SUPERFLUID HELIUM ON ORBIT TRANSFER (SHOOT)

Michael J. DiPirro
NASA Goddard Space Flight Center
Greenbelt, Maryland

A number of space flight experiments and entire facilities require superfluid helium as a coolant. Among these are the Space Infrared Telescope Facility (SIRTF), the Large Deployable Reflector (LDR), the Advanced Xray Astrophysics Facility (AXAF), the Particle Astrophysics Magnet Facility (PAMF or Astromag), and perhaps even a future Hubble Space Telescope (HST) instrument. Because these systems are required to have long operational lifetimes, a means to replenish the liquid helium, which is exhausted in the cooling process, is required. The most efficient method of replenishment is to refill the helium dewars on orbit with superfluid helium (liquid helium below 2.17 Kelvin). To develop and prove the technology required for this liquid helium refill, a program of ground and flight testing was begun. The flight demonstration is baselined as a two flight program. The first, described in this paper, will prove the concepts involved at both the component and system level. The second flight will demonstrate active astronaut involvement and semi-automated operation. The current target date for the first launch is early 1991.

This paper describes the objectives of the program, some of the critical components developed for the flight, and the progress to date in their development.

A number of space facilities will require superfluid helium (SFHe), that is liquid helium below 2.17 Kelvin (K), to cool individual instruments or the entire facility. These facilities are required to have long lifetimes, and since the helium is gradually expended to provide cooling, it must be replenished. By far the most economical method would be to resupply the superfluid helium to the facility on orbit. The technology necessary to accomplish this is to be demonstrated by the SHOOT Flight Demonstration. Critical components must be designed, developed, and where feasible, tested on the ground. The complete system, including fluid acquisition devices which cannot be adequately tested on the ground, must then be tested on orbit. Diagnostic instrumentation, such as mass gauging instruments, flow meters, and perhaps liquid/vapor detectors will also be developed and demonstrated on this mission.

The SHOOT experiment as pictured here atop a Multi Purpose Experiment
Support Structure (MPESS), consists of two 210 liter capacity liquid
helium dewars with demountable cryostats and electronics for control
and data acquisition. The entire assembly excluding MPESS and
Hitchhiker avionics weighs 950 pounds. The dewars are designed to
allow the removal of any critical component to allow easy changeout.
To this end nearly all the components, including valves, plumbing,
burst disks, couplings, wiring, and instrumentation are part of the
removable cryostats. The dewars are linked by a vacuum jacketed
transfer line, through which the superfluid helium may be pumped in
either direction.

SUPERFLUID HELIUM ON ORBIT TRANSFER
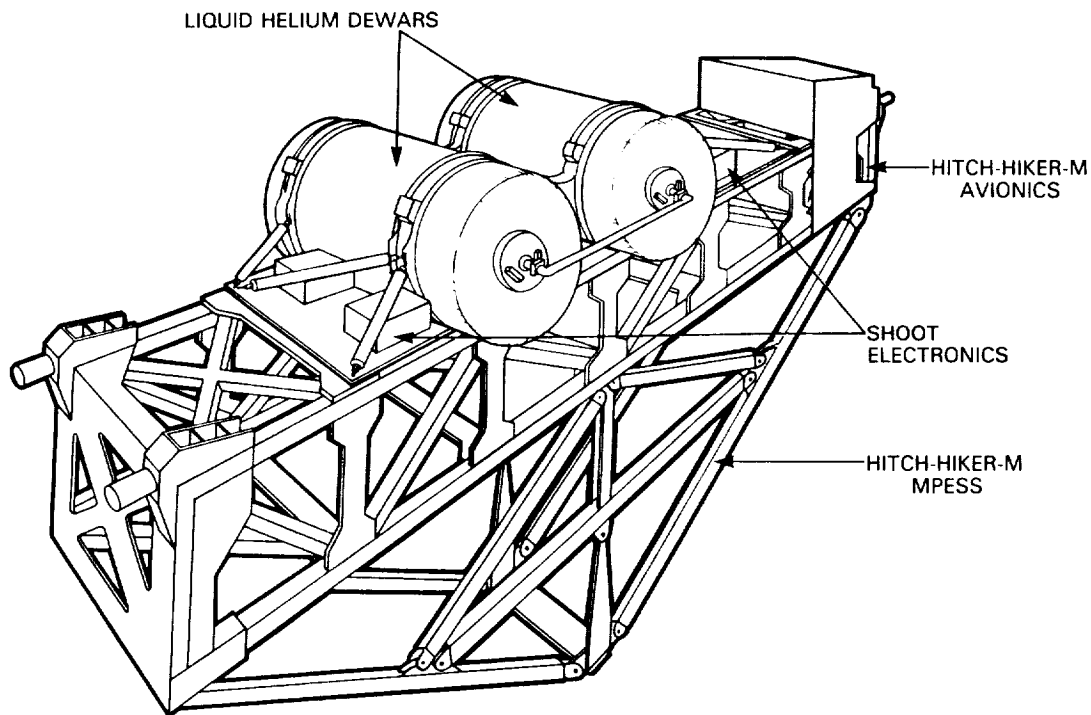# FLIGHT DEMONSTRATION

Figure 1

Figure 2 is a schematic of the dewars and cryostats emphasizing the valving and plumbing. The cryostats are identical to allow each to operate as the supply or the receiver dewar. This gives more time for experimentation allowing helium to be transferred back and forth between the two dewars. A typical transfer sequence goes as follows:

