N93-27802

SUPERFLUID HELIUM NEEDS AND RESUPPLY ON SPACE STATION

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JANUARY 16, 1990

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Since its first orbital use in 1983, superfluid helium (He II) has found increasingly many uses in space. In the area of astrophysics one finds applications in the infrared, xray, gamma ray, and cosmic ray particle areas. Examples include the InfraRed Astronomical Satellite (IRAS) in 1983, the shuttle based InfraRed Telescope (IRT) in 1985, the Cosmic Background Explorer (COBE) in 1989-1990, the Infrared Space Observatory (ISO) to be launched in approx. 1992, the Space InfraRed Telescope Facility (SIRTF) in approx. 1999, and the Large Deployable Reflector (LDR). The Advanced Xray Astrophysics Facility (AXAF), scheduled for launch in 1997, has its most sensitive instrument, the X-Ray Spectrometer (XRS), cooled by He II. The space station based cosmic ray facility called Astromag (1999) uses He II to cool large superconducting magnets. Recent ground based detectors using ultra low temperature germanium detectors have been used for gamma rays. Such a system in space would use He II as the heat sink.

Earth observation projects also have baselined He II cooling for SAFIRE, an EOS instrument, and a superconducting gravity gradiometer for a gravity mapping mission.

WHAT IS SUPERFLUID HELIUM (He II) USED FOR IN SPACE?

- ASTROPHYSICS

  INFRARED ASTRONOMICAL SATELLITE (IRAS)

  INFRARED TELESCOPE (IRT)

  COSMIC BACKGROUND EXPLORER (COBE)

  INFRARED SPACE OBSERVATORY (ISO)

  SPACE INFRARED TELESCOPE FACILITY (SIRTF)

  ADVANCED XRAY ASTROPHYSICS FACILITY XRAY SPECTROMETER (AXAF/XRS)

  COSMIC RAY DETECTOR FACILITY (ASTROMAG)

  LARGE DEPLOYABLE REFLECTOR (LDR)

