

THE LOW TEMPERATURE MICROGRAVITY PHYSICS FACILITY

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Abstract

The Low Temperature Microgravity Physics Facility (LTMPF) currently in the design phase is a multiple user and multiple flight facility intended to provide a long duration low temperature environment onboard the International Space Station. The Facility will provide a unique platform for scientific investigations requiring both low temperature and microgravity conditions. It will be attached to the Japanese Experiment Module's Exposed Facility (JEM-EF) and can house two science instruments each flight. The Facility consists of a 180-liter superfluid helium dewar, a support enclosure, and control electronics. The facility will be launched full of cryogen, and retrieved after the cryogen is depleted. Industrial partners are responsible for building the reusable facility and standard parts of the instruments. Principal Investigators from universities and other institutions are contracted to develop major parts of the science instrument package. Detailed technical capabilities of the facility will be presented in this paper.

Introduction

The Low Temperature Microgravity Physics Facility (LTMPF) is the next step in a series of three very successful space flight low temperature experiments – The Superfluid Helium Experiment (1985), the Lambda Point Experiment¹ (1992), and the Confined Helium Experiment² (1997). This series of experiments have proven that very high-resolution experimentation can be implemented in the hostile environment of space. For example, it was shown that temperature can be measured to better than 0.1 nano Kelvin in space using Superconducting Quantum Interference Device (SQUID) magnetometers². These high-resolution components, which require operating at low temperatures, when combined with the microgravity condition due to the ISS's orbit, open the door to many exciting new investigations with the potential of making breakthrough findings. The LTMPF is designed to broaden investigation opportunities requiring these high-resolution capabilities in Space. Already, there are six investigations planned for the first two flights. To meet the demands of the science community, the Jet Propulsion Laboratory has partnered with Ball Aerospace and Technologies Corporation (BATC) to build the dewar and the facility enclosure. Design-Net Engineering has been selected to develop the electronics and software, and Swales Aerospace has been selected to help build the instrument thermal mechanical structure. In the following, we will describe the design and the capabilities of the facility.

System Design and Capabilities

Figure 1 below shows the LTMPF. It consists of the dewar, the electronics, the radiators, the science instruments which mount inside the dewar, and the facility enclosure that houses the dewar, the electronics and various interface components.

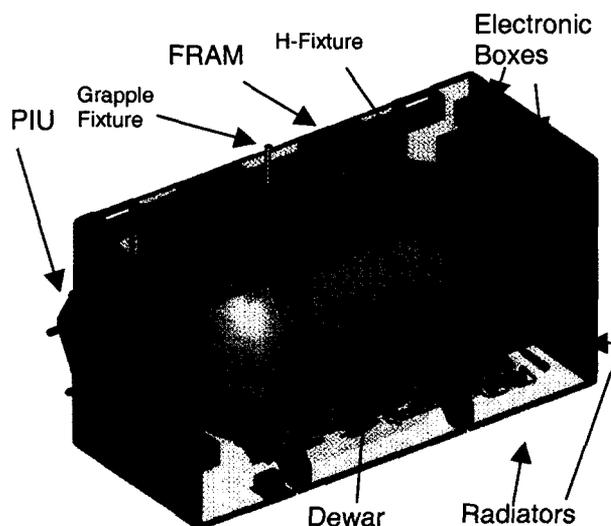


Figure 1: LTMPF overview.

These interface components will be provided to LTMPF by ISS and NASA. They consist of the Grapple Fixture for the JEM robotic arm to hold onto; the Flight Releasable Attachment Mechanism (FRAM) for attaching to the launch carrier and the ISS robotic arm, and the Payload Interface Unit (PIU) for attaching to the JEM-EF and accessing the 120 V DC electrical power and the communication interfaces. The first of three VME chassis is used to control the dewar and to communicate with the ISS; the other two electronics assemblies are used to control experiments in the two cryogenic inserts. Tools on the end of the space station robotic arm also interface with the H-Fixture for transferring the payload to and from the Shuttle. The maximum power available to the electronics during the mission is limited by the ability of the radiators to reject heat of about 235 W. Uplink low rate commands of no more than 864 bits/sec. are provided for the payload through a 1553B interface, and the high-speed downlink telemetry for the data is capable of handling 1.5 Mbps using Ethernet. Total mass of the LTMPF is limited to 600 Kg and the envelope size is 1.85 m by 0.816 m by 1.037 m.