o Initial state: valves A,B,C,D,E closed, valves F,G,H open, transfer line warm

o Precool transfer line: open valves B(source), E(receiver), start pump

o Begin transfer: open valves C,D(receiver), D(source), close valve E(receiver), adjust pump for optimum flow

o Monitor transfer: perform mass gauging operation, flow checks and temperature checks

o Stop transfer: stop pump, close valves B,D(source), C,D(receiver), open valves E
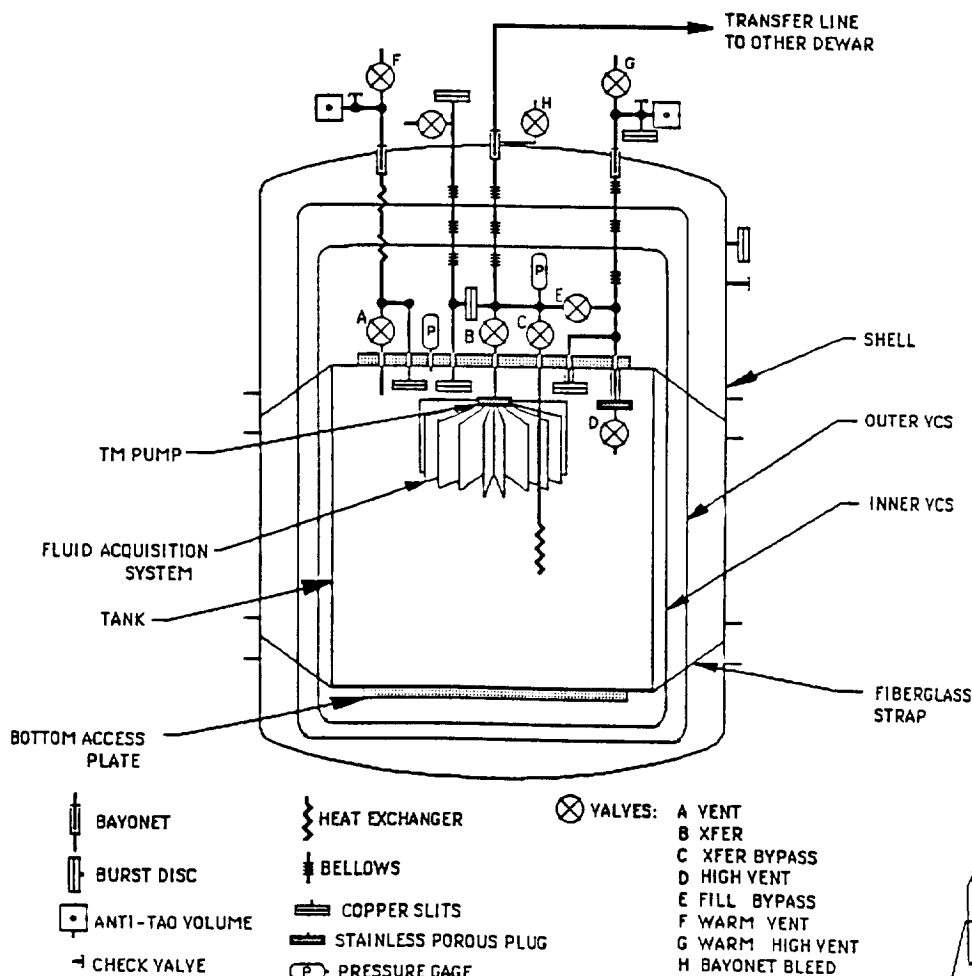
SHOOT DEWAR & CRYOSTAT WITH TM PUMP

Figure 2

127

Containing liquid helium within the dewars in a low g environment requires a method to separate the liquid phase from the vapor phase. In previous superfluid helium space dewars this function was performed by a porous plug; a disk made of sintered metal powder with an interconnected array of pores of the order of a few microns in diameter. Phase separation is achieved utilizing the thermomechanical (TM) effect, a property unique to superfluid helium. Briefly, the effect is described as follows. SFHe may be modeled as two interpenetrating fluids, a "normal" fluid with a viscosity and the ability to transport heat (entropy), and a "super" component having zero viscosity and entropy. The relative densities of the two fluids are determined by the temperature; the lower the temperature the higher the proportion of super component. Referring to figure 3a, when container A is heated, the normal component moves from A to B carrying heat. Super component in B moves counter to the normal component to keep the relative densities of the two components and hence the temperatures of A and B nearly equal. This convective type motion of SFHe makes it a very good thermal conductor. When a constriction, such as a porous medium, is introduced between the two containers, the flow of the normal helium (and hence the heat) is impeded due to its viscosity, while the super component may still pass freely. The chemical potential difference between the hotter A and cooler B drives the super component into A as in Figure 3b. Net flow stops when the chemical potential due to the temperature difference is balanced by the hydrostatic potential due to the pressure head as in Figure 3c. This is the basis for the TM pump described later. Figure 3d indicates that if B were allowed to deplete, the porous plug would become a phase separator, with liquid boiling at its surface and the TM pressure overcoming the saturated vapor pressure to contain the liquid in A.

