTH UP TO 50 METERS

RECONFIGURED IN NOVEMBER 1991

- REFLECT EOS BASELINE DESIGN
  - TRANSPORT LENGTH REDUCED TO 12 METERS
  - REPLACED CONDENSER W HP/HX - 1600 W LIMIT
  - SYSTEM VOLUME 1.5 GALLONS + RESERVOIR

# INSTRUMENT THERMAL TEST BED

## OPERATION RESULTS

### ORIGINAL CONFIGURATION

- PROTOTYPE CAPILLARY COLD PLATE (PCCP) EVAPORATORS
  - DEMONSTRATED OPERATION RANGE: 600 W TO 4000 W
  - LONG TERM OPERATION VERIFIED ABOVE 1800 W
- HPSTM EVAPORATORS
  - DEMONSTRATED OPERATION RANGE: 400 W TO 3200 W
  - LONG TERM OPERATION VERIFIED ABOVE 800 W
- CAPL COLD PLATES
  - DEMONSTRATED OPERATION RANGE: 600 W TO 1600 W
  - LONG - TERM OPERATION VERIFIED ABOVE 800 W

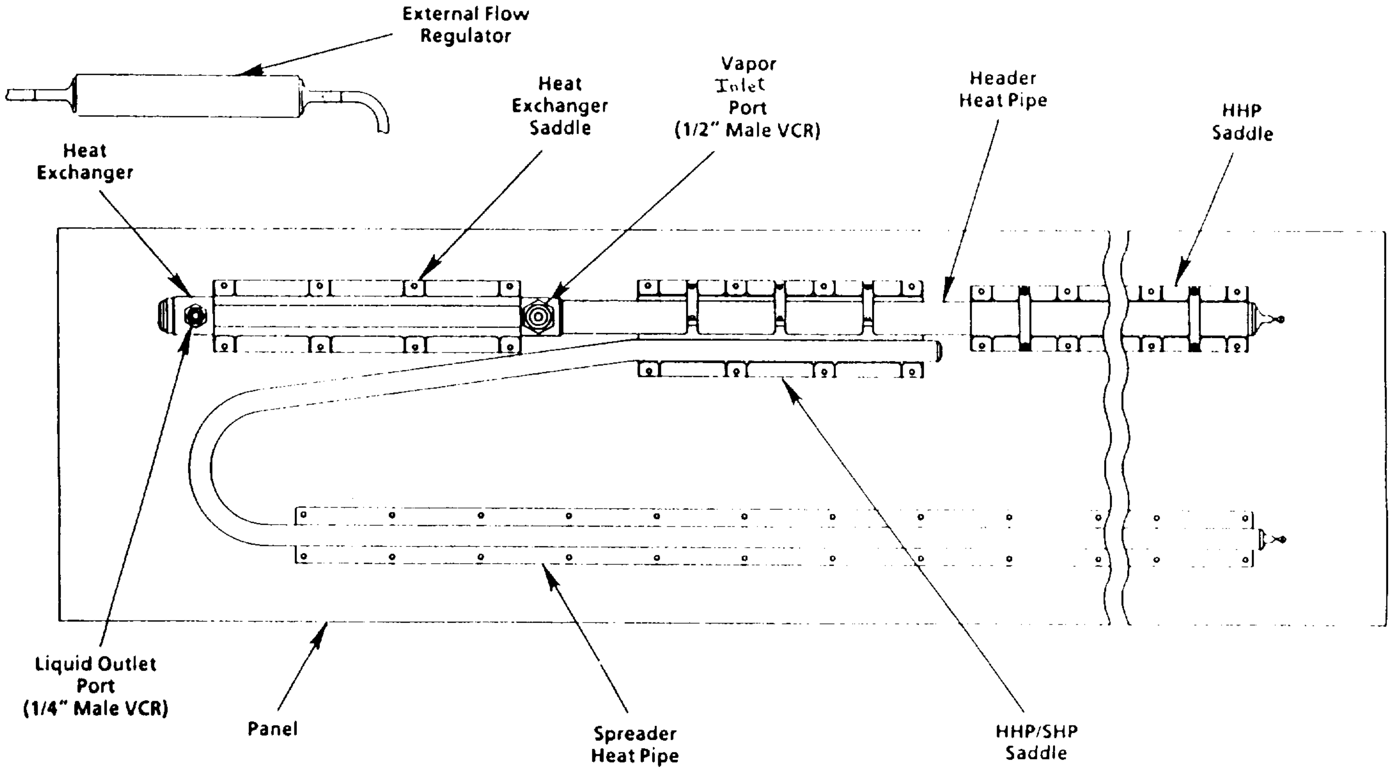
### MODIFIED CONFIGURATION

- HPSTM RESULTS
  - LOW POWER LIMIT DETERMINED TO BE 100 W
  - LONG TERM OPERATION DEMONSTRATED AT 100 W
- CAPL COLD PLATE RESULTS
  - LOW POWER LIMIT DETERMINED TO BE 600 W
  - LONG TERM OPERATION DEMONSTRATED AT 600 W