  FUTURE GAMMA RAY DETECTORS

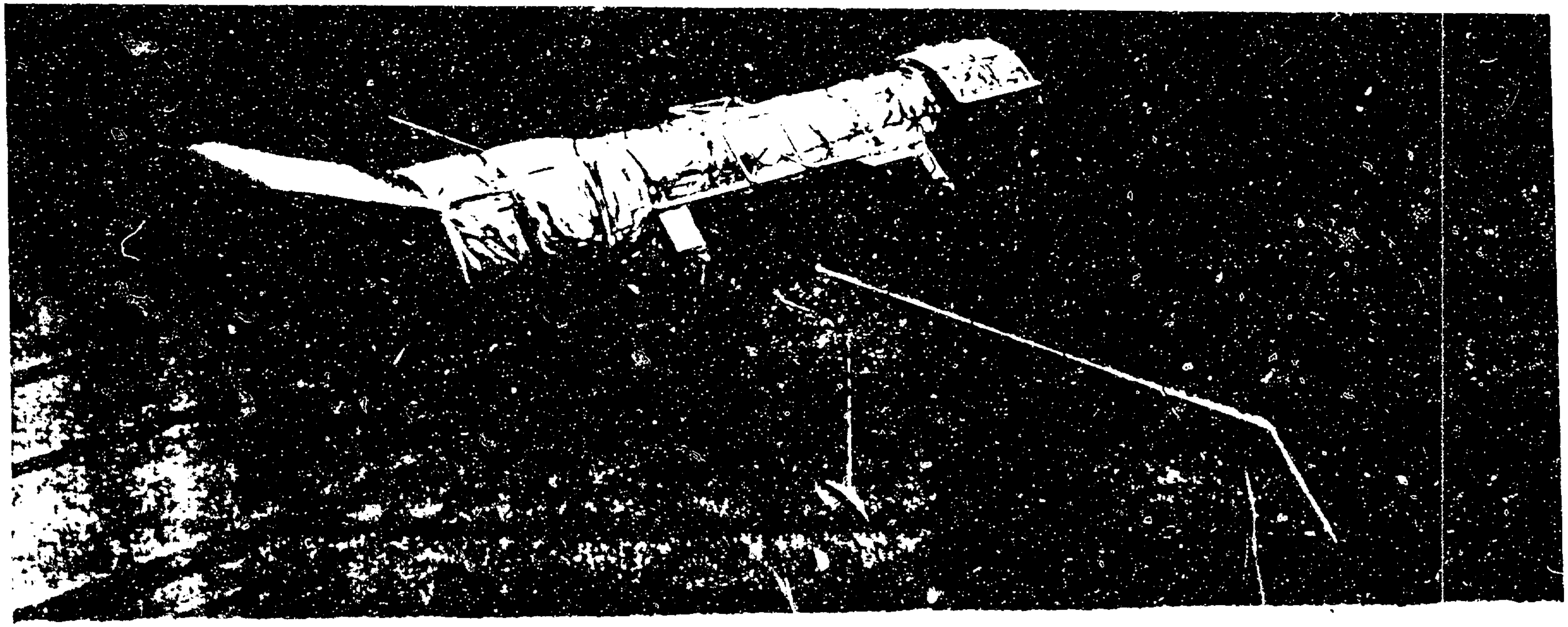
- EARTH OBSERVING

  GRAVITY MAPPING MISSION

  SAFIRE (EOS INFRARED INSTRUMENT)