The pore size and total cross-sectional area is crucial to the proper operation of the porous plug. The pores must be small enough to restrict the flow of normal component, but at the same time be large enough to carry heat out of the dewar to the outer surface of the plug where evaporation of the helium, and hence the cooling, takes place. Furthermore, if the pores are too small for the heat load, the TM pressure will be large enough to drive the liquid back into the porous plug allowing only vapor through the pores, increasing the pressure drop and hence the temperature within the dewar. Reference 1 contains further details. The high vent porous plug on SHOOT downstream of Valve D is sized to accomodate 2 to 30 Watts of heat input to the dewar, typical values for the heat generated in the supply dewar during transfer. Valve D will be closed at other times to prevent SFHe from escaping through the rather large pores of this plug.

THERMOMECHANICAL EFFECT

(a) $T_A = T_B$

(b) $2.17\,K > T_A > T_B$

(c) $\varrho g h = \varrho s(T_A - T_B)$
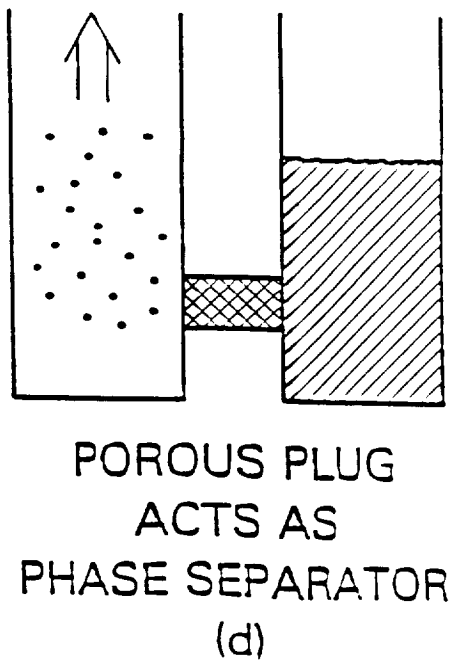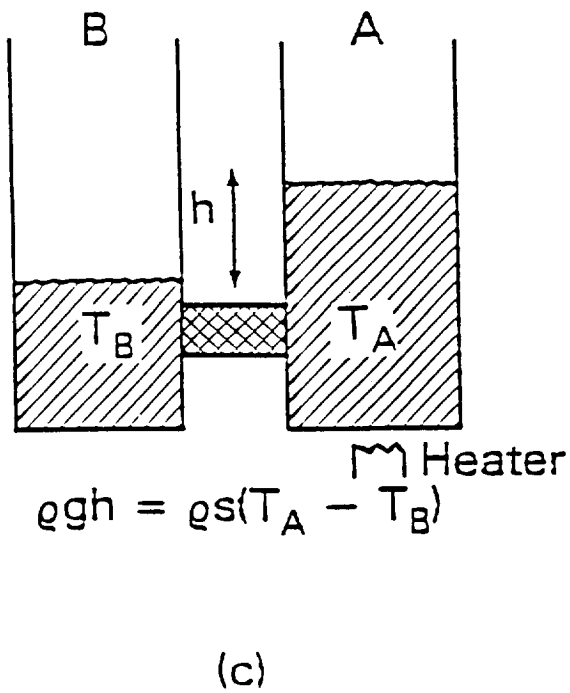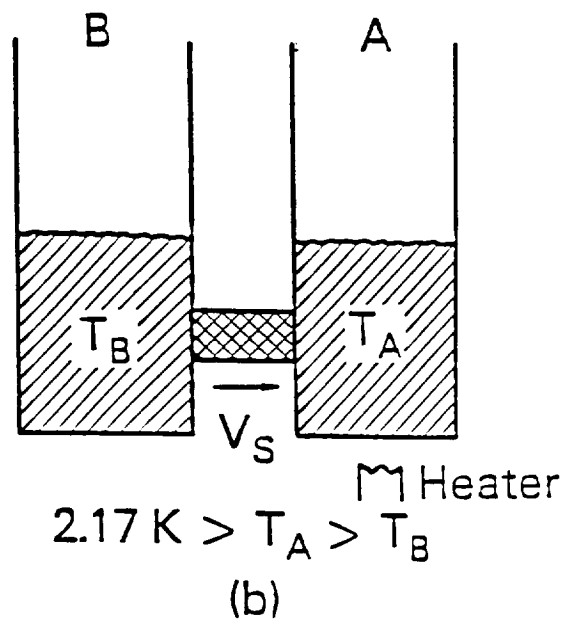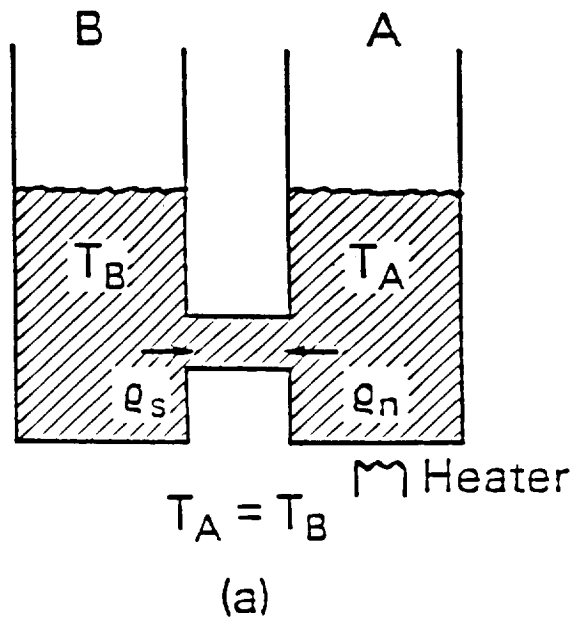
(d) POROUS PLUG ACTS AS PHASE SEPARATOR