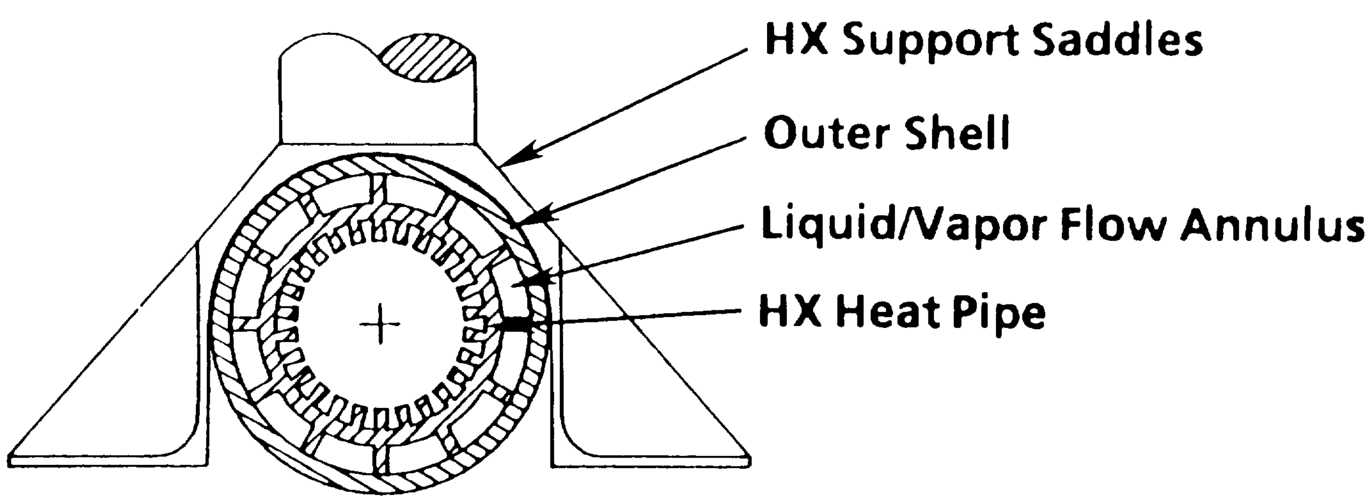
# HEAT PIPE HEAT EXCHANGER TESTING

- TWO INDEPENDENT CAPL PROTOTYPE DESIGNS
  - AXIALLY GROOVED POROUS WICK HEAT EXCHANGER W/ HEADER AND SPREADER HEAT PIPE
  - HELICAL FIN HEAT EXCHANGER W/HEADER AND SPREADER HEAT PIPE AS WELL AS STAND ALONE POROUS WICK FLOW REGULATOR AND VAPOR BARRIER
- TEST PROGRAM CONDUCTED TO DETERMINE FLIGHT DESIGN
  - HEAT EXCHANGER MUST TRANSFER 350 W @ 5 C OR LESS TEMPERATURE DIFFERENTIAL
  - HEADER HEAT PIPE TO DEMONSTRATE 432 W-M @ 35 C
  - SPREADER HEAT PIPE TO DEMONSTRATE 178 W-M @ 35 C
  - FLOW REGULATIONS AND NGC PROVISIONS
- EACH HP/HX WAS INSTALLED AS ITTB CONDENSER FOR TESTING

# HPHX DESIGN




# HPHX CROSS SECTION



# INSTRUMENT THERMAL TEST BED

## HEAT PIPE HEAT EXCHANGER RESULTS

- HEAT PIPE HEAT EXCHANGER TEST RESULTS
  - HELICAL FIN DESIGN SELECTED
  - AXIALLY GROOVED POROUS WICK DESIGN FAILED TO DEMONSTRATE HEAT TRANSFER REQUIREMENTS AND DISPLAYED HIGHER THAN EXPECTED PRESSURE DROPS
- HELICAL FIN PROTOTYPE CURRENTLY SERVES AS ITTB CONDENSER EVENTUALLY WILL BE INSTALLED IN MATERIALS LIFE TEST CPL

## FUTURE PLANS

- RESERVOIR TESTING
  - TEST CAPL PROTOTYPE RESERVOIR IN ITTB TO DETERMINE PERFORMANCE IN EXPERIMENT SCALE LOOP
- EVAPORATORS
  - TEST INDIVIDUAL 1/2 INCH EVAPORATOR PUMPS
  - TEST COLD PLATE CONSTRUCTED OF 1/2 INCH PUMPS
- CAPL SYSTEM LEVEL TESTING
  - CONFIGURE ITTB WITH CAPL PROTOTYPE COLD PLATE, CONDENSER, MECHANICAL PUMP, AND RESERVOIR TO SIMULATE FULL SCALE CAPL SYSTEM

# GSFC FLIGHT EXPERIMENTS

## WHY FLY EXPERIMENTS ?

- FLUID AND THERMAL PHYSICAL PHENOMENA ARE KNOWN TO BE DIFFERENT IN MICRO-GRAVITY;
  - PRESSURE DROPS
  - HEAT TRANSFER COEFFICIENTS
  - MIXING EFFICIENCIES
- FLUID MANAGEMENT MUCH MORE DIFFICULT IN MICRO-GRAVITY.
- EXISTING ANALYTICAL MODELS WEAK AND UNVERIFIED.
- FLIGHT DATA THUS NEEDED TO OPTIMIZE DESIGN AND REDUCE RISK.
  - BENEFITS INCLUDE LOWER WEIGHT, LOWER EQUIPMENT COST, AND GREATER RELIABILITY.

## GSFC THERMAL FLIGHT EXPERIMENTS

| EXPERIMENT | TYPE | POWER(KW) | STATUS |
|---|---|---|---|
| CPL-GAS | CAPILLARY | 0.2 | FLOWN (1985) |
| CPL-HH/G | CAPILLARY | 0.6 | FLOWN (1986) |
| TEMP 2A3 | MECHANICAL | 0.9 | MANIFESTED (7/92) |
| CAPL | CAPILLARY | 1.2 | MANIFESTED (10/93) |

NOTE: THE CPL-GAS AND CPL-HH/G REPRESENT THE ONLY FLIGHT TESTS TO DATE OF ANY TWO-PHASE THERMAL CONTROL TECHNOLOGY. ALSO, THE TEMP 2A3 WILL BE THE FIRST TEST OF A MECHANICALLY PUMPED TWO-PHASE SYSTEM.

