

# THE RECONFIGURATION OF THE LOW TEMPERATURE MICROGRAVITY PHYSICS FACILITY

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## ABSTRACT

The Jet Propulsion Laboratory (JPL) is building the Low Temperature Microgravity Physics Facility (LTMPF) as a multi-user research facility for the International Space Station. The LTMPF is a multiple flight facility that will provide a long duration low temperature environment for performing state of the art experiments that need to be performed in microgravity. During each mission, two distinct primary experiments can be accommodated. Secondary experiments utilizing the hardware built for the primary experiments will also be accommodated during each mission. The LTMPF will fly attached to the Japanese Experiment Module (KIBO) Exposed Facility on the outside of the ISS. Much progress and change have occurred recently on the LTMPF. Some of the flight hardware has been built, and prototypes of much of the remainder of the facility have been developed and successfully tested. During the summer of 2002, the initial flight of the LTMPF was delayed from late 2005 until early 2008 by a two years slip in the ISS manifest due to budget overruns. Further delays have occurred since because of the Columbia accident grounding the Shuttle fleet, but the LTMPF is still being developed for a launch readiness of early 2008. Also in early 2003, the experiments that will fly as part of the first mission were modified so that one Gravitational and Relativistic experiment and one Low Temperature Condensed Matter experiment will fly on the initial flight of the LTMPF. The experiments that will fly on the initial mission of the LTMPF will be DYNAMX and the Superconducting Microwave Oscillator Experiment (SUMO). Significant progress on the accommodation of the new experiment (SUMO) has been performed in the LTMPF design over the last 10 months.

## INTRODUCTION

The Jet Propulsion Laboratory (JPL) has been developing the Low Temperature Microgravity Physics Facility (LTMPF) since its inception in 1995. The LTMPF will be a multiple-user, multiple flight ISS Facility dedicated to breakthrough Fundamental Physics research requiring long-duration microgravity environments and a stable low temperature ( $T \sim 2K$ ) environment.

The LTMPF has evolved from JPL's legacy of developing and supporting low temperature payloads in space, both as part of astronomical satellites (IRAS, SIRTf), and Shuttle based micro-gravity experiments. JPL developed and flew a low temperature facility for micro-gravity experiments on the Space Shuttle three times from 1985 to 1997. The initial flight, in 1985, was part of Spacelab-2, and contained the Superfluid Helium Experiment (SFHE).<sup>1</sup> In 1992, the facility flew again as part of the first United States Microgravity Payload (USMP) with the Lambda Point Experiment (LPE)<sup>2</sup> installed. Finally, in 1997 the facility flew as part of USMP-4 with the Confined Helium Experiment (CHeX)<sup>3</sup> installed. All three of these experiments were highly successful, and they showed how to achieve extremely high precision measurements (sub-nano-Kelvin resolution temperature measurements, for example) in the hostile environment of space.

## LTMPF RECONFIGURATION

While the LTMPF has been in development since 1995, the Facility has been significantly reconfigured over the past year. These changes in the Facility have been caused by the change of the experiment complement for the first flight of the LTMPF.

In late 1999, the experiments for the initial flight of the LTMPF were selected to be Critical Dynamics in Microgravity (DYNAMX, Principle Investigator (PI) Prof. Robert Duncan of the University of New Mexico)<sup>4</sup> and the Microgravity Scaling Theory Experiment (MISTE, PI Dr. Martin Barmatz of JPL)<sup>5</sup>. The Facility design had been moving forward for over three years based on accommodating these two experiments. In February of 2003, NASA decided that the initial flight of the LTMPF should include a general relativity, clock based experiment that would complement the Primary Atomic Reference Clock in Space (PARCS) payload NASA was planning on flying concurrently with the first mission of the LTMPF. So, NASA moved the Superconducting Microwave Oscillator experiment (SUMO, PI Prof. John Lipa of Stanford University)<sup>6</sup> from the second flight of the LTMPF to the initial flight. MISTE was returned to the ground program along with the other selected mission-2

experiment. So no experiments were left in the flight program in development for the second LTMPF mission. The experiments for the second LTMPF mission will be selected through the competitive NASA Research Announcement process in the future.

The inclusion of this different experiment in the initial LTMPF payload has caused some significant changes in the Facility design. These changes along with a description of the Facility and the initial experiments will be covered in the remainder of this paper.

### CONCEPT

The LTMPF will be a self contained, reusable cryogenic facility that will accommodate a series of primary experiment pairs to be conducted attached at the Japanese Experiment Module Exposed Facility (JEM-EF) of the ISS. The LTMPF will expand upon the capabilities provided for the previous Shuttle based low temperature experiments. The Facility will provide a significantly longer duration of low temperatures for experiments beyond the approximately two weeks limitation imposed by the Shuttle. This longer duration enables experiments that need months in a microgravity environment to achieve their scientific goals. Because of the longer duration available to perform science, guest investigations using the primary experiments existing hardware will also be accommodated in the LTMPF.