Figure 3

The previous method of phase separation works only with SFHe. With liquid above the superfluid transition temperature such as will occur during cooldown of a warm dewar, another method of phase separation must be devised. We are presently developing a thermodynamic phase separator which will also work with SFHe at low flow rates. The principle is to force the escaping liquid off the liquid/vapor coexistence curve by limiting flow and heating. To be efficient, all the heat must be obtained from the remaining liquid within the dewar. The phase separator must provide adequate heat and fluid flow to cool the remaining liquid in a reasonable time and at the same time, not compromise the fluid retaining capability for SFHe to a degree such that a low level adverse acceleration would overcome the TM pressure. Further details are given in reference 2. The conditions require small, relatively uniform flow paths surrounded by high thermal conductivity material. We are trying two geometries to accomplish this. The first is shown in Figure 4, consisting of a number of approximately 5 micron wide slits in parallel fabricated from high conductivity 99.999% pure copper. The second technique being used by Alabama Cryogenic Engineering is to make a number of parallel pores of approximately 1 to 1.5 micron diameter in OFHC copper.

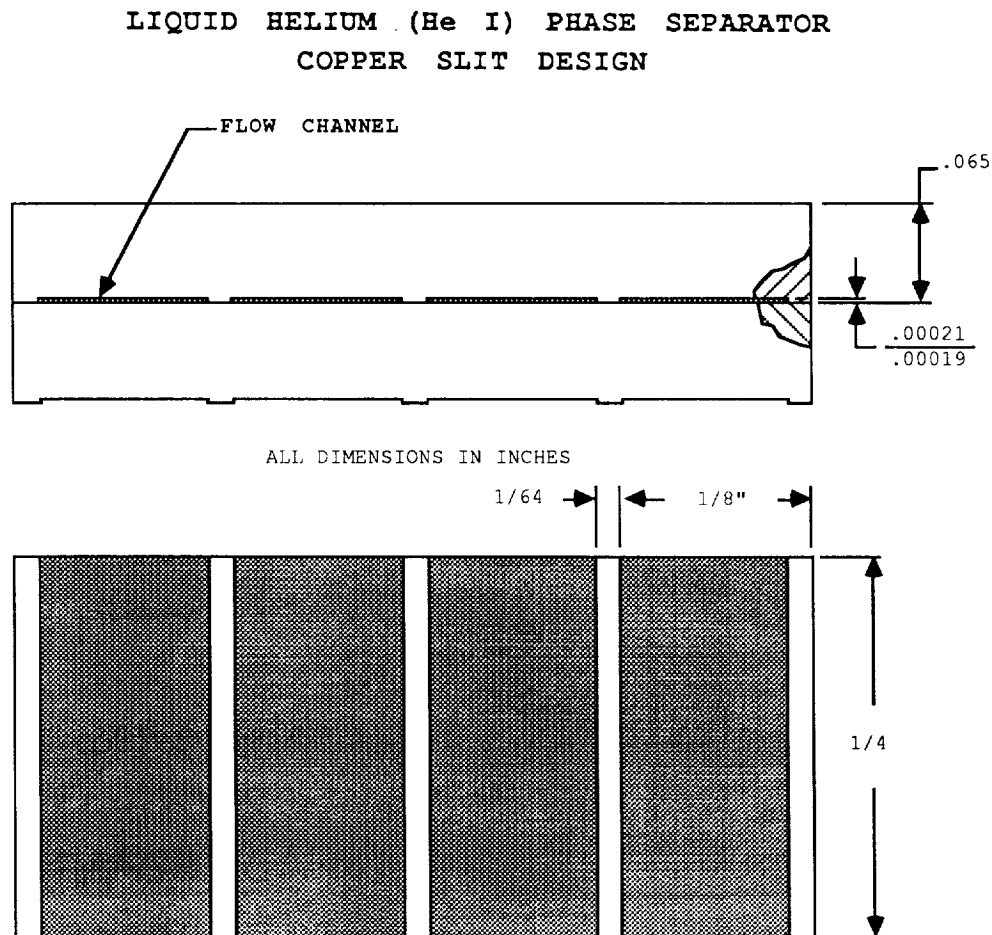LIQUID HELIUM (He I) PHASE SEPARATOR
COPPER SLIT DESIGN

Figure 4

The TM effect as previously described has been known for a few
decades. It has also been used on a laboratory scale as a pump to