# THERMAL ENERGY MANAGEMENT PROCESSES

## TEMP 2A-3

## FLIGHT EXPERIMENT

# TEMP 2A-3 FLIGHT EXPERIMENT OBJECTIVES

FIRST DEMONSTRATION OF A MECHANICALLY PUMPED TWO-PHASE AMMONIA THERMAL CONTROL SYSTEM IN MICRO-GRAVITY

EVALUATE MICRO-GRAVITY FLUID MANAGEMENT TECHNIQUES UTILIZING A PROPULSION TYPE RESERVOIR DESIGN

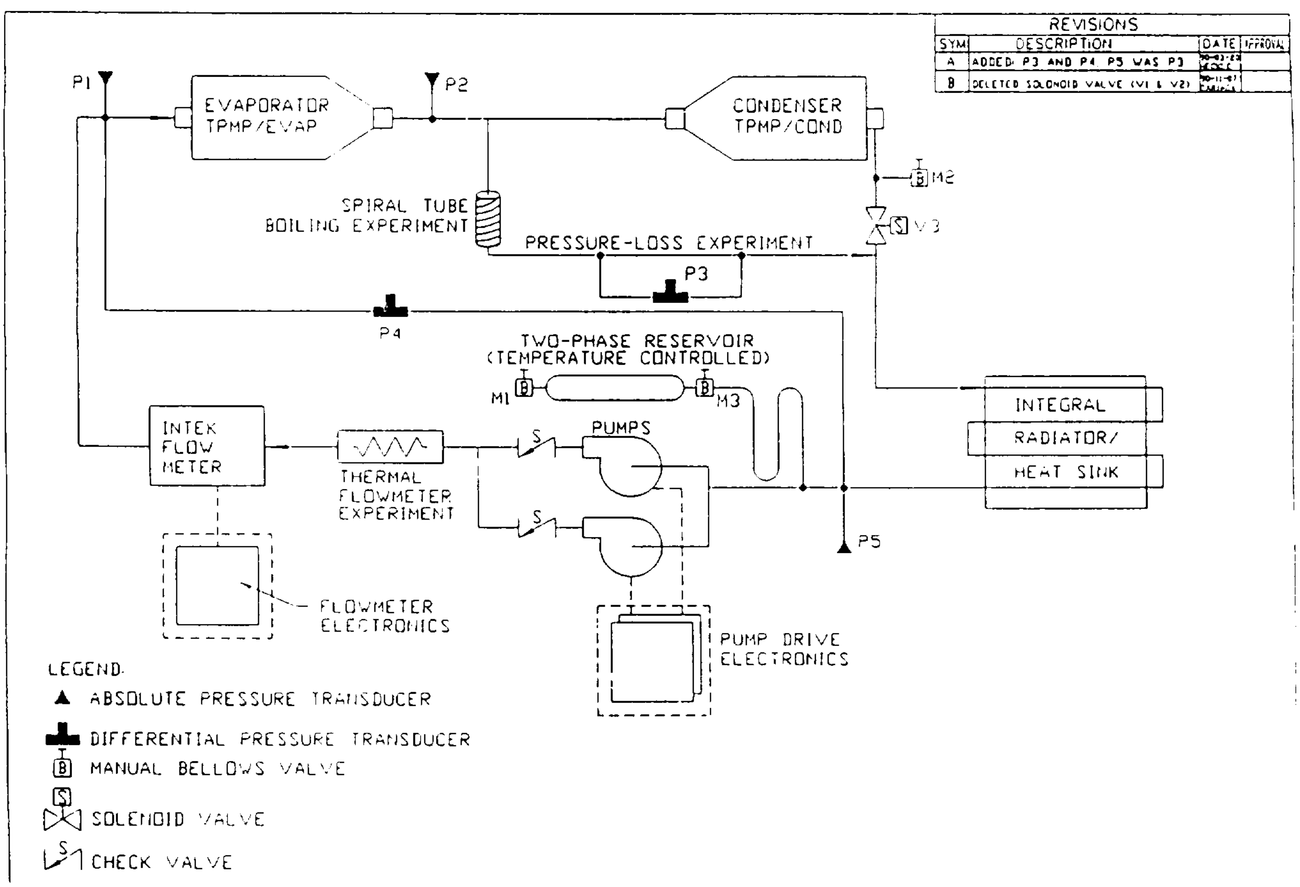
MEASURE PRESSURE LOSSES IN A TWO-PHASE FLOW LINE

MEASURE HEAT TRANSFER COEFFICIENTS IN A TWO-PHASE BOILER EXPERIMENT

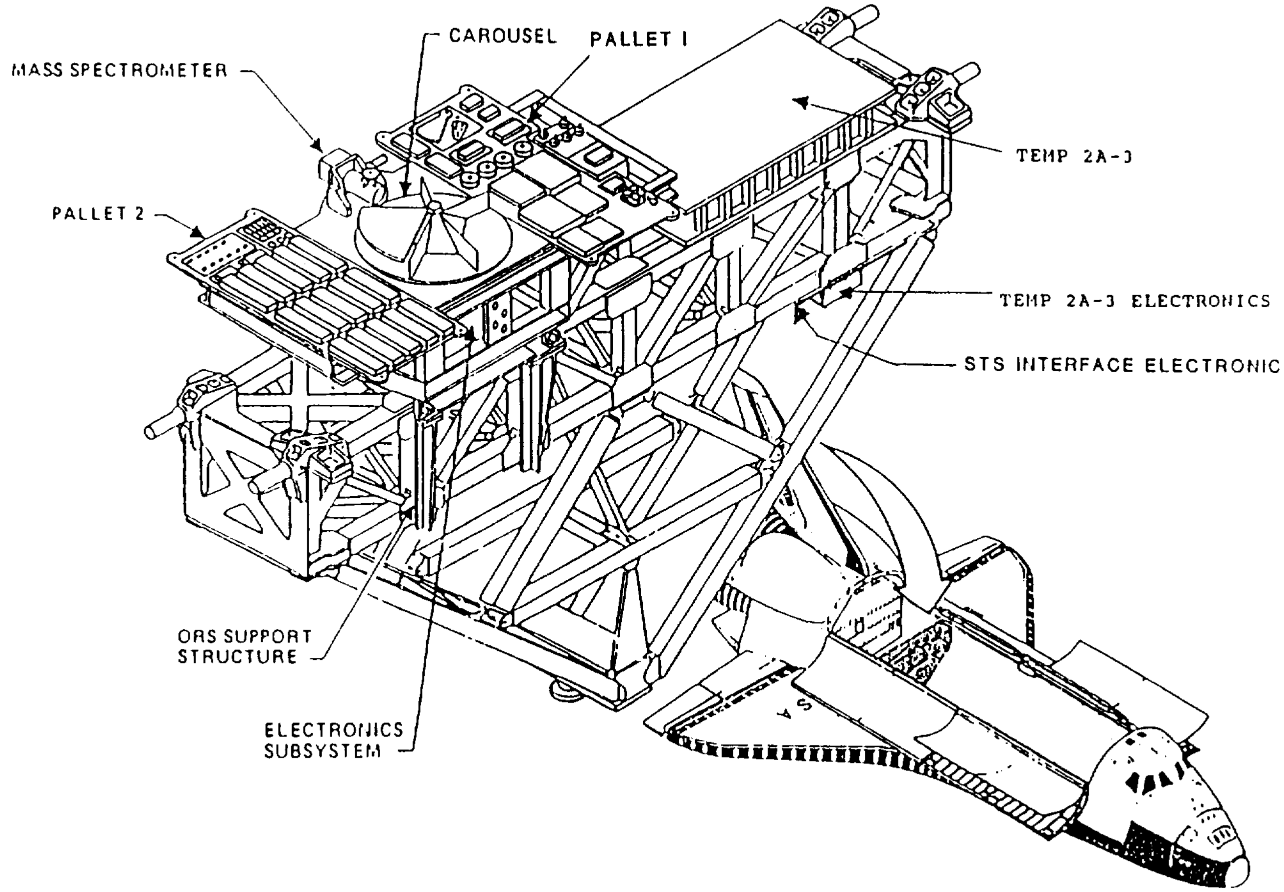
EVALUATE A DIRECT CONDENSATION RADIATOR

MEASURE ATOMIC OXYGEN EFFECTS ON JSC ANODIZED RADIATOR

## NO RELEVANT MICRO-GRAVITY DATA IS AVAILABLE TODAY



# EOIM-III/TEMP 2A-3 EXPERIMENT



# CAPILLARY PUMPED LOOP

# (CAPL)

# FLIGHT EXPERIMENT

# CAPL FLIGHT EXPERIMENT OBJECTIVES

TO DEMONSTRATE THE OPERATION OF A FULL SCALE CAPILLARY PUMPED HEAT TRANSFER SYSTEM IN MICROGRAVITY

DEMONSTRATE FLUID MANAGEMENT TECHNIQUES
- NEW RESERVOIR DESIGN
- CAPILLARY STARTER PUMP

VERIFY OPERATION OF HEAT PIPE HEAT EXCHANGER/RADIATOR

STUDY PRESSURE LOSSES IN CAPILLARY SYSTEMS

DEVELOP AND VERIFY ANALYTICAL MODELS

CAPILLARY COLD PLATES
- PROVIDE CONSTANT TEMPERATURE HEAT SINK
- PARALLEL PLATES DEMONSTRATE HEAT SHARING
- NEW MINI-PUMP DESIGN (1/2 INCH DIA)