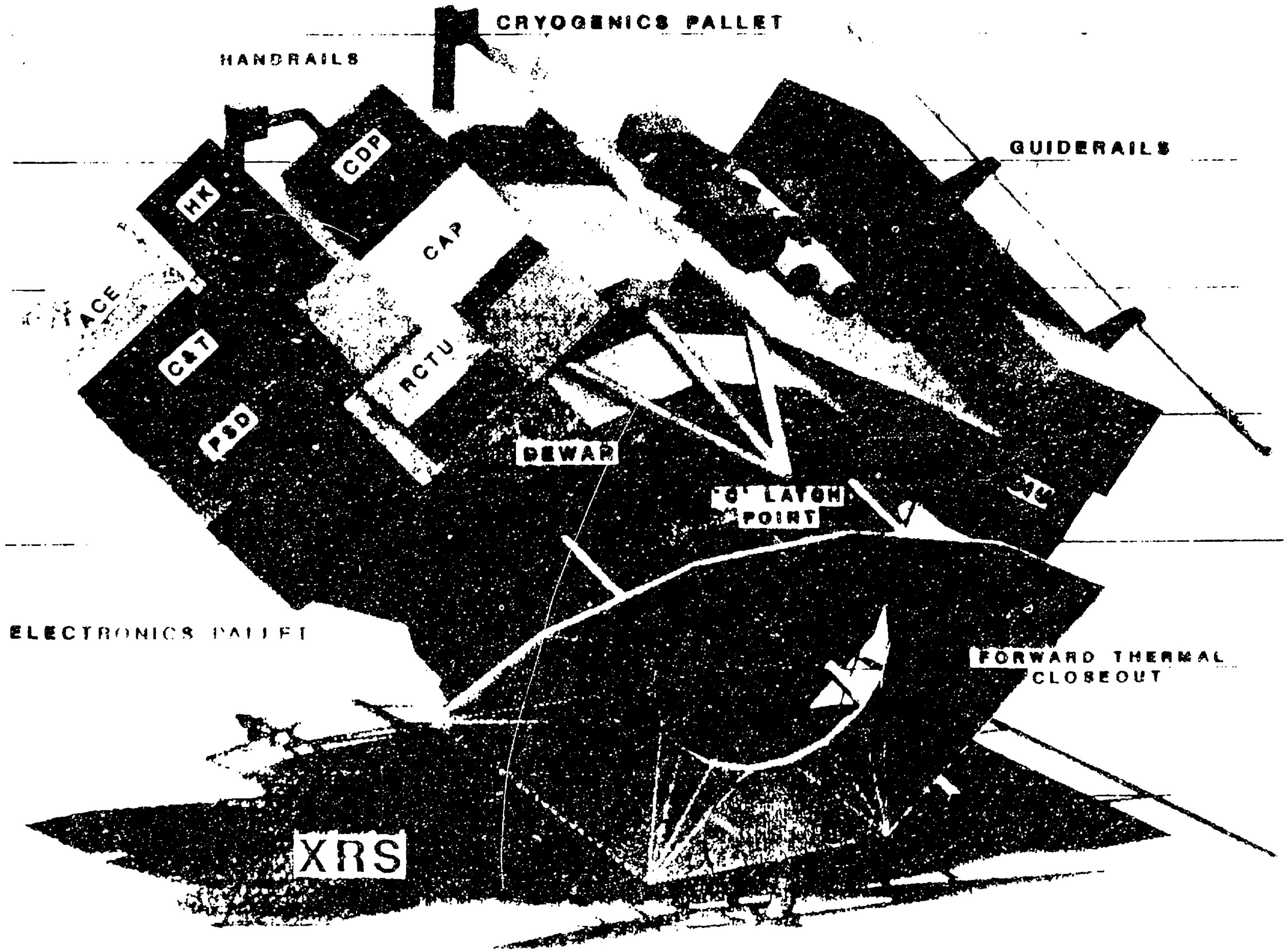
The Advanced Xray Astrophysics Facility (AXAF), to be launched in 1997, is scheduled to be serviced every 5 years, eventually from the space station.