The LTMPF will be transported to and from the ISS on the Space Shuttle. The facility will be launched full of cryogen, operated for approximately 4.5 months and retrieved some time after the cryogen is depleted. Once the Facility has returned to Earth, the experiments will be removed, the Facility refurbished, and the next set of experiments installed. The LTMPF will be able to be launched every 22 months with a new set of experiments, assuming the Shuttle is available to transport the Facility on this schedule.

### DESIGN

The LTMPF consists of a superfluid helium Dewar, an Enclosure, Electronics, Software, two independent experiment Instruments, and the government furnished equipment (GFE) necessary for interfacing with the launch vehicle, the remote manipulating systems, and the JEM-EF (see Figure 1). The Facility fits within the envelope of a standard JEM-EF payload, 1.85m X 1.0m X 0.8m. The facility mass will be less than 600kg to meet constraints imposed by the remote manipulating arms of the Space Shuttle and the ISS.

### Dewar and Enclosure Subsystem

The central feature of the Facility is the approximately 180 liter superfluid helium Dewar that enables the experiments to run at temperatures below 2K. The Dewar provides the main mechanical structure of the LTMPF. A set of lightweight aluminum honeycomb panels forming the Enclosure will be hung from the dewar to provide attachment sites for the electronics boxes, the radiators, the Payload Interface Unit (PIU), and for thermal blankets. Both the Dewar and Enclosure are being developed with modular designs to support easy refurbishments between flights

As can be seen in Figure 1, the cross section of the Dewar is ob-round, not circular, in shape to maximize the use of the volume available within the envelope of a JEM-EF payload. This large helium volume not only increases the lifetime of the facility, but the mass of helium also keeps the Dewar below the superfluid transition temperature without active evacuation prior to launch. During the last fill prior to launch, the helium and everything else in the Dewar will be cooled to as low a temperature as possible. Because of the small heat leak into the Dewar and the large thermal mass of the liquid helium, the helium will then warm slowly until the vent valve is opened a few minutes into launch.

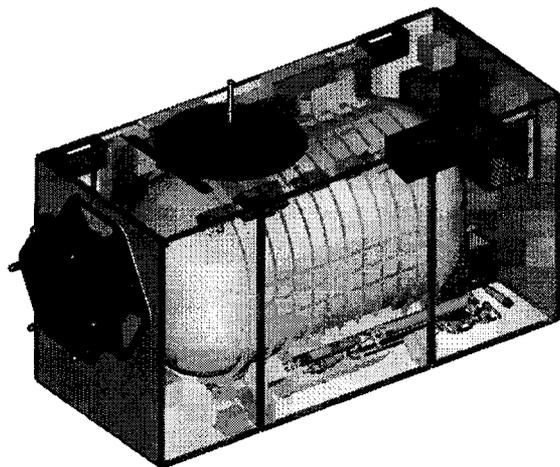
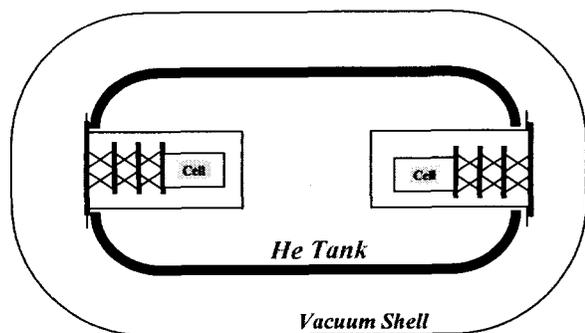


Figure 1: LTMPF overview.

Figure 2: Cartoon of the LTMPF Dewar and instruments.



The Dewar is currently being fabricated by Ball Aerospace and Technologies Corporation. The Dewar design is complete, and all major components of the Dewar either have been fabricated or are currently being fabricated. Ball has started the assembly of these components into the Dewar. In contrast, the Enclosure design has yet to be finalized.

#### Electronics and Software Subsystem

The Facility Electronics subsystem includes several electronic boxes mounted to the Enclosure for telemetry and control of the Facility and the scientific instruments located inside the Dewar. The electronic boxes include three 10 slot multi-card VME boxes, one for each experiment and one for the Facility. Each of these VME boxes includes an independent single board computer dedicated to run an experiment or the Facility. The Facility provides a standard set of boards in each box to measure and control temperatures, and heaters. Additional slots are available in each experiment's dedicated box for any custom electronics applications the experiment teams may have. Additional electronics boxes will house the most sensitive experiment amplifiers and controllers. These include custom boxes developed for the experiments and Superconducting Quantum Interference Device (SQUID) controllers. These boxes are located as close to the Dewar as possible and away from the potential noise source of the digital electronics in the main electronics assemblies. Radiators on the earth facing and aft facing sides of the LTMPF will be used to provide passive, vibration free cooling of the electronics.

The Software to run the Facility is being developed with an architecture that will allow the experimenters to run their experiments using Python scripts. Separate "C" modules are being developed to control the PI and Facility electronics boards which are callable from Python to create a fast and flexible software environment for the PI teams. The Software is being developed concurrently with the electronics

The Electronics and Software are being developed by Design Net Engineering. Engineering models of most of the Facility provided electronics have been built and

are currently under test along with the initial release of the flight software.

