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Microgravity Scaling Theory Experiment

Experiment Implementation Plan
(DRAFT)

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Jet Propulsion Laboratory
California Institute of Technology

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2 Introduction

2.1 Purpose

Microgravity Scaling Theory Experiment (MISTE) is a candidate experiment competitively peer reviewed and selected for flight definition from the 1996 Fundamental Physics NASA Research Announcement (NRA). MISTE project has passed the science concept review (SCR) in Dec 98, and was recommended to proceed to the requirement definition review (RDR) on Nov 30, 1999. This document provides the experiment implementation plan through end-of-mission. This work is sponsored by NASA's Microgravity Science and Application Division and is managed by the Marshall Flight Center as part of the Microgravity program.

The experiment will be performed in the Low Temperature Microgravity Physics Facility (LTMPF) which will provide low temperature and microgravity conditions on board the International Space Station (ISS). The baseline of this experiment implementation plan (EIP) is to deliver MISTE science instruments, or equivalently, the integrated sensor package (ISP), conduct the experiment, and analyze/publish science data. The schedule and resources of this plan assume the current LTMPF project implementation plan.

2.2 Scope

This document addresses all elements required for the definition, development, test, launch, operation, and data analysis. Upon approval by JPL and the P.I. this EIP will be the baseline plan for the implementation of the MISTE flight project. Changes outside the control of the MISTE project, such as launch slip, invalid assumptions, or changes in LTMPF and ISS requirements, cannot be accommodated within this plan and may require additional resources.

2.3 General

The Microgravity Scaling Theory Experiment (MISTE) will perform static thermodynamic measurements along various thermodynamic paths near the liquid-gas critical point of ^{3}He in microgravity environment. Due to the strong divergence in compressibility of the fluid near its critical point (T_c=3.315K), the quality of Earth-bound experiments is hampered by the gravity rounding effect. The result of the successful microgravity flight experiment will provide better quality data to the scientific community. Historically, similar low temperature experiments studying the superfluid transition of helium have been successfully performed in a space shuttle using a low temperature facility. In the future, a new LTMPF will be built to provide a microgravity low temperature environment. Considering the range of temperature, pressure, and required hardware for the experiment, the MISTE became an ideal candidate experiment for the LTMPF on board ISS. A detailed description of MISTE science is given in the science requirement document (SRD). This document will cover activities of MISTE engineering to achieve the requirements specified in SRD.

An overview of the MISTE experiment and the science requirements for key instrument components will be described first. Implementation plans for development of a flight instrument and plans to validate the flight readiness in each component before RDR are described with the components. The important interfaces of the MISTE ISP to the LTMPF are discussed next, followed by plans for flight experiment development including the instrument, electronics, and software. Assumptions about the mission are then given, and then the items in the schedule from RDR to final report are described in more detail. The final section details the program management, and appendices contain a schedule, work breakdown structure and a top level budget analysis.

2.4 Plan Revisions

During the experiment implementation activities, resource requirement and schedule revisions will probably occur which will invalidate portions of the baseline EIP. Deviations from the baseline plan and its revision will be documented. If there is major changes in scope, resource requirements, budget, or schedule, this EIP should be revised accordingly. Revised versions of the EIP will include the approvals of those approving the original release (see Flight experiment guideline JPL D-1315).

3 Reference Documents

The following figure shows a breakdown of relevant project documents. LTMPF project maintains updated version of documents in the web based server (http://LTMPF-lib.jpl.nasa.gov). All members of the LTMPF and P.I. team have access privilege to this site. As an experiment flown in this reusable facility MISTE will assume that the LTMPF project system engineer will filter all appropriate higher level documents and requirements and pass on relevant information or documents to us.