AXAF - ADVANCED X-RAY ASTROPHYSICS FACILITY

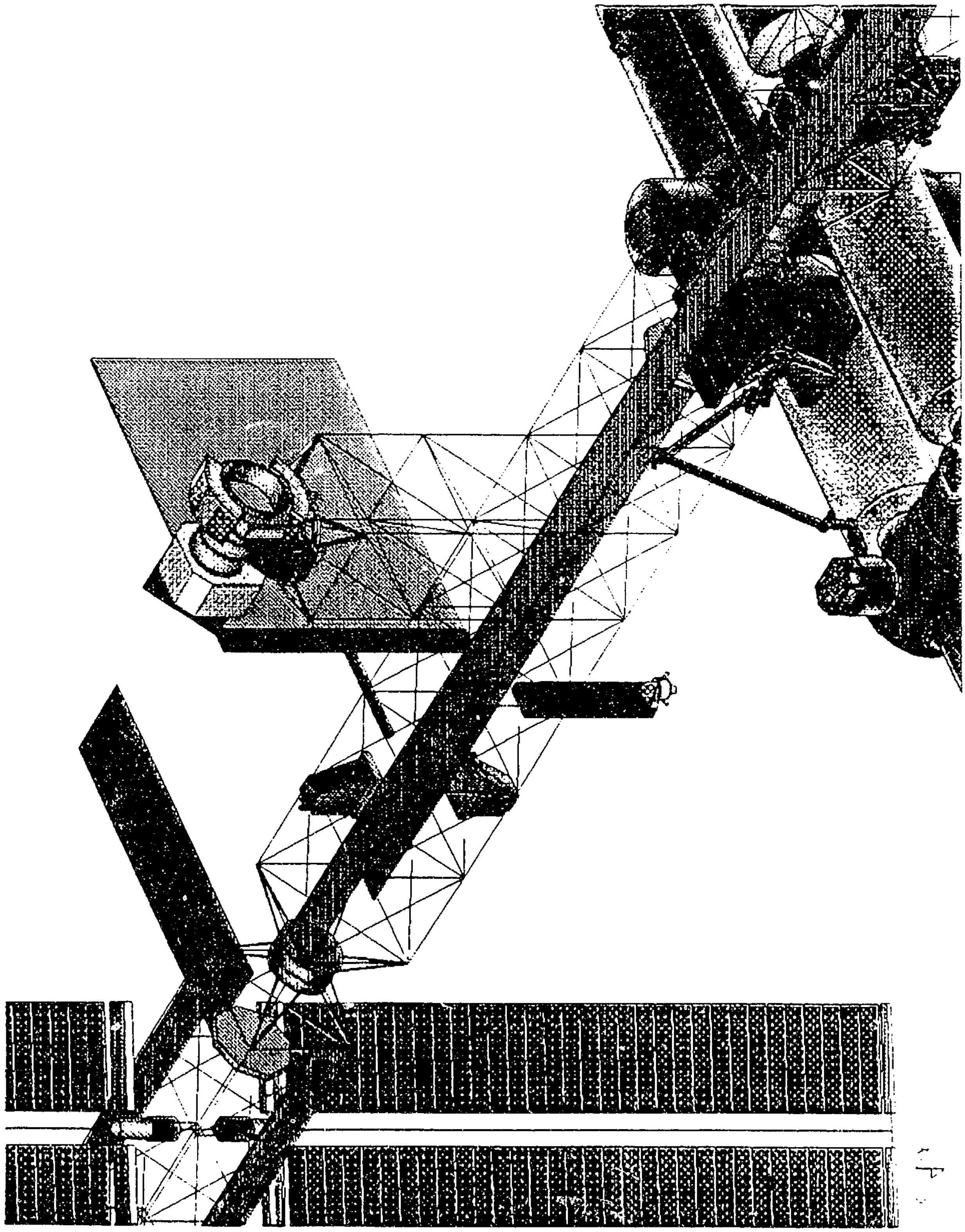


The X-Ray Spectrometer (XRS), one of three focal plane instruments on AXAF, will have a 400 liter He II dewar. Its 4 year lifetime can be extended by He II resupply.

XRS - X-RAY SPECTROMETER



The space station attached Astromag, a cosmic ray facility, is shown here at the center near the top of the picture. It consists of a 3000 to 4000 liter dewar of He II which cools a pair of superconducting magnets. Two instruments are shown attached to the core facility.



Superfluid helium will also be used in various fundamental physics experiments, such as the very sensitive test o Einstein's general relativity theory, Gravity Probe-B (GP-B) scheduled for launch in the late 1990's. Other planned experiments will test the equivalence principle between inertial and gravitational mass, superconducting gravity gradiometer tests of general relativity and the "fifth force", and critical point phenomena tests beginning with sensitive measurements of the specific heat of liquid helium at the superfluid transition (lambda point), which is scheduled to fly in 1991 as a shuttle attached payload. A critical point phenomena facility (CPPF) has been proposed for space station to support these various experiments.

In addition, a previously proposed materials processing facility (MPF) using a superconducting magnet to aid in low g alloying and crystal growth experiments, would use He II. Nuclear Magnetic Resonance (NMR) and Magnetic Resonance Imaging (MRI) machines are standard laboratory and medical tools on earth may eventually be used in space.

- <u>FUNDAMENTAL PHYSICS</u>

  GRAVITY PROBE-B (GP-B)

  EQUIVALENCE PRINCIPLE TESTS

  GENERAL RELATIVITY AND "FIFTH FORCE" TESTS USING GRAVITY GRADIOMETER

  CRITICAL POINT PHENOMENA (CPPF) INCLUDING LAMBDA POINT, CRITICAL POINT AND TRICRITICAL POINT EXPERIMENTS

- <u>OTHER</u>

  MATERIALS PROCESSING FACILITY (MPF) (USES SUPERCONDUCTING MAGNET)

  NMR DEVICES

Space station serves as the base of operation for Astromag, the CPPF, the MPF and other users of He II such as for small infrared telescopes. It also serves as the eventual servicing area for free flyers such as AXAF. For other satellites, in far different orbits such as SIRTF, the space station may serve as a transportation node - - a storage depot for liquid helium resupply missions. One possible commercial use of the moon is the mining and return to earth of He3, the rare isotope of helium. This may be used in clean fusion reactions on earth. It is most easily shipped as a liquid, requiring He II refrigeration.

HOW DOES SPACE STATION FIT IN?

- AS BASE OF OPERATION

  ASTROMAG

  CPPF

  MPF

  NMR DEVICES AND OTHER SMALL USERS (e.g. SMALL IR TELESCOPES)

- AS SERVICING AREA

  AXAF

- AS TRANSPORTATION NODE

  LDR

  SIRTF

  LUNAR USES, ETC. (e.g., RETURN OF He^3 FROM THE MOON)

Several technology issues arise from superfluid helium use on the space station. One must consider long term storage of superfluid including the size and location of the tankage and boil off rate (lifetime) requirements. Venting is a concern including contamination of other space station users, emergency venting in the event of tank puncture, and pressurized lab module penetrations for liquid helium fill and vent of small experiments.

Another issue to be addressed is whether the boil off gas can be reliquefied and reused on orbit. This raises questions about power requirements, vibration, and capturing the vented gas. At this time resupply appears much more feasible.

Fluid management in low gravity is the key to He II resupply.