TWO-PHASE RESERVOIR
- PROVIDES SATURATION TEMPERATURE CONTROL
- AUTOMATICALLY ADJUSTS FLUID INVENTORY
- UTILIZES CAPILLARY WICKS FOR FLUID MANAGEMENT

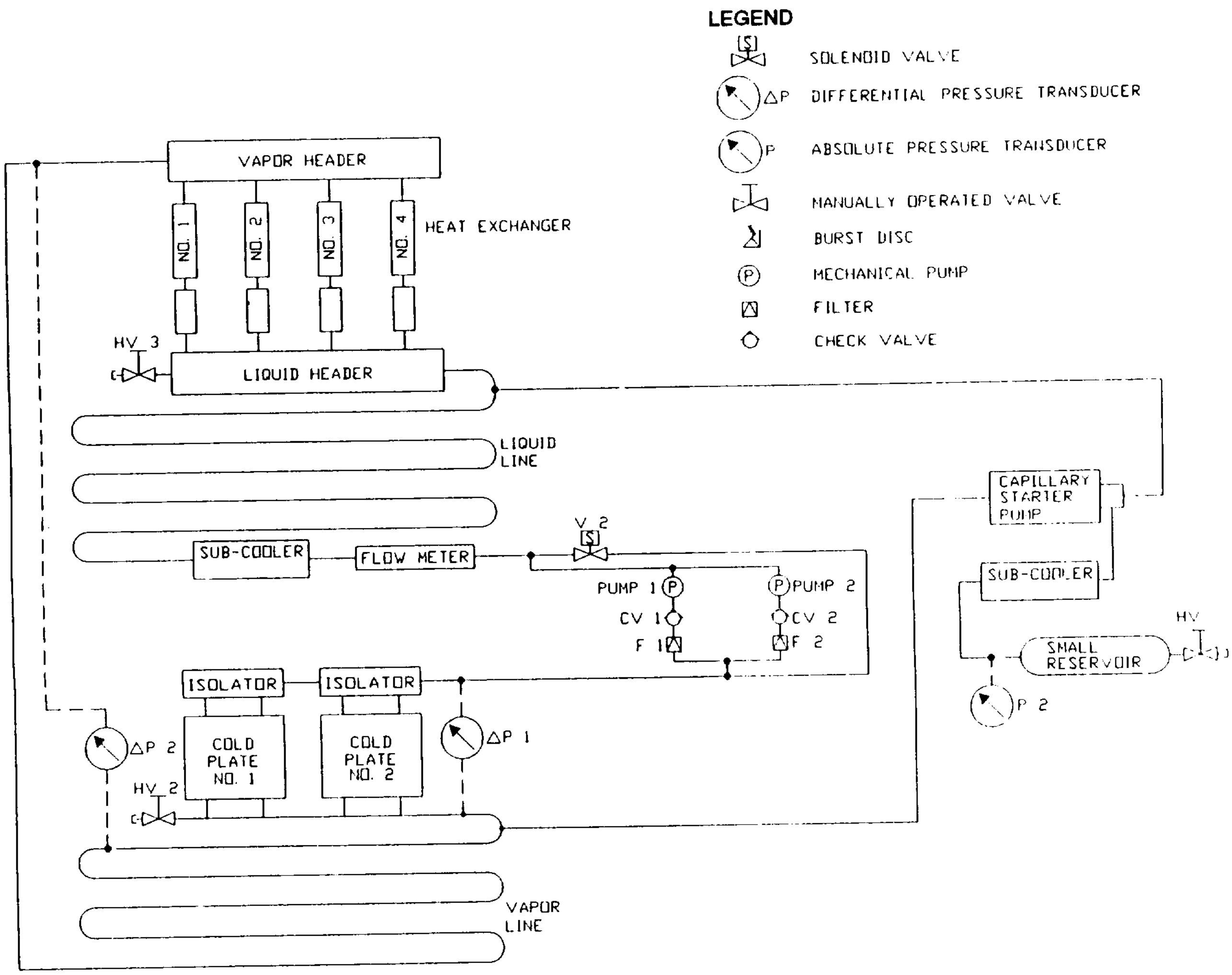
HEAT PIPE HEAT EXCHANGERS
- PROVIDES HEAT REJECTION FOR CAPL
- "SHIELDS" LOOP FROM METEORITE HITS
- INCLUDES NON-CONDENSIBLE GAS TRAP

LIQUID AND VAPOR TRANSPORT LINES
- DEMONSTRATES HEAT TRANSPORT OVER 8 METERS
- PROVIDE MICRO-G DATA ON PRESSURE LOSSES
- STAINLESS STEEL TUBING (1/4 AND 1/2 INCH DIA)

SYSTEM COMPONENTS
- THERMISTORS - MICRO-G HEAT TRANSFER COEFFICIENTS
- PRESSURE TRANSDUCERS - ABSOLUTE AND DIFFERENTIAL
- FLOWMETER - NON-INTRUSIVE THERMAL DESIGN
- MECHANICAL PUMP - PROVIDES BACKUP