move small amounts of SFHe. We have been developing a TM pump for
use on SHOOT capable of transfer rates in excess of 500 liters per
hour. As first steps in the development of this pump we have made
and tested two smaller versions; one using a porous plug of the type
used in the Infrared Astronomy Satellite (IRAS), and the second using
a porous plug of much smaller pore size. In both cases the plugs
were much smaller in diameter (by factors of 6 and 5 respectively)
than the SHOOT TM pump will require. The main limitation of our
ground based system has been the relatively low pumping speed of our
helium bath mechanical pumps when compared to the flight vent system.
As the mechanical pump system is upgraded, the size of TM pump and
hence the maximum SFHe transfer rate will be increased to near that
expected in flight.

Figure 5 is a schematic of the SHOOT TM pump, a relatively simple
device using a porous plug with nominal 1 micron diameter pores, a
woven wire heater on the downstream side and germanium resistance
thermometers (GRT'S) on both sides to monitor performance.
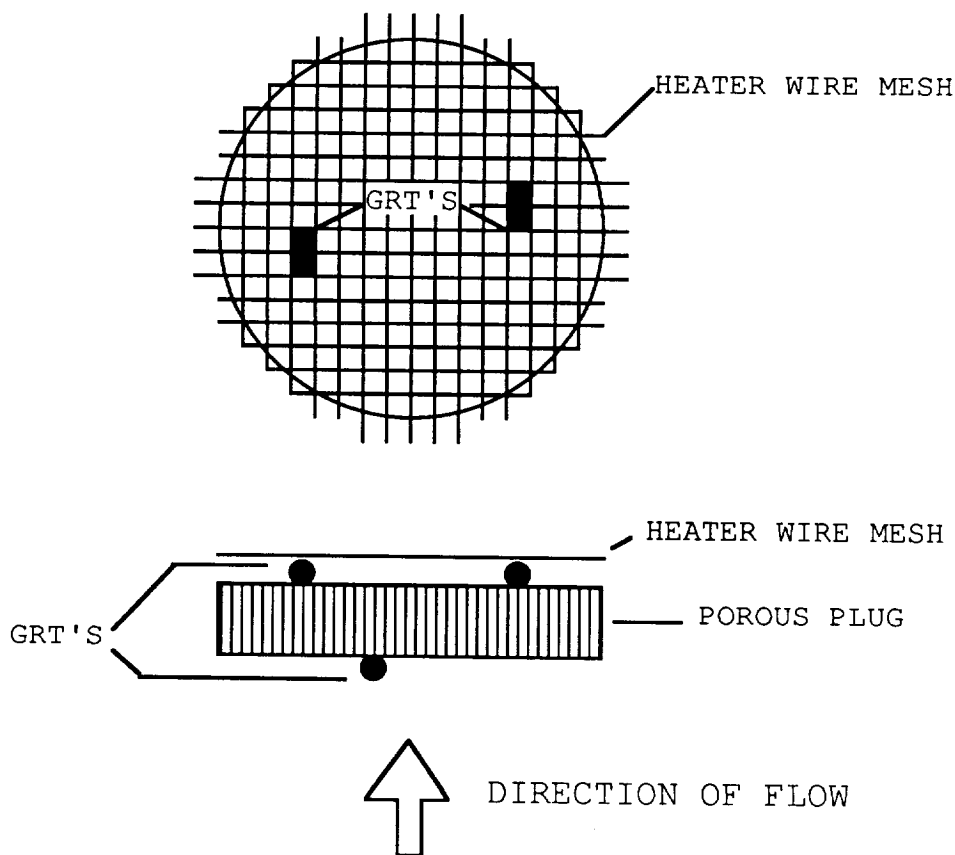
TM PUMP SCHEMATIC

Figure 5

Laboratory test results, plotted as efficiency versus transfer rate, are shown in Figure 6. Efficiency is defined here as the mass transferred divided by the mass removed from the source dewar. The amount transferred is reduced by the mass that would be lost in order to pump the receiver back down to the temperature of the SFHe in the source dewar. All values are approximately those of steady state, i.e., start up transients were excluded from the data.