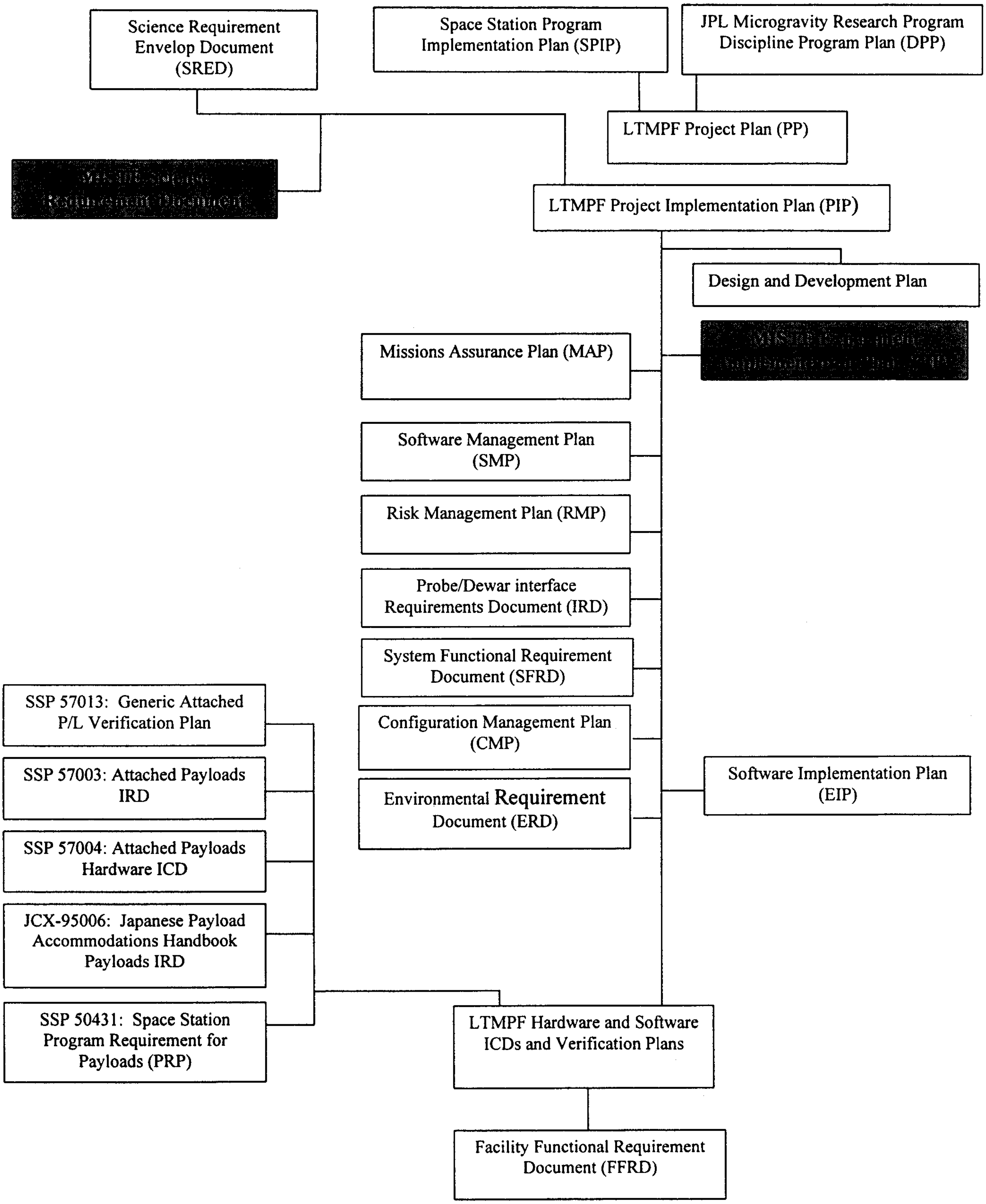


Figure 1 Related document tree

4 Experimental Description

4.1 MISTE science overview

The main objective of the MISTE flight experiment is to test the scaling predictions of critical phenomena theories near the liquid-gas critical point by measuring with high precision several thermodynamic properties in the same experiment. The specific objectives of the experiment are:

1. Perform measurements of the specific heat at constant volume, C_V, along the critical isochore and over the reduced temperature range of $10^{-6} \le |t| \le 10^{-1}$. The data within the experimentally determined asymptotic region will be used to determine the leading critical amplitudes $A_0^{\pm}$ and background term B_{sh} while fixing the critical exponent α and universal amplitude ratio A_0^+/A_0^- at their theoretically predicted values.
2. Perform measurements of the susceptibility, χ_T, along the critical isochore and over the reduced temperature range of $10^{-6} \le t \le 10^{-1}$. The data within the experimentally determined asymptotic region will be used to determine the leading critical amplitude Γ_0^+ fixing the critical exponent γ at its theoretically predicted value.
3. Perform susceptibility measurements along the critical isotherm over the reduced density range of $1\times10^{-2} \le |\Delta\rho| \le 2\times10^{-1}$. The data within the experimentally determined asymptotic region will be used to determine the leading critical amplitude D_0 fixing the critical exponent δ at its theoretically predicted value.

4.2 Experimental overview

The experiment consists of three independent measurements: heat capacity at constant volume, linear susceptibility, and P-ρ curve measurements at constant temperature. A cylindrical shaped sample cell will be equipped[1] with a germanium resistance thermometer (GRT), a high-resolution thermometer (HRT), a pressure gauge, and a capacitive density sensor. The experimental cell will be mounted on the platform of the LTMPF low temperature probe. The heat capacity measurement will be performed along several isochores with the sample cell filled with ^{3}He near the critical density. The linear susceptibility will also be measured along several isochores and isotherms by using both an electrostriction technique and a direct P-ρ measurement.

4.2.1 Heat Capacity Measurement

The adiabatic heat pulse technique will be mainly used to obtain the heat capacity of the sample very close to the critical point. This technique was successfully used in similar microgravity experiments on the superfluid transition in ^{4}He. The main sensors involved in the measurement are two thermometers and a precision heater. A miniaturized high resolution thermometer has been specially designed for the MISTE project, and the thermometer should also meet the needs of future low temperature facility experiments. The measurement strategy is similar to that used in previous experiments. The sample cell is weakly (thermally) connected to the radiation shield stage. The shield stage temperature will be actively controlled close to the sample temperature to reduce heat transfers and obtain a stable sample stage temperature. A heat pulse will be applied to the sample cell while monitoring the sample stage temperature. After the measurement, each stage temperature will be readjusted for the next point. After completion of measurements at different temperatures, the density of the sample will be changed by

[1] The actual flight cell may be equipped with more sensors depending on future redundancy requirements on sensors.

adding or withdrawing helium using an *in-situ* sample filling system consisting of a charcoal pump and a valve.

4.2.2 Susceptibility Measurement

Application of a constant DC voltage across the density sensor capacitor plates immersed in the sample will create a local constant field gradient between the inside and outside of the sensor. This field will produce a pressure gradient and induce a mass flow into the capacitor. The amount of mass squeezed inside is directly related to the linear susceptibility. A similar technique has been used in other space flight experiments. This electrostriction technique will be the primary method of measuring the linear susceptibility along several isochores and isotherms. On a given isochore the linear susceptibility and heat capacity measurements will be performed together. For the isothermal measurements the sample stage will be actively controlled using the HRT while the shield stage is controlled slightly below the sample temperature.

4.2.3 P-ρ Curve Measurement

The pressure-density relation will be measured along several isotherms. While the sample temperature is controlled using the HRT, the sample will be slowly taken out of the cell using the charcoal pump. The pressure gauge and density sensor will be monitored during the ramping of the density. These measurements will be used to determine the critical density and linear susceptibility.