ANALYTICAL MODELLING
- DEVELOP TWO-PHASE FLUID ANALYSIS CAPABILITY
- MICRO-GRAVITY VERIFICATION OF FLUID MODELS

CAPL WILL PROVIDE THE EXPERTISE NEEDED FOR EOS

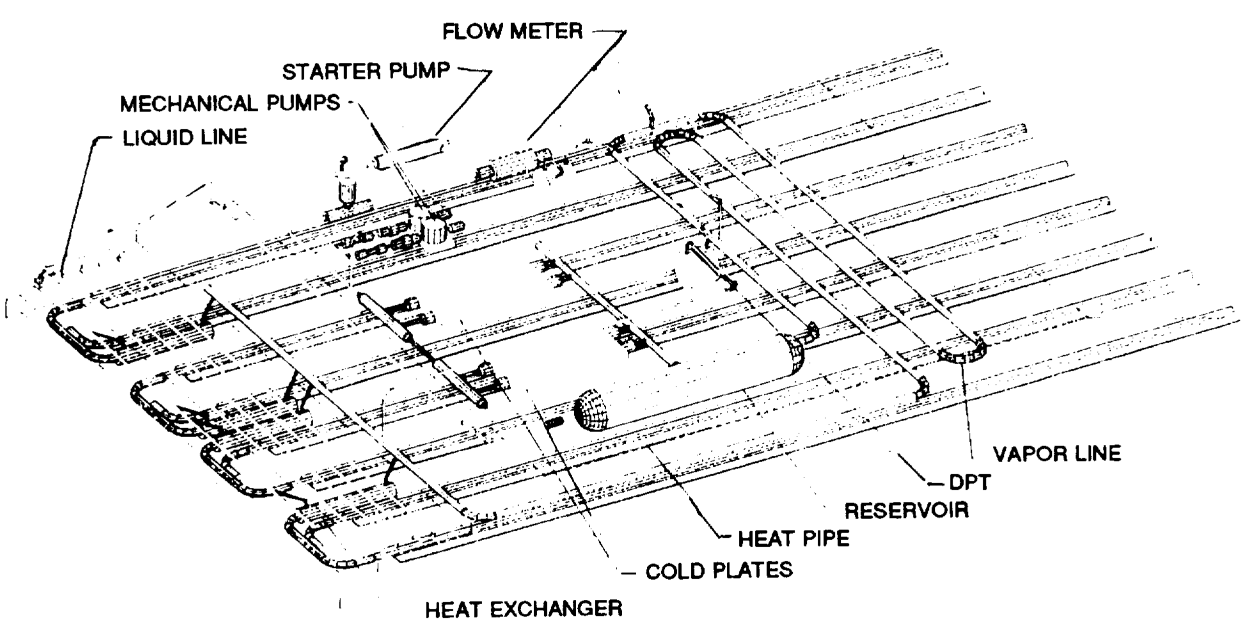



# CAPL SCHEMATIC

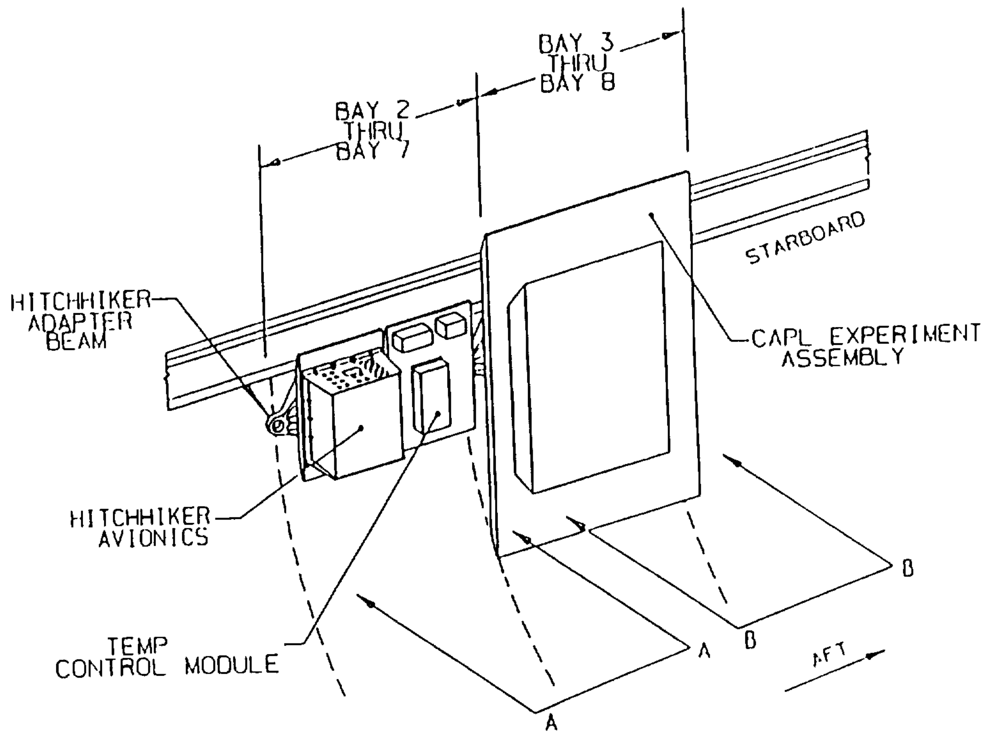
# CAPL CHARACTERISTICS
## REVISED EOS BASELINE

| LATEST EOS | ORIGINAL CAPL | REVISED CAPL |
|---|---|---|
| 30 TO 300 WATTS | 400 TO 1200 WATTS | 50 TO 1200 WATTS |
| 3 TO 8 METER LINES | 15 METERS | 8 METERS |
| FULLY FLOODED | PARTIAL/FULLY FLOOD | FULLY FLOODED |
| 1/4" DIA VAPOR<br>1/8" DIA LIQUID | 3/4" DIA VAPOR<br>3/8" DIA LIQUID | 1/2" DIA VAPOR<br>1/4" DIA LIQUID |
| 2 POUND CHARGE | 8 POUND CHARGE | 4 POUND CHARGE |
| 1/2" DIA PUMPS | 1" DIA PUMPS | 1/2" DIA PUMPS |
| HPHX RADIATOR | HPHX RADIATOR | HPHX RADIATOR |

## ENHANCED CAPL COMPONENT LAYOUT



## CAPL Hitchhiker-G Flight Configuration

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# CRYOHP OVERVIEW

- Justification
  - NASA -- EOS Platforms and Other Instrument Payloads
- Comparison to Alternatives
  - Heat Pipes Offer Redundancy and Design Flexibility Versus Direct Integration of Sensor/Cooler
- Need for Space Flight
  - No Micro Gravity Data for Cryogenic Heat Pipes
  - l-G Data Not Reliable, 100% Above Theory
  - Start-Up From Super Critical State Could be Significantly Different in Micro Gravity

# Cryogenic Heat Pipes

Current NASA cryogenic heat pipe requirements:

- Up to one meter length
- Operation at 60-80 K
- Transport capacity of up to approximately 5 watts
- High-lift wick design to enhance ground testability

Current state-of-the-art cryogenic heat pipes:

- Axially grooved wick - poor lift capability
- Oxygen working fluid - safety considerations
- Should meet heat transport requirements; needs to be demonstrated

C.4

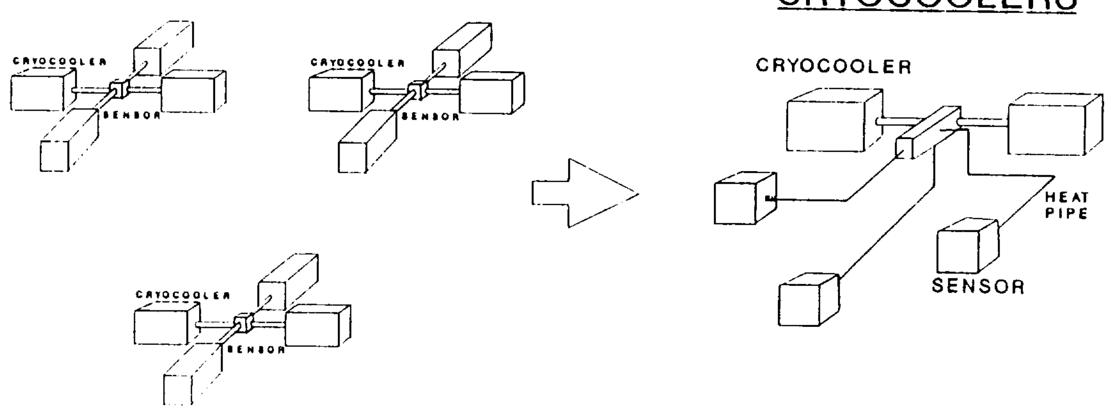
# CRYOGENIC HEAT PIPE APPLICATION

This diagram depicts the concept of how cryogenic heat pipes may provide a benefit to cooling a sensor or set of sensors (or optics, electronics, etc.). By providing a buffer between the cryogenic cooler and the sensor to be cooled, it reduces the effect of the mechanical cooler's vibration and EMI. In addition, if a number of sensors need to be cooled on the same spacecraft cryogenic heat pipes could be used to provide a link to a central bank of cryocoolers. This concept would significantly reduce the number of cryocoolers needed, and hence their weight and cost.