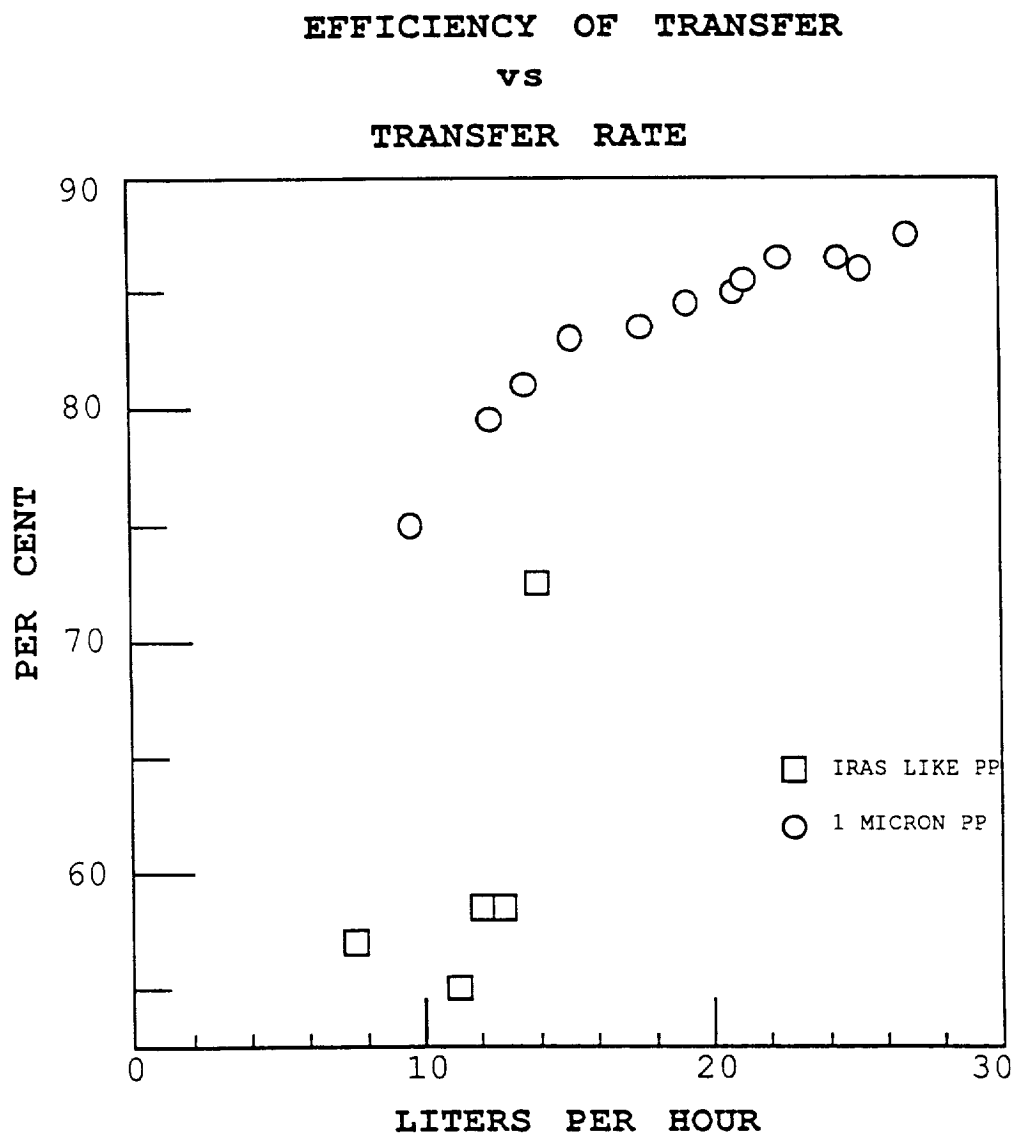**EFFICIENCY OF TRANSFER**

**vs**

TRANSFER RATE

Figure 6

The majority of the losses in these measurements was due to the parasitic heat leak into the SFHe from the transfer line. In the first case the heat leak was approximately 3 Watts and in the second 2 Watts. The heat leaks resulted from bayonet couplings in the first case and lack of Multilayer Insulation (MLI) in the second. While these heat loads would be acceptible for a full up flight system (the goal is 3 Watts for SHOOT), they are comparitively large when the transfer rate is small as in these subscale experiments. The next ground test set up will use a much better insulated transfer line with a state-of-the-art bayonet coupling as described in the next section. Figure 7 indicates the performance of the lab TM pumps when the transfer line parasitic heat leak is scaled back to 0.15 W. The ideal efficiency of the TM pump is strongly dependent on the source dewar temperature, however for the expected range of temperatures the ideal losses are calculated to be between 1.5 and 4 %.