#### Instrument Subsystem

The final element and heart of the LTMPF are the two Instruments. Each Instrument includes a cryogenic insert and all the electronics, plumbing, cabling, and software necessary to perform the given experiment. As shown in Figure 2, the Dewar has two openings into the liquid helium volume, one on each end, to mount the two separate Instrument inserts. The inserts are installed inside individual vacuum cans each 20 cm in diameter and 45 cm long that sit in the Dewar helium bath. Each insert consists of the experiment specific sensor package developed by the science investigators and a cryo insert provided as a standard interface to the Dewar by JPL. The JPL provided cryo insert also provides mechanical support, thermal isolation and magnetic shielding for the cryogenic portion of the experiments.

Both PI teams have developed and tested prototypes of their instrument hardware. DYNAMX is currently building portions of their flight experimental sensor package, and the JPL provided cryo insert has been manufactured for both experiments.

#### Recent Changes in the LTMPF Design

Because of the experiment swap performed early in the year, significant modifications to the Facility design have been needed compared to the previous baseline design. Changes made in the past year include a redesign of the Dewar vent line to lower the on orbit temperature of the liquid helium bath from 1.6K to 1.4K, significant wiring modifications to accommodate the microwave drives needed for SUMO, reconfigured electronics boxes, and a redesigned magnetic shield to meet SUMO's strict requirements. Additionally, a lot of work has been spent on defining how SUMO and the LTMPF will interface with the PARCS experiment while both are on the JEM-EF to fully exploit the synergy of these two payloads.

#### EXPERIMENTS

As mentioned above, two primary experiments have been selected to fly on the first mission of the LTMPF. In addition, one guest investigation has also been selected to fly as part of the first mission, and a second guest investigation is in the flight definition phase. The decision will be made this summer on its possible inclusion on the flight.

All of the investigations were selected initially through the NASA Research Announcement (NRA) process. The NRA process chooses multiple candidate experiments to compete for the two primary slots available on each mission. These initial experiments were reduced to the two mission experiments through the standard flight experiment review process. As mentioned above, NASA chose to rearrange the experiments for inclusion on the first mission from what was originally a pool of four experiments selected to fly on the first two missions of the Facility under the process described above. The guest investigations for the first mission were selected from NRAs occurring after the primary experiments had been chosen.

#### DYNAMX and CQ

The DYNAMX experiment will study the behavior of helium under a very small heat flow very near the superfluid transition temperature. Starting with the experimental cell completely in the superfluid state, a constant amount of heat will be added to one end of the cell to raise the temperature of the helium until a small portion of the helium passes through the superfluid transition and becomes normal fluid. By monitoring the temperature as a function of time at three locations in the cell, the experiment will be able to measure many interesting properties of the helium (like the helium thermal conductivity) extremely close to the phase transition, and as a function of applied heat current.

The experiment the Heat Capacity at Constant Heat Flux (CQ, PI Prof. David Goodstein of the California Institute of Technology)<sup>7</sup> was confirmed almost two years ago as a guest investigation utilizing the DYNAMX hardware. CQ will measure the heat capacity near the superfluid transition in the presence of a steady applied heat flux to investigate the onset of normal-fluid behavior. CQ will use these measurements of the heat capacity as a function of temperature and heat flux to understand the transition temperature and to confirm ground observations of an enhancement of the heat capacity due to the applied heat flux.<sup>7</sup>

An additional guest investigation, CP (PI Prof. John Lipa, Stanford University) was selected from the 2001 NRA to possibly use the DYNAMX hardware. CP will be reviewed at a combined Science Concept and Requirements Definition Review this summer to determine if it will have authority to proceed to flight.

#### SUMO

SUMO belongs to a class of experiments exploring gravitational and relativistic physics using the

technological advantages provided by a low temperature microgravity environment. SUMO will perform gravitational and relativity experiments utilizing two perpendicularly mounted ultra-stable superconducting microwave cavity oscillators. SUMO can be used for both relativity and clock experiments either by itself or in conjunction with other types of clocks on the ISS or on the ground. As mentioned above, the motivation for moving SUMO to the first mission was to fly SUMO concurrently with the PARCS experiment. SUMO enhances the scientific return from PARCS because SUMO can be used as a local oscillator for other types of clocks like the cold-atom clock in PARCS.

#### CONCLUSIONS

The LTMPF is being built as a multiple-user, multiple flight ISS Facility dedicated to enabling breakthrough research requiring a long duration, stable, low temperature environment in a microgravity environment. The Facility has recently successfully passed its Critical Design Review, and is in the Implementation Phase for the first mission. The Facility is currently being developed to be fully tested and integrated in time for a launch as early as January 2008. The actual launch date for the LTMPF is likely to be no earlier than April 2009 due to the slips associated with the current grounding of the Space Shuttle fleet.

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