OAET

INDIVIDUALLY COOLED SENSORS

CENTRAL BANK OF CRYOCOOLERS



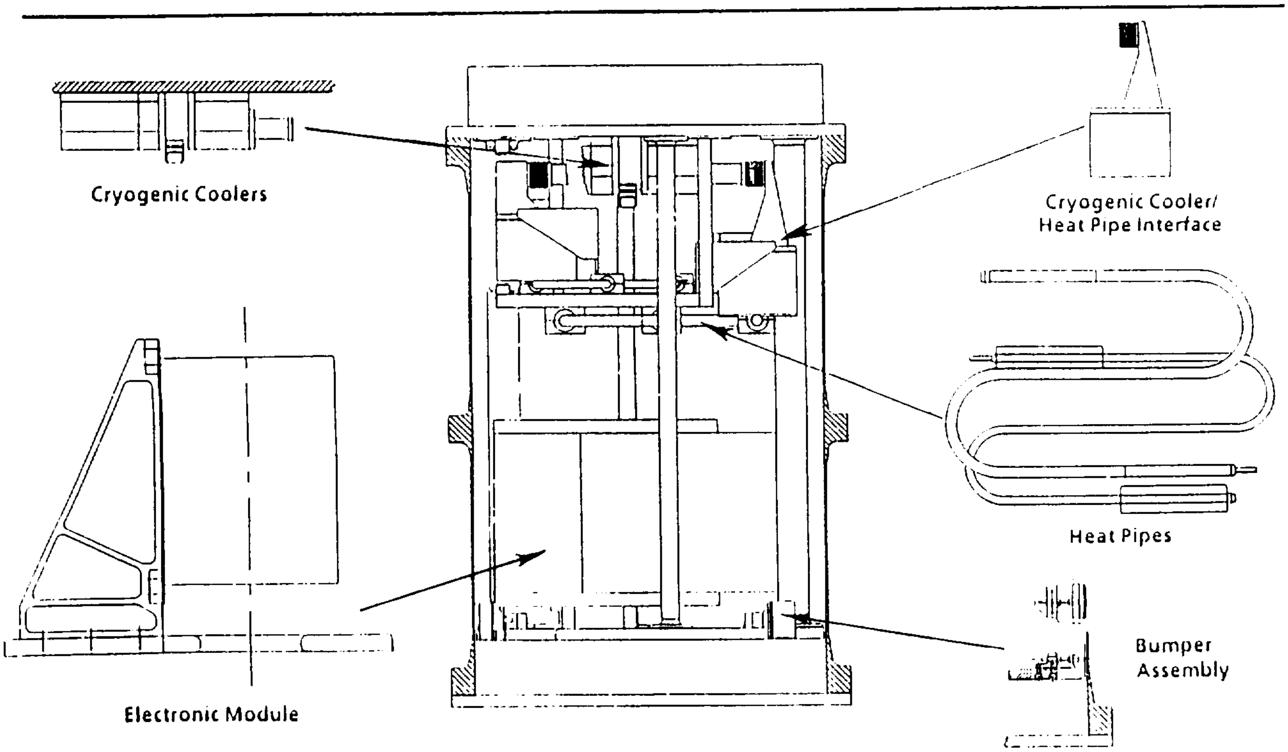

THREE SENSORS,
12 CRYOCOOLERS

THREE SENSORS,
2 TO 6 CRYOCOOLERS

# EXPERIMENT OBJECTIVES

- Primary - Cryogenic Heat Pipe
  - Oxygen Performance 70 - 110K
  - Correlation of Models
    * Ground Testing
    * Theory
  - 0-g Priming
  - Demonstrate 200 Watt-Inch Thermal Transport of Better
- Secondary
  - Cryogenic Test Bed
    * Cryogenic Refrigerators
    * Gain Flight Experience
  - Cooler Induced Vibration/Heat Pipe Transport

## CRYOHP SUBSYSTEM IMPLEMENTATION



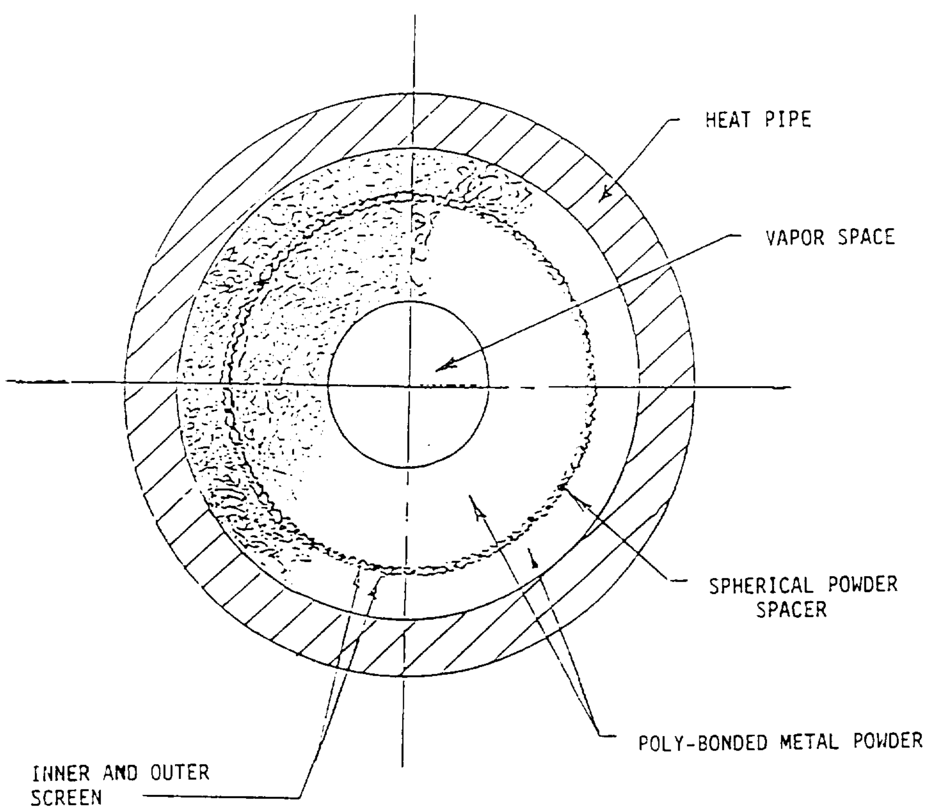
# Sintered Powder Artery-Free Wick Cryogenic Heat Pipe Experiment (SPAC)