SPACE STATION He II TECHNOLOGY ISSUES

- LONG TERM STORAGE
  - -- TANK SIZE AND LOCATION
  - -- BOIL OFF RATE
- VENTING
  - -- CONTAMINATION
  - -- LAB MODULE PENETRATIONS FOR FILL AND VENT
  - -- EMERGENCY RELIEF
- RECYCLABILITY
  - -- POWER REQUIREMENTS, VIBRATION, CAPTURING VENT GAS
- RESUPPLY
  - -- FLUID MANAGEMENT

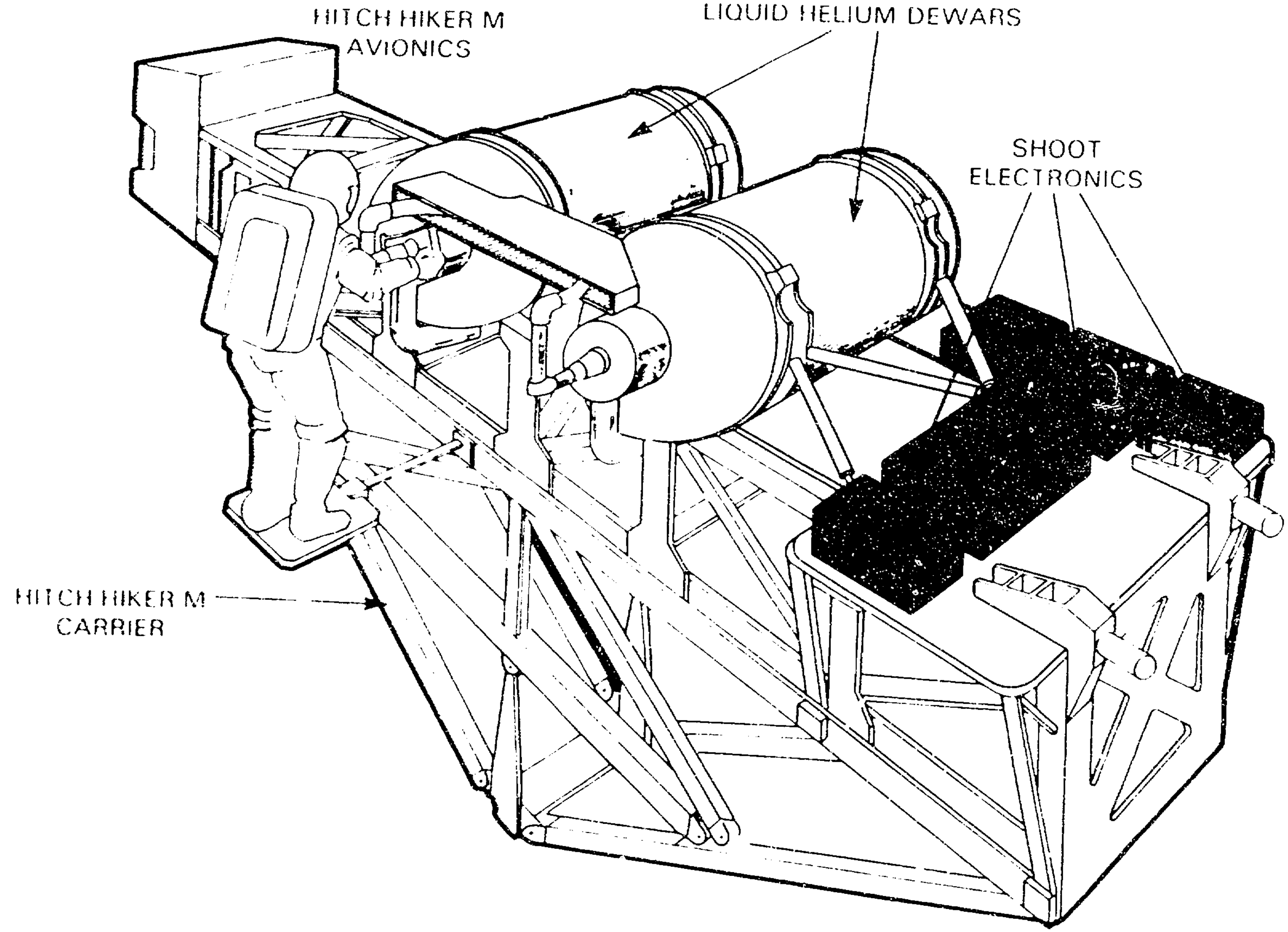
Some of the component technologies in the fluid management of He II in space are listed here. The transfer line coupler must provide a low heat input to the superfluid while maintaining a safe environment for an EVA. To produce a low heat leak a demateable cold seal must be employed. Cryogenic valves for use with superfluid helium have been developed for many programs. Cryogenic relief valves are required for potential trapped volumes. Repeatable burst pressures for emergency venting burst disks have been developed over the past few years. A superfluid helium pump capable of delivering He II to the receiver vessel at a reasonable flow rate (a few hundred liters per hour) is required. Phase separation to allow boil off while retaining liquid within the dewar is essential. Liquid acquisition within the supply tank to gather liquid and feed it to the pump at the required flow rate is needed for efficient transfer. To control the transfer accurate methods of measuring the transfer rate and amount of liquid in the supply and receiver is required.