The main flight activities will be measurements close to the critical point in the asymptotic region. The high resolution thermometer will be mainly used in the asymptotic region. Outside this region a germanium resistance thermometer will be used. The location of the maximum in the heat capacity and linear susceptibility will be used to determine the critical temperature. The inflection point in the linear susceptibility, which is obtained from the isotherm P-ρ curve at the critical temperature, will be used to define the critical density. Each experiment will take approximately 3~5 weeks. The optimal data taking scenario will be studied during the course of the ground based measurements. Ground science activities will continue to improve the data on the ground in parallel with flight activities. This activity will help to develop an optimal flight scenario. Ground data with a smaller sample height will also increase the range of the calibration between flight and ground data.

4.3 Science Requirements

4.3.1 MISTE ISP

4.3.1.1 Temperature sensor

The first flight experimental objective will be to measure the heat capacity over the reduced temperature range of $1\times10^{-6} \le t \le 2\times10^{-2}$ with an accuracy greater than 1%. This requires a temperature resolution of 3.3×10^{-8} K. To achieve this objective the thermometer must resolve the reduced temperature $t = 1\times10^{-6}$ to 1% and resolve the temperature change from a heat pulse 100 times smaller than the minimum required reduce temperature of $t = 1\times10^{-6}$. As a result, we require the temperature resolution to be 10^{-8} K while the MISTE experimental goal is to achieve a resolution of 10^{-9} K in temperature in 1 Hz bandwidth. Since measurements of C_V and χ_T will be taken near the critical point over a period of several months, we define the requirement for the drift rate of the thermometer to be $<1\times10^{-13}$ K/sec.

4.3.1.2 Pressure Sensor

The temperature stability limits the fundamental requirement for the pressure resolution. Temperature stability of $\delta T/T = 1\times10^{-8}$ corresponds to pressure stability of $\delta P/P \sim 3\times10^{-8}$ near 3 K. This limitation on the pressure resolution will not hinder the susceptibility measurements since an electrostrictive technique will be used close to the critical point. For consistency check between two different techniques (electrostriction and PVT measurements) over reduced temperature range $10^{-4}<t<10^{-3}$, the pressure gauge resolution requirement is set to be 3×10^{-7}. The required drift rate for the pressure gauge to be $< 3\times10^{-7}$/day or $\sim 4\times10^{-12}$ /sec.

4.3.1.3 Density Sensor

For the susceptibility measurement close to the transition a density difference of $\Delta\rho/\rho = 2\times10^{-4}$ needs to be resolved better than 1% to meet the science requirement. Furthermore, this required resolution of $\delta\rho/\rho = 2\times10^{-6}$ must be met under the condition that the excitation voltage on the capacitor be less than 1V rms in order to reduce the systematic error caused by the nonlinear effect in the χ_T measurement. Since, in the electrostrictive technique, a typical density difference ($\sim \delta\rho/\rho = 2\times10^{-4}$) will be established over a time period comparable to the fluid relaxation time (~ hour close to the transition), the requirement for the capacitor drift rate ($\delta\rho/\rho$/per sec) to be 1×10^{-9}. The drift rate of the present capacitor has been verified to be $\sim 1.2\times10^{-10}$, which meets the flight requirement.

4.3.1.4 In-situ Sample Filling System

In-situ sample filling system consists of a charcoal adsorption pump and valves. Requirement on density manipulation using the filling system is $\delta\rho/\rho = 0.1$ (say this in terms of number of mole. Exact number TBD). The valve leak rate requirement is $< 1\times10^{-6}$ std-cc helium/sec in order to maintain the density constant to 0.02% over a one-month maximum expected on-orbit time for runs at a given fixed density. This requirement can be relaxed somewhat because the sample density will be continuously monitored and re-filling the cell is possible. The requirement that the pre-flight filling density not change by more than 0.1% over a 6-month launch campaign gives about the same leak rate requirement.