## Specifications

- Total power capability of 4-5 watts at 70-80 K
- Overall thermal conductance of 1.0 W/°C
- One meter length, 15 mm OD, U-shaped heat pipe body
- Sintered powder metal wick material - no arteries or grooves
  - 5-15 times improvement in lift capability
  - 10-100 times better evaporative heat transfer coefficient than axial groove wick
- Nitrogen working fluid - decreased safety concern

## Configuration

- Self-contained Hitchhiker payload in a modified GAS canister
- Projected launch date - September 1993



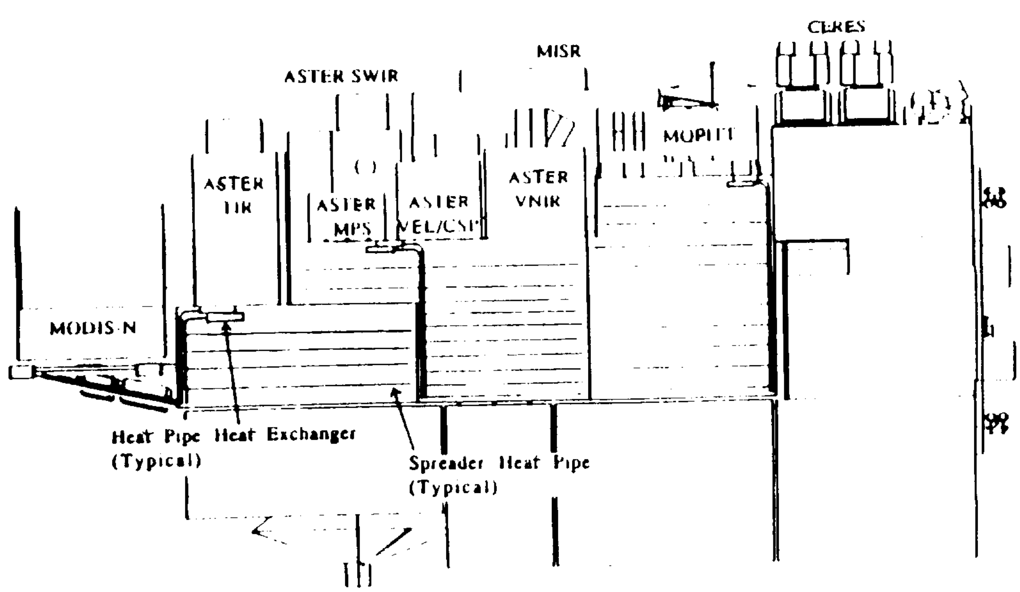

**SPAC Heat Pipe Wick Cross Section**

# EOS-AM PLATFORM

## EOS-AM SET THERMAL ACCOMMODATION

* CENTRAL CPL THERMAL BUS BASELINED FOR ORIGINAL, LARGE EOS PLATFORM
* EOS SCALED DOWN TO TWO SMALLER PLATFORMS, AN "AM" AND A "PM" SET.
  - SUITABILITY OF CPL THERMAL CONTROL SYSTEM REEVALUATED AGAINST HEAT PIPES
  - MINI-CPL CONCEPT ADOPTED AS NEW BASELINE
* EOS-AM WILL HAVE THREE MINI-CPL LOOPS
  - TWO FOR THE ASTER INSTRUMENT (300 W AND 140 W)
  - ONE FOR THE MOPITT INSTRUMENT (270 W)

**CPL MINI-LOOP - INSTRUMENT RADIATOR HEAT PIPE NETWORKS**



# ANALYTICAL TOOLS

## GSFC ANALYTICAL TOOLS

SINDA/FLUINT
SOPHISTICATED, STATE-OF-THE ART NODAL MODEL; BASED ON FIRST PRINCIPLES; VERSATILE BUT COMPLEX; TRANSIENT CAPABILITY

SINFAC
MODULAR, EQUATION-OF-STATE APPROACH; QUASI STEADY STATE; MODERATE COMPLEXITY

CPL MODELER
USER FRIENDLY, SIMPLIFIED MODEL; STEADY STATE CAPABILITIES ONLY; CAPILLARY SYSTEMS ONLY

# ADDITIONAL THERMAL TECHNOLOGY DEVELOPMENT

## OTHER THERMAL RESEARCH EFFORTS

- CAPILLARY EVAPORATOR USING CERAMIC WICK
- TRANSPARENT CAPILLARY EVAPORATOR TO ALLOW FLOW VISUALIZATION STUDIES
- COMPONENTS FOR USE WITH AMMONIA, ESPECIALLY MECHANICAL PUMPS
- HEAT PUMPS

# TRANSPARENT CAPILLARY EVAPORATOR

## SMALL BUSINESS INNOVATIVE RESEARCH

RESEARCH PROGRAM TO PROVIDE SEED MONEY TO SMALL
BUSINESSES TO DEVELOP INNOVATIVE TECHNOLOGY
FOR THE SPACE PROGRAM AND COMMERCIAL APPLICATIONS

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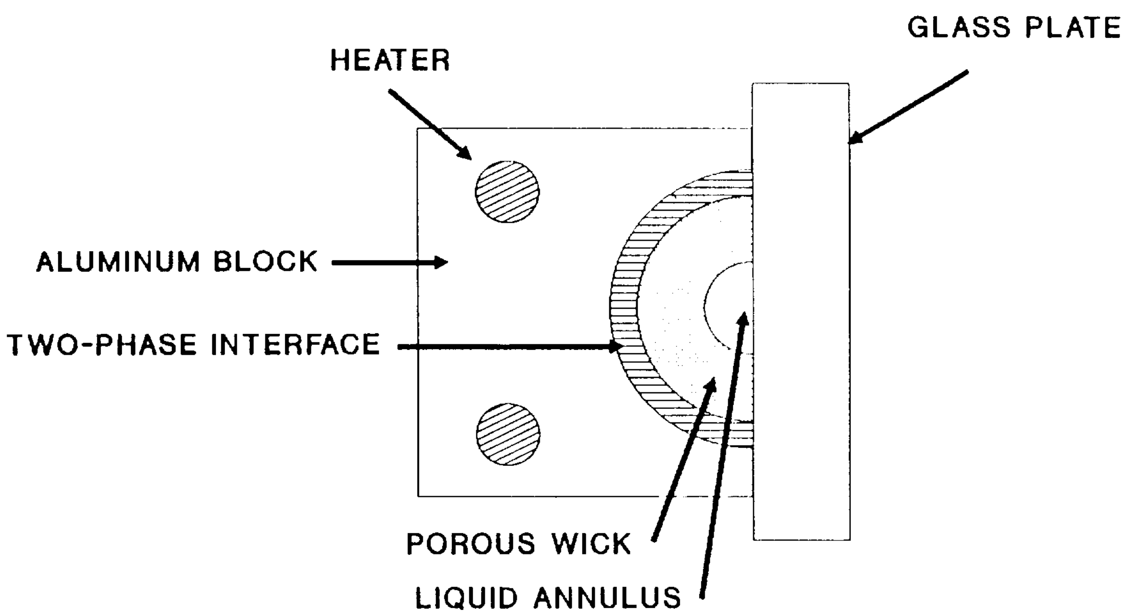
# TRANSPARENT CAPILLARY EVAPORATOR