Dewar Design and Capabilities

The dewar contains approximately 180 liters of liquid helium and is expected to last about 4.5 months on orbit. The cross section is not cylindrical, but oblong in shape to maximize the use of the available volume within the Standard JEM-EF envelope. This large volume also helps the dewar to stay below the superfluid transition temperature, without active evacuation, for 112 hours prior to launch, so that full science time can be achieved if launched within the first 2 attempts. If launched at the third and later attempts the on-orbit science time will be reduced. The dewar is designed to operate at a base temperature of 1.6K. It has two 20 cm diameter openings, one on each end, to allow two separate science instruments to be mounted. Shielded low conductivity wires are routed through the dewar vacuum space, while high current leads and coaxial cables are routed through the vent line tubing to allow for better heat exchange with the vent gas. The superfluid in the dewar permits the maintenance of a heat sink ($< 8\text{mW}$) at a stable temperature ($\sim 1.7\text{K} \pm 0.05\text{K}$) over many months.

Enclosure Design and Capabilities

The dewar's Vacuum Shell is the primary structural component of the LTMPF system. The electronics boxes and JEM-EF interface are mounted inside aluminum honeycomb panels that form a rectangular box around the system. The nadir-, wake, and part of the zenith-facing surfaces are thermal radiators while blankets cover the remaining panels. A separate honeycomb panel is used to support the releasable mechanism (FRAM) that attaches LTMPF to its launch carrier. These panels and the thermal design are being provided by BATC.

Electronics Capabilities

There are three main electronic assemblies each housed in a separate VME box with its own single board computer. The Facility Electronic Assembly controls the function of the dewar and handles power and communication with the JEM-EF. It provides housekeeping data on various parts of the dewar and controls the vent valves of the two instruments. Small heat pulses can be used to estimate the amount of helium remaining. In addition, it provides environmental data on charged particle radiation and acceleration by interfacing with an onboard charged particle monitor and a Space Acceleration Measurement System (SAMS) accelerometer provided by Glen Research Center.

The two Experiment Electronic Assemblies each control one science instrument. The standard boards support resistance measurements of Germanium elements to determine the temperature; low-, high-, and very high-precision heaters; high resolution measurements over extremely large dynamic ranges are made using DC superconducting quantum interference device (SQUID) magnetometers. Capability for relatively coarse temperature control is provided using germanium resistance thermometers and micro-watt heater elements. For more precise control at and near the science cell a paramagnetic salt pill coupled to a SQUID with a high-precision heater can control the temperature to better than 1 nK.. There are spare slots for Investigator's custom electronics boards unique to their experiment. All boards must conform to the VME64 standard with a 6U form factor and run with VxWork real time operating system.

The Facility electronics also include SQUID preamplifier/controller boxes that on one side interface with the high-resolution sensors inside the dewar and on the other a digital interface to a board in a VME chassis. On ascent a pressure-sensitive device or baroswitch and a battery pack are used to open a valve that allows the vacuum of space (above 100,000 feet) to pump on the liquid helium in the dewar and cool it down. In addition for the first mission a custom electronics box, the Capacitance Bridge Box will be used to make high-precision measurements of the pressure and density in one of the experiment cells.

Because of the ultra-high sensitivity of LTMPF's science cells and sensors the small amounts of heat left behind when a charged particle passes through these components represents a noise source; measurements from a charged-particle monitor can be correlated with the sensor-data noise to reduce their impact. In a similar fashion the accelerometer provided by the SAMS Project allows comparison of small vibrations with increases in signal noise. In this way Investigators are able to understand and mitigate a couple unwanted features of space experiments.

Insert Design and Capabilities

LTMPF provides to each Investigator a standard frame on which to build their cryogenic Insert. The assembled Insert for each science instrument is 20 cm diameter and 45 cm long. An Insert consists of a base plate (or Cold Plate) to which is mounted a thermo-mechanical truss (the Probe) which in turn supports the science cell and its actuators and sensors (the Instrument Sensor Package, or ISP). The science team integrates the unique components that they have developed in their laboratories on the standard Probe; they then attach the many wires and capillaries between the ISP and the Cold Plate required to control the experiment. The Cold Plate feeds those connections through a vacuum-tight interface into the Dewar vacuum space and ultimately to the outside of the dewar. The Probe interfaces the science instrument package to the dewar providing mechanical support and thermal isolation.