Table I. Summary of MISTE Science Requirements

Parameter	Goal	Requirement
Temperature Sensors		
Resolution in 1 Hz bandwidth at 3.3 K	$\sim 1\times10^{-9}$	$< 1\times10^{-8}$
Drift rate (K/Sec)	$\sim 3\times10^{-14}$	$< 1\times10^{-13}$
Pressure Sensors		
Resolution in 1Hz bandwidth at 1.1 bar	$\sim 3\times10^{-9}$	$< 3\times10^{-7}$
Drift rate (bar/sec)	1×10^{-13}	4×10^{-12}
Range (bar)	2	2
Density Sensor		
Resolution in 1Hz bw at ρ_c (0.014 mole/cc)	2×10^{-6}	$< 1\times10^{-5}$
Absolute drift rate ($\delta\rho/\rho_c$ per sec)	3×10^{-10}	$< 1\times10^{-9}$
Sample		
^{4}He impurity (PPM)	~ 0.01	< 0.1
Heat capacity measurement		
Energy pulse accuracy (%)	~ 0.05	< 0.1
Temperature step accuracy (%)	~ 0.1	~ 1
Stray heat input (W)	$\sim 5\times10^{-9}$	$< 5\times10^{-8}$
Critical isochore determination ($\lvert\rho/\rho_c - 1\rvert$)	5×10^{-4}	1×10^{-3}
Measurement Range		
Single Phase		
Inner/Outer limit ($t = T/T_c - 1$)	$1\times10^{-7} < t < 1\times10^{-1}$	$1\times10^{-6} < t < 1\times10^{-1}$
Two Phase		
Inner/Outer limit ($t = T/T_c - 1$)	$5\times10^{-5} < t < 1\times10^{-1}$	$1\times10^{-4} < t < 1\times10^{-1}$
Susceptibility Measurement		
Isochore Measurement Range		
Outer limit (T/T_c - 1)	1×10^{-1}	1×10^{-1}
Inner limit (T/T_c - 1)	6×10^{-7}	1×10^{-6}
Critical isochore determination ($\lvert\rho/\rho_c - 1\rvert$)	5×10^{-4}	1×10^{-3}
Isotherm Measurement Range		
Outer limit $\lvert\rho/\rho_c - 1\rvert$	3.5×10^{-1}	3.5×10^{-1}
Inner limit $\lvert\rho/\rho_c - 1\rvert$	7×10^{-3}	1×10^{-2}
Critical isotherm determination (T/T_c - 1)	3×10^{-7}	8×10^{-7}
Acceleration Environment		
DC	2 μg	5 μg
The total integrated acceleration spectrum over the range 10^{-3} Hz < Frequency < 500 Hz	750μg	1500 μg
Charged Particle Environment		
C-P heating rate (pW/per gram copper)		
Inside Equatorial Band (|latitude| < 30)	< 0.5	0.5 ~ 1.0
outside Equatorial Band (|latitude| > 30)	< 5	< 10
Within SAA (South Atlantic Anomaly)	N/A	N/A

4.3.2 LTMPF related requirements

The previous requirements listed for MISTE do not include a set of requirements deemed to be common among all the LTMPF candidate experiments. This set includes a minimum 4.5 month on-orbit dewar lifetime, thermal isolation stages, SQUID and GRT performance requirements and many others. These requirements are captured in the Science Requirements Envelope Document (SRED). The SRED was finalized at the LTMPF RDR after being written with extensive flight-candidate PI input as well as LTMPF project and BATC evaluation. We assume that the facility will meet the requirements contained in the SRED, and that with the exception of the ratio transformer / lock-in system the MISTE team is not responsible for the implementation or verification of those requirements.

4.3.3 Acceleration Environment

4.3.4 Charged Particle Environment

4.3.5 Experiment Timeline

The main experiment will be performed after the LTMPF is installed on the JEM-EF module. At present we assume that no experiment power or telemetry will be available from launch lock-up through turn-on on the JEM-EF. The experiment timeline after turn-on and LTMPF facility checkout will include about a week of calibrations and checks, followed by a set of preliminary data using the initial filling density of the cell and then more complete full data runs.