RESUPPLY - - FLUID MANAGEMENT ISSUES

- TRANSFER LINE COUPLER
- CRYOGENIC VALVES
- RELIEF VALVES AND BURST DISKS
- PUMP
- PHASE SEPARATION
- LIQUID ACQUISITION
- QUANTITY GAUGING
- FLOW METERING

The Superfluid Helium On-Orbit Transfer (SHOOT) Flight Demonstration is shown mounted on a Hitchhiker carrier with avionics. SHOOT consists of two 210 liter superfluid helium dewars connected by a transfer line. The dewars are identical with plumbing components arranged so that either may act as a supply or receiver dewar. SHOOT is manifested for flight in July, 1992.

SUPERFLUID HELIUM ON ORBIT TRANSFER FLIGHT DEMONSTRATION

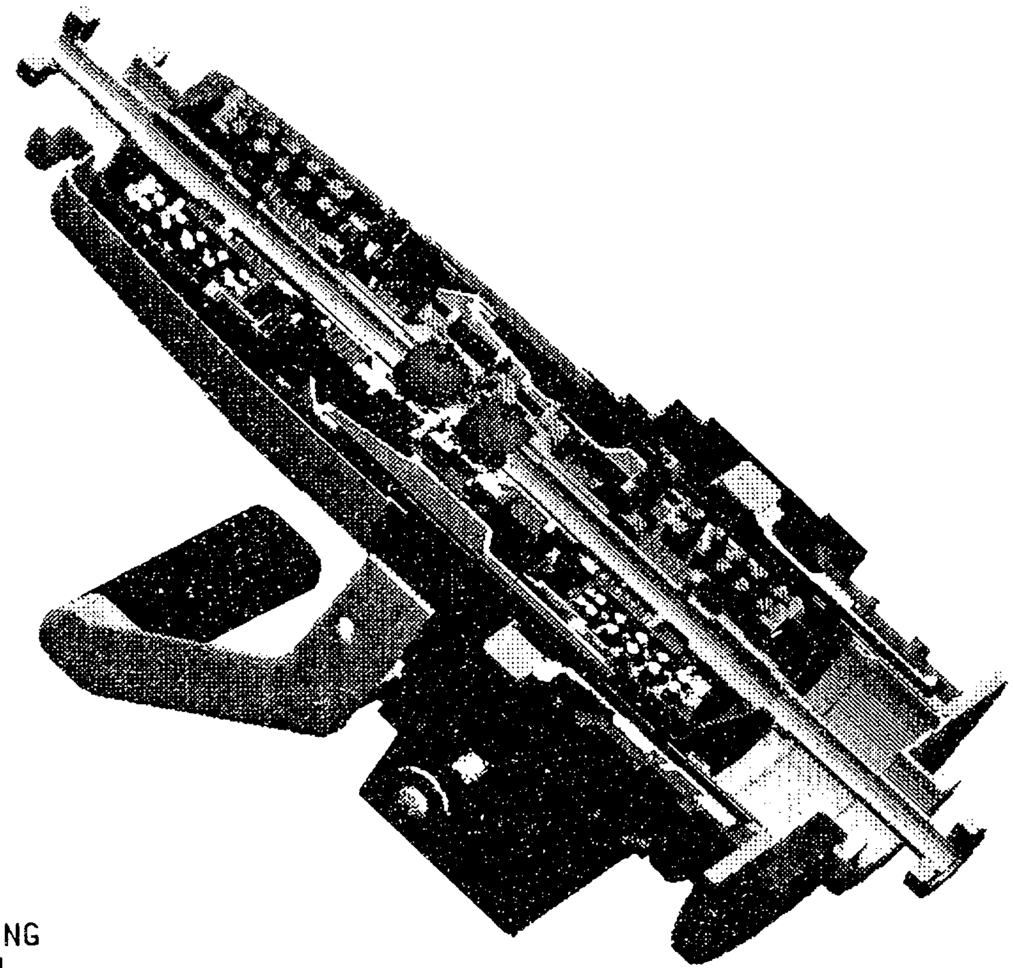


Many of the components required for successful He II resupply have been developed for SHOOT. Stepper motor driven cryogenic valves with no detectable leakage to superfluid have been developed for SHOOT by Utah State University. Repeatable, replaceable cryogenic burst disks have been developed by Katema Corp. Low throughput cryogenic relief valves for relieving trapped volumes have been developed by the Goddard Space Flight Center (GSFC). A thermomechanical (TM) effect pump capable of flow rates in excess of 900 liters per hour and pressures above one half an atmosphere has been developed at GSFC. In addition, the GSFC has developed phase separators that work at high flow rates with little pressure drop and other separators that work with He I and its vapor as well as He II. The mass gauging technique used in SHOOT will be a more sensitive version of the heat pulse method of heat capacity determination first used in space in the Superfluid Helium Experiment aboard Spacelab 2. Our sensitivity should be 1%. To measure flow rates a non-cavitating venturi will be used. Also, by measuring the heater power and outlet temperature of the thermomechanical pump the flow rate may be determined. An EVA compatible coupler has been partially developed for Johnson Space Center (JSC) by Moog and Ball Aerospace. The present design has some drawbacks in performance, weight, complexity, and cost. An improved version should be developed.

FLUID MANAGEMENT TECHNOLOGY DEVELOPED FOR SHOOT