EFFICIENCY OF TRANSFER
vs
TRANSFER RATE

CORRECTED FOR HEAT LEAK

Figure 7
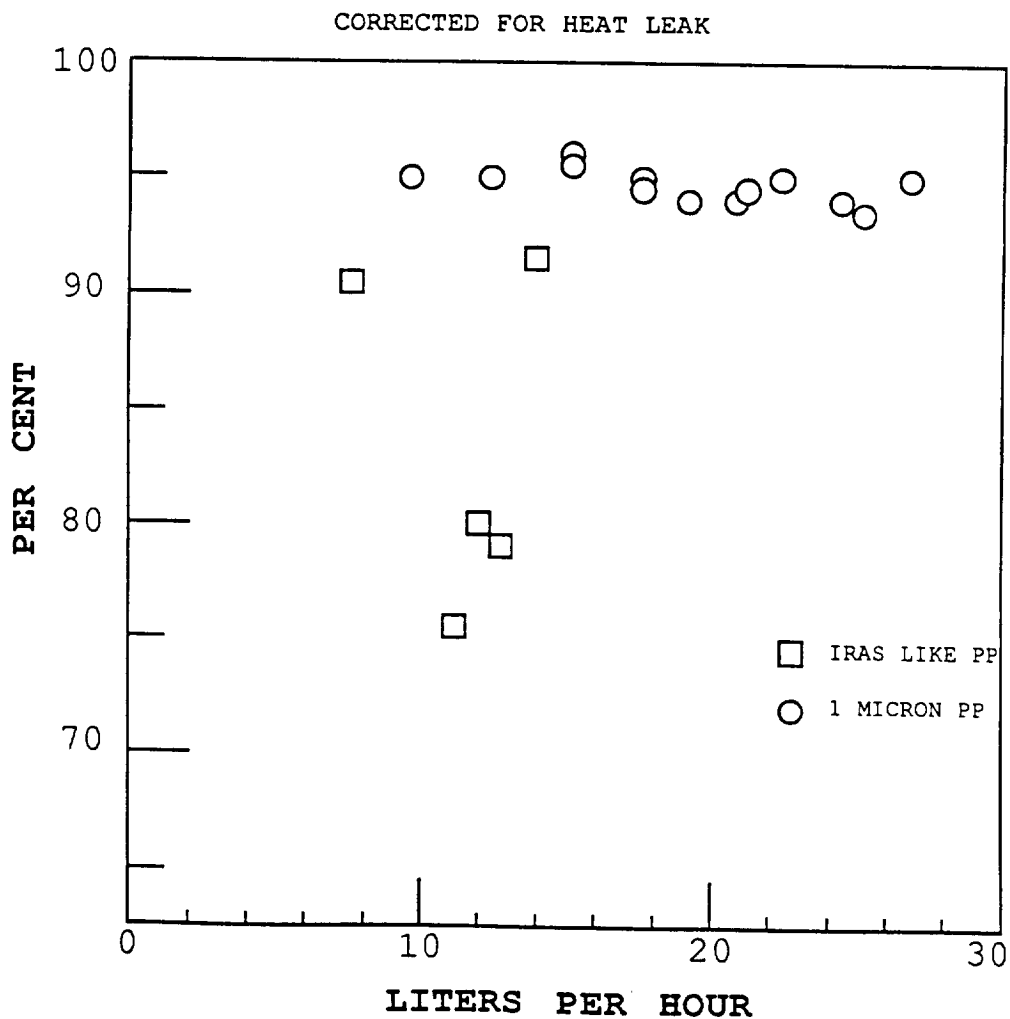
One of the largest potential parasitic heat leaks is due to the transfer line coupler. Prior to 1986 the lowest heat leak for a such a coupler was about 1.3 W, due mostly to conduction down the bayonet walls and leaks past rudimentary nose seals. Cryolab, Inc. designed and developed a high performance bayonet coupler for potential use in SHOOT. The results of tests using SFHe indicated a remarkably low 0.25 W heat leak into the nominal 0.5 inch diameter line. (See Reference 3.) Figure 8 shows the design of the laboratory model produced by Cryolab. Many of these design features may be incorporated into the flight couplings to be used in SHOOT.
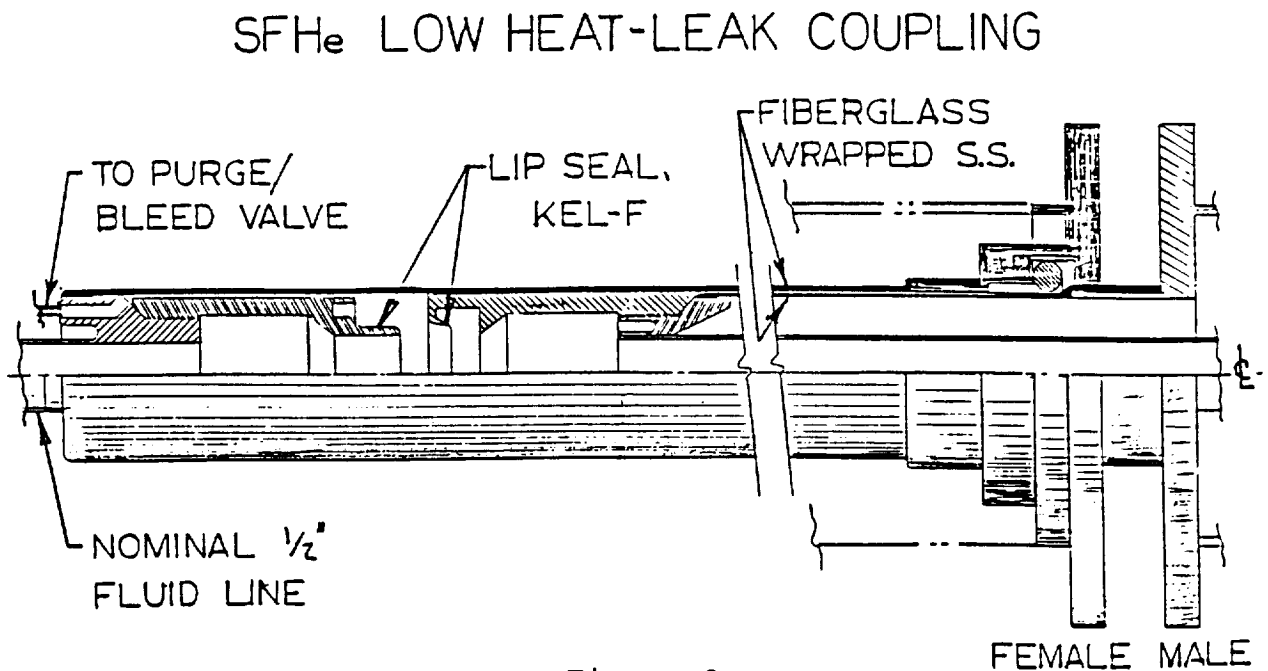
SFHe LOW HEAT-LEAK COUPLING