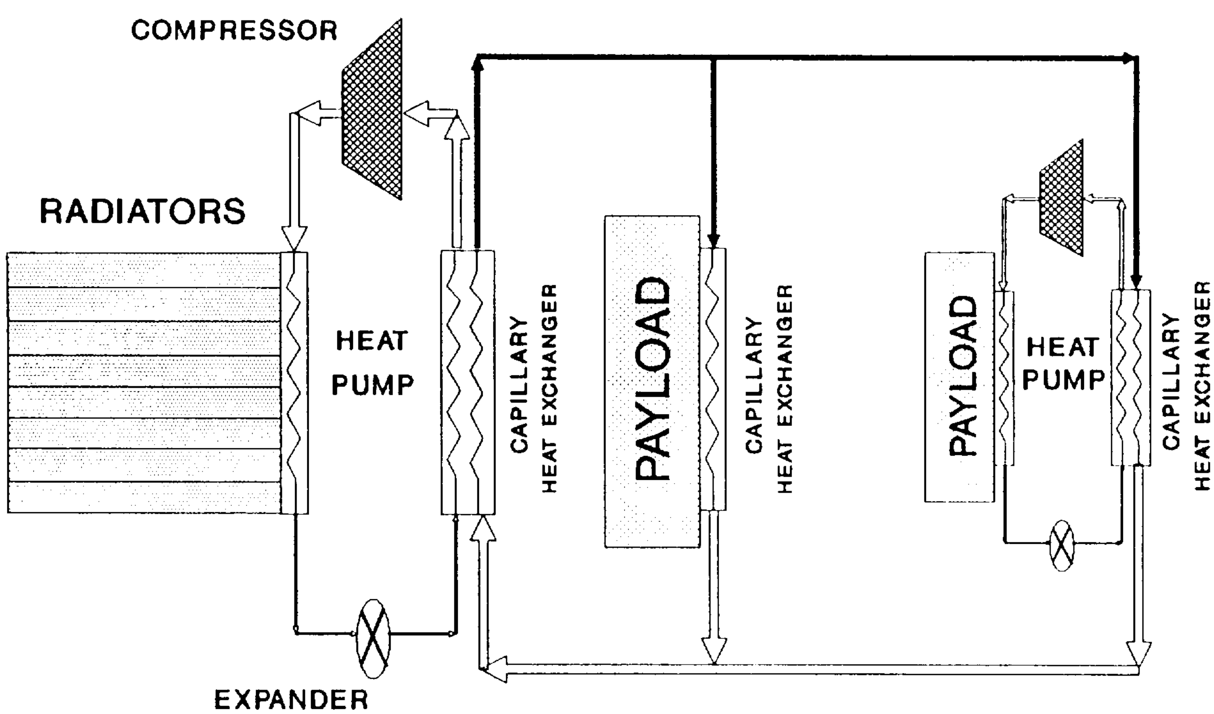
Capillary based evaporators have now been studied for almost a decade. Their performance at a component level is fairly well understood, but the internal workings of these devices is largely unknown. This is due to the difficulty of obtaining internal temperature measurements and in locating the liquid/vapor interface. The objective of this effort is to fabricate a see-through evaporator which will permit such measurements. While special construction techniques will be needed to fabricate such a device, it will essentially represent a conventional capillary evaporator sectioned longitudinally.



# HEAT PUMP TWO-PHASE BUS CONCEPT

## -INCREASE REJECTION TEMPERATURE/COOL PAYLOAD-

Recent analytical studies have indicated that for thermal control applications in a hot thermal sink, existing technology is inadequate. A prime example is a Lunar Base, where during the lunar day a conventional radiator would have to look at either the sun or the hot lunar surface. The effective sink temperature under these circumstances is about 35 $^0$C, which is above normal room temperature. Hence, conventional heat rejection is impossible. A heat pump could be used to increase the heat rejection temperature in order to permit direct rejection. In addition, there are other reasons for developing space qualified heat pumps; energy management and conservation, refrigeration below central bus temperatures, and improved utilization of resources.



# SMALL BUSINESS INNOVATIVE RESEARCH

RESEARCH PROGRAM TO PROVIDE SEED MONEY TO SMALL BUSINESSES TO DEVELOP INNOVATIVE TECHNOLOGY FOR THE SPACE PROGRAM AND COMMERCIAL APPLICATIONS

# SBIR 1991 PHASE I STUDIES

- COMPACT HEAT EXCHANGERS FOR AMMONIA REFRIGERANT
  - DEVELOP COMPACT LOW MASS HEAT EXCHANGERS FOR USE WITH AMMONIA REFRIGERATION SYSTEMS IN LOW AND MICRO GRAVITY ENVIRONMENTS
  - PHASE A GOALS: DESIGN ALGORITHM, PROTOTYPE DESIGN OF SPECIFIC EQUIPMENT
- UTILIZATION OF LOW TO MEDIUM TEMPERATURE WASTE HEAT
  - CONVERT LOW TO MEDIUM TEMPERATURE WASTE HEAT TO ELECTRICAL POWER BY USE OF PYROELECTRICS
  - PHASE A GOALS: MEASURE USEFUL LIFETIME OF PYROELECTRIC CONVERSION MATERIAL, DETERMINE MATERIAL PROPERTIES DURING THERMAL AND ELECTRICAL CYCLING ELECTRICAL CYCLING PERIODS

# SBIR PHASE II STUDIES

MODULAR CHEMICAL/MECHANICAL HEAT PUMP

- CONSTRUCT LOW LIFT/LONG LIFE, CHEMICAL/MECHANICAL HEAT PUMP TO DEMONSTRATE 20% + INCREASE IN COP OVER COMPARIBLE MECHANICAL DESIGN
- PHASE A IDENTIFED POSSIBLE FLUID WORKING PAIRS AND 20% + COMPUTER BASED COP IMPROVEMENT OVER OTHER AVAILABLE VAPOR COMPRESSION SYSTEMS

# SUMMARY

- CPL'S DO WORK
- GOOD GROUND HERITAGE
- LIMITED FLIGHT DATA
- GOOD PEER REVIEW

# FUTURE

- CONTINUED TESTING AND MODELING
- COMET
- CAPL FLIGHT EXPERIMENT
- EOS SPACECRAFT
- MILITARY APPLICATIONS