- EVA COMPATIBLE He II COUPLER DEVELOPED FOR JSC BY MOOG AND BALL
  - -- FLIGHT UNIT MAY NOT BE COMPLETED AND HAS DRAWBACKS
- STEPPER MOTOR DRIVEN CRYOGENIC VALVES DEVELOPED BY UTAH STATE U.
- REPEATABLE, REPLACEABLE CRYO BURST DISKS DEVELOPED BY KATEMA
- CRYO RELIEF VALVES DEVELOPED AT GSFC
- TM PUMP DEVELOPED AT GSFC
- PHASE SEPARATORS FOR HIGH FLOW RATES AND He I AS WELL AS He II
- MASS GAUGING WILL BE MORE SENSITIVE VERSION OF HEAT PULSE TECHNIQUE USED IN SPACELAB 2 SUPERFLUID HELIUM EXPERIMENT
- VENTURI FLOWMETER ALONG WITH TM PUMP TEMPERATURE MEASUREMENTS WILL BE USED

Cut away view of the He II EVA compatible coupler developed for JSC by Moog Corp.



HE II COUPLING
SECTION VIEW
BOTH HALVES MATED
2/3/89
MOOG INC., SPD

The most critical components that require the low gravity environment of space to demonstrate its operation fully are the liquid acquisition devices. Simply stated, the devices must deliver liquid to the pump inlet at the required flow rates (up to say 1000 liters per hour in the low g environment. To keep operations from being frequently interupted, adverse accelerations (accelerations which tend to settle the bulk liquid away from the pump) of up to 0.1 milli-g must be overcome by the liquid acquisition system. In the event of a larger acceleration that drives liquid away from the pump., the device must recover in a time much shorter than the total resupply time.

LIQUID ACQUISITION DEVICES FOR ON ORBIT TRANSFER

- MUST DELIVER LIQUID TO THE PUMP INLET AT THE REQUIRED FLOW RATE EVEN IN THE PRESENCE OF ADVERSE ACCELERATIONS
  - -- ACCELERATIONS OF THE ORDER OF 10^{-4} SHOULD BE OVERCOME
- DESIGN MUST ALLOW RECOVERY IN SHORT TIME IN THE EVENT OF LARGER SUSTAINED ACCELERATION

SHOOT has selected two types of liquid acquisition devices, both of which use surface tension to keep vapor away from the pump inlet. The first type is a screened channel made of a fine mesh screen covering a stainless steel duct. The screen to be used for SHOOT is similar to that which may be applicable to liquid hydrogen as well. It is a 325 X 2300 Dutch twill weave. The other type of liquid acquisition system uses vanes feeding a sponge reservoir which surrounds the TM pump.