Figure 8

One component that requires a long term micro-g environment to be fully tested is the fluid acquisition system that provides SFHe to the pump inlet at a rate equal to the desired transfer rate. The present concept for the fluid acquisition system uses two parts: a sponge in intimate contact with the pump inlet, and either a screened channel or capillary system along the dewar walls providing SFHe to the sponge. The screened channel system uses a differential pressure to move liquid into the channels with the fine mesh screen preventing gas from entering the channel due to surface tension. For most liquids a differential pressure can be easily maintained, however, due to the high thermal conductivity of SFHe a temperature differential and hence a pressure exceeding the saturated vapor pressure will be difficult to accomplish. The only hope for this technique is the fact that the fine mesh of the screen will limit the heat flow by limiting the flow of normal component. As an alterate, a capillary action device such as closely spaced fins or wires along the dewar walls may be used. Laboratory tests of a subscale model of a screened channel device prepared by Martin Marietta Corporation are being readied at Goddard to aid in the device selection.

OTHER COMPONENTS

o Cryogenic valves - stepper motor driven SFHe leak tight valves able to operate at SFHe temperature

o Burst disks - relief devices to prevent crogen tank burst, precisely calibrated to burst at 22 psid at liquid helium temperatures

o Electrical feedthroughs - SFHe leak tight multi-pin electrical feedthroughs for use at liquid helium temperature

o Mass gauging instrumentation - 0.00005 K precision, 0.001 K accuracy GRT's and readout system and heaters for heat capacity mass determination

o Flow meter - possible use of venturi type or heat transport type flow meter in transfer line

o Other instrumentation - diagnostic GRT's and heaters, pressure transducers, and possible liquid/vapor phase detectors

SUMMARY

A need has arisen for the replenishment of SFHe in space. To prove the enabling technology the SHOOT flight demonstration will test components and the system aspects necessary for the transfer and fluid management of SFHe in orbit. Currently, components such as the cryogenic valves, quick connect fluid coupling, SFHe pumps, phase separation devices and a fluid acquisition system are being developed and tested in the laboratory. SHOOT is being readied for launch aboard the shuttle in early 1991.

REFERENCES

1. M. DiPirro, F. Fash, and D. McHugh, "Precision Measurements on a Porous Plug for Use in COBE", Proceedings of 1983 Space Helium Dewar Conference, ed. by J.B. Hendricks and G.R. Karr, (1983), p.121.

2. M. DiPirro and S. Castles, "Superfluid Helium Transfer Flight Demonstration Using the Thermomechanical Effect", Cryogenics 26, (1986), p.84. This issue of Cryogenics has a number of papers on the subject of helium transfer.

3. G.E. McIntosh, D. Martindale, and D.S. Lombard, "Superfluid Helium Transfer Tube Quick Disconnect", Final Report on NASA contract NAS5-29224, report #500799.