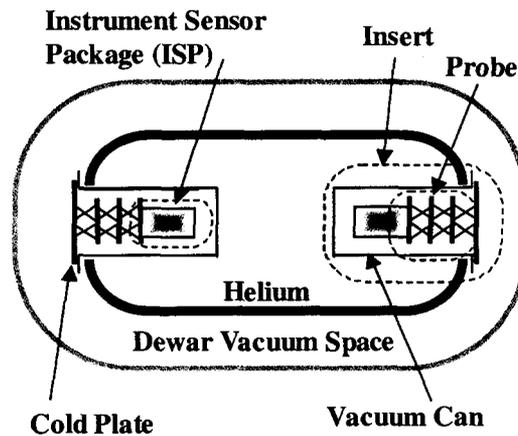


Figure 2: Dewar Interior.

The thermal mechanical structure, or Probe, provides mechanical support and thermal isolation to the science instrument package. It consists of high strength and low thermal conductivity struts intercepted by thermal isolation stages made of high thermal conductivity material. It is designed to support 8 Kg of mass during launch and provide enough thermal isolation for the inner most stage to be operating at sub-nano-Kelvin stability. Figure 2 shows a picture of one such structure made of stainless steel struts and aluminum thermal isolation stages. In tests, this structure survived 7.7 g rms random vibration while supporting a 6.2 Kg mass. Each thermal stage has also demonstrated an ability to intercept most of the heat variations from the previous stage, allowing only one part in 7000 to leak through to the next stage. With 3 stages, this is more than enough to allow thermal control to sub-nano-Kelvin stability.

The resonance frequency of the structure together with the supported mass is an important parameter in mitigating the launch-heating problem. It was successfully demonstrated by Cui et al⁴ that if this resonance frequency is sufficiently higher than the resonance frequency of the dewar, there is very little launch-heating. This implies that most of the heating arises from the flexing of the mechanical members of the instrument package. During testing, the structure shown in Figure 3 and discussed above had a resonance of 72 Hz compared with the 48 Hz resonance expected of the dewar. Thus we expect some mitigation of launch heating from this structure.

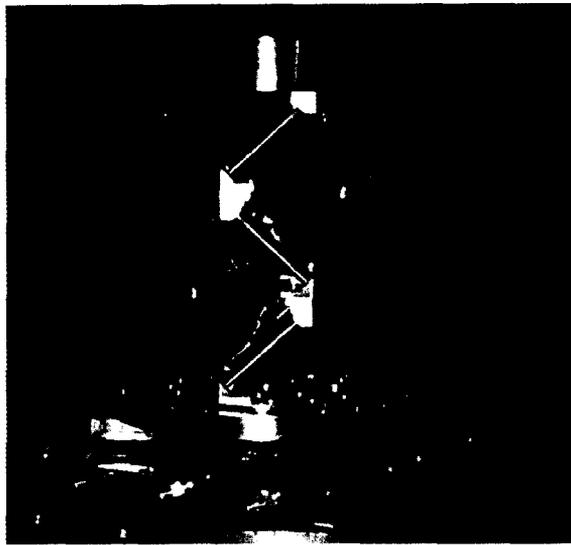


Figure 3: A picture of the thermal mechanical structure.

Vacuum Can and the Adsorption Pump

A Vacuum Can maintains a high vacuum around each Insert for thermal isolation purposes. As long as the vacuum can is leak tight against the surrounding helium in the dewar, maintaining a high vacuum should not be a problem, since all gases except helium freeze. It has been learned in previous flights that the science instrument package can heat up to close to 10K under the strong vibration of the launch if the Insert is launched in a vacuum. If the vacuum can is filled with ^3He -exchange gas the heat will be quickly conducted away from the ISP to prevent it from heating up. Once on orbit, the exchange gas is vented to space and an adsorption pump, with activated charcoal, will be used to absorb the rest of the gas. The adsorption pump's design and operation are described in detail by Lysek et al³.

Due to their high sensitivity to magnetic fields, SQUIDS are usually operated inside a dewar with an external magnetic shield. This type of magnetic shield is heavy, weighing perhaps as much as 30 Kg. A way to reduce weight is to locate the shield outside the vacuum can instead. The shield is being developed and will be made of a special magnetic material – Cryoperm⁴ 10, which is known to have permeability of 50,000 at low temperatures. It is expected to weigh less than 6 Kg and provides a magnetic environment with less than 10 mGauss of field variation inside.

Conclusion

The LTMPF currently under development will provide a unique environment of low temperature and microgravity for long duration. When the facility is ready for launch in late 2005, it will open up exciting new science investigation opportunities onboard the International Space Station. JPL will provide the necessary infrastructure and services to enable a user-friendly interface to the scientific community, making easy and low cost access to space a reality for scientists.

Acknowledgements

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