The screened channel device, designed and made by Martin-Marietta, operates by preventing the passage of vapor through a wetted screen by the surface tension of the He II. The relatively low value of this surface tension (about 0.34 dynes/cm) requires the use of fine mesh to keep the vapor out. Even so, a relatively small helium head of a few centimeters is enough to break through this screen in one g. Small scale tests of this device have been performed at GSFC and Martin-Marietta. Large scale tests are on-going at the University of Wisconsin. The calculated performance of the screen can be seen only for short periods of time before cavitation in the superfluid column occurs. The cause of this cavitation is as yet unexplained, although it has been observed by many experimenters over the last 30 years. At relatively low pressure heads, cavitation is infrequent, however, lending hope for the success of this device in space use.

The sponge material used in the second liquid acquisition system is made from foam silica, similar to that used in the thermal protection system on the shuttle. Wicking and pressure drop measurements have been made at the GSFC and the University of Wisconsin on this material. The sponge will act as a "high"-g reservoir for the pump. The vanes which feed the sponge are mylar sheet arranged radially in the tank. The advantage of this type of device is the predictable recovery from an adverse acceleration. Its disadvantage is that an adverse acceleration of just over 0.1 milli-g is enough to disrupt the flow to the pump.

LIQUID ACQUISITION DEVICES FOR SHOOT

- SHOOT HAS SELECTED TWO TYPES OF DEVICES USING SURFACE TENSION
  - -- SCREENED CHANNEL DEVICE (325 X 2300 DUTCH TWILL)
  - -- SPONGE / VANE COMBINATION (LOW DENSITY SILICA AND MYLAR VANES)
- TESTING OF SCREENED CHANNELS AT MARTIN-MARIETTA, GSFC AND U. OF WISCONSIN INDICATE PROBABILITY OF SUCCESS
  - -- INFREQUENT CAVITATION AT LOW PRESSURE HEADS
  - -- CALCULABLE PERFORMANCE FOR RELATIVELY SHORT TIMES
  - -- MORE TESTING TO BE PERFORMED
  - -- FINAL DATA FROM SHOOT FLIGHT
  - -- LIQUID / VAPOR DETECTORS TO AID IN FAILURE AND RECOVERY DETECTION
- SPONGE MATERIAL HAS BEEN INVESTIGATED BY GSFC AND U. OF WISCONSIN
  - -- ADVANTAGE IS PREDICTABLE RECOVERY FORM CAVITATION
  - -- DISADVANTAGE IS LOWER SUSTAINABLE NEGATIVE HEAD, AND MORE IMPEDANCE TO FLOW

The photograph shows a screened channel device without the screen with liquid/vapor detectors strung along its length. These low dissipation devices developed at the GSFC will aid in the measurement of the screened channel performance relative to cavitation and recovery.

To summarize, there are many applications for He II in space, some of which have already flown, or are being planned. The space station may play an important role in many of these uses as either a base of operations, for servicing or as a transportation node. Space station issues of venting and servicing connections must still be addressed. Most of the resupply technology issues for He II are being addressed by the SHOOT Flight Demonstration. However, a better design of the transfer line coupler is needed. In addition, more extensive study of liquid acquisition in low gravity will help in predicting behavior of future systems.

SUMMARY

- MANY SPACE APPLICATIONS ARE PLANNED FOR SUPERFLUID HELIUM
- SPACE STATION MAY PLAY AN IMPORTANT ROLE AS BASE OF OPERATIONS, SERVICING, OR TRANSPORTATION NODE FOR RESUPPLY FOR THESE USERS
- MOST RESUPPLY TECHNOLOGY ISSUES FOR He II ARE BEING ADDRESSED BY THE SHOOT FLIGHT DEMONSTRATION
- BETTER DESIGN OF EVA COMPATIBLE COUPLER IS REQUIRED
- MORE EXTENSIVE STUDY OF LIQUID ACQUISITION TECHNIQUES IS DESIRABLE
- SPACE STATION ISSUES OF VENTING AND SERVICING CONNECTIONS MUST STILL BE ADDRESSED

* U.S. GOVERNMENT PRINTING OFFICE: 1990--730-163/E4549