In the measurement plan, which is described in more detail in the SRD, all science activities are counted with a minimum of 10% allowance for SAA passes, and for some of the data nearest the critical point we allow up to a factor of two increase in the time required because of charged particle heating disturbances. Our current timeline plan assumes that station assembly will be complete at the time of the LTMPF-M1 flight. At this time that is the expected situation, though schedule slips in ISS assembly could easily change the situation. Calculations show that MISTE is not extremely sensitive to vibrations, so we assume that we can take data during 80% of the "non-microgravity-mode" station time (which is about half of the total time). Given this, we should be able to take a considerable amount of data even if the experiment begins in the more vibration plagued period before station completion. The plan for the initial period of system checkout and calibration contains significant allowance for loss of telemetry contact with the ISS, since these activities will probably be done near-real-time to watch for anomalies. After this initial period the system is expected to be automated enough that no significant loss of time due to telemetry blackout is anticipated.

With these allowances for disturbances, our baseline data set is completed within the SRED-required 4.5 month data taking period, including 18 days of time specifically held for investigating anomalies or unexpected and interesting effects. The baseline set meets all of MISTE's experimental data requirement and some of the extended goals. In the event of a reduced available measurement period the range of the data at low reduced temperatures and densities will be restricted. Since the data nearest the critical point takes the longest to take, only a slight reduction in data range could accommodate a large loss of data-taking time. If, on the other hand, a larger than required amount of time is available, either because of better than required dewar performance or because of less charged particle or vibration impact than expected, the baseline data measurements can be repeated for statistical error reduction, and the data be extended towards the lower reduced temperature and density science goals. Other effects such as supercooling into the two-phase region can be investigated if time permits.

4.4 Technical Summary

4.4.1 LTMPF

LTMPF is a facility that supports multiple experiments in a long-term cryogenic environment. It will be operated on the JEM Exposed Facility ("Kibo") as an attached payload. LTMPF dewar provides up to 4.5 months of on-station cryogenic lifetime (1.6 Kelvin) for total 30 kg instrument inserts including vacuum can, and science instruments. Structural support, power, telemetry, and common ISS services are provided by the JEM-EF through the Payload Interface Unit (PIU). The facility provides a passive vibration isolation system. Acceleration and charged particle will be monitored with an ISS-provided or LTMPF detector. Instrument command and data collection is effected through use of commercially available electronics and computer except P.I. specific electronics hardware. The system initial booting and check-out is performed at JPL and routing science data collecting sequence will be conducted by P.I. facilities using telemetry and command services through JPL. JEM-EF services are limited to minimal telemetry (24kbps) and command (600 commands/day). The facility consists of a dewar, two electronic control boxes, the Payload Interface Unit (PIU), and the Grapple Fixture. The planned carrier of the first Facility is the HII-A rocket Transfer Vehicle (HTV). The planned launch site for the first flight is Tanegashima Space Center of Japan. Figure 1 shows the conceptual drawing of LTMPF and JEM-EF.

4.4.2 MISTE ISP

MISTE ISP is cryogenic flight hardware designed to achieve science objectives of MISTE. The ISP ~~comprised~~ of the sample cell containing the helium sample, high resolution thermometer, pressure gauge, density sensor, cryogenic valves, a thermal radiation shield, and charcoal adsorption pump. This P.I. specific instrument will be integrated into the LTMPF probe to obtain the required cryogenic environment for the experiment. The LTMPF probe will provide dc SQUID sensors and electronics, magnetic shielding, vacuum can, thermo-mechanical structure, and standard thermometers, heaters and its control electronics. Figure 2 shows a system block diagram of MISTE ISP and LTMPF system. Communication to the instrument will be done through two independent data interface. The command uplink will be through 1553B bus. Telemetry downlink is through the Ethernet bus. The facility will support two electronics box for two different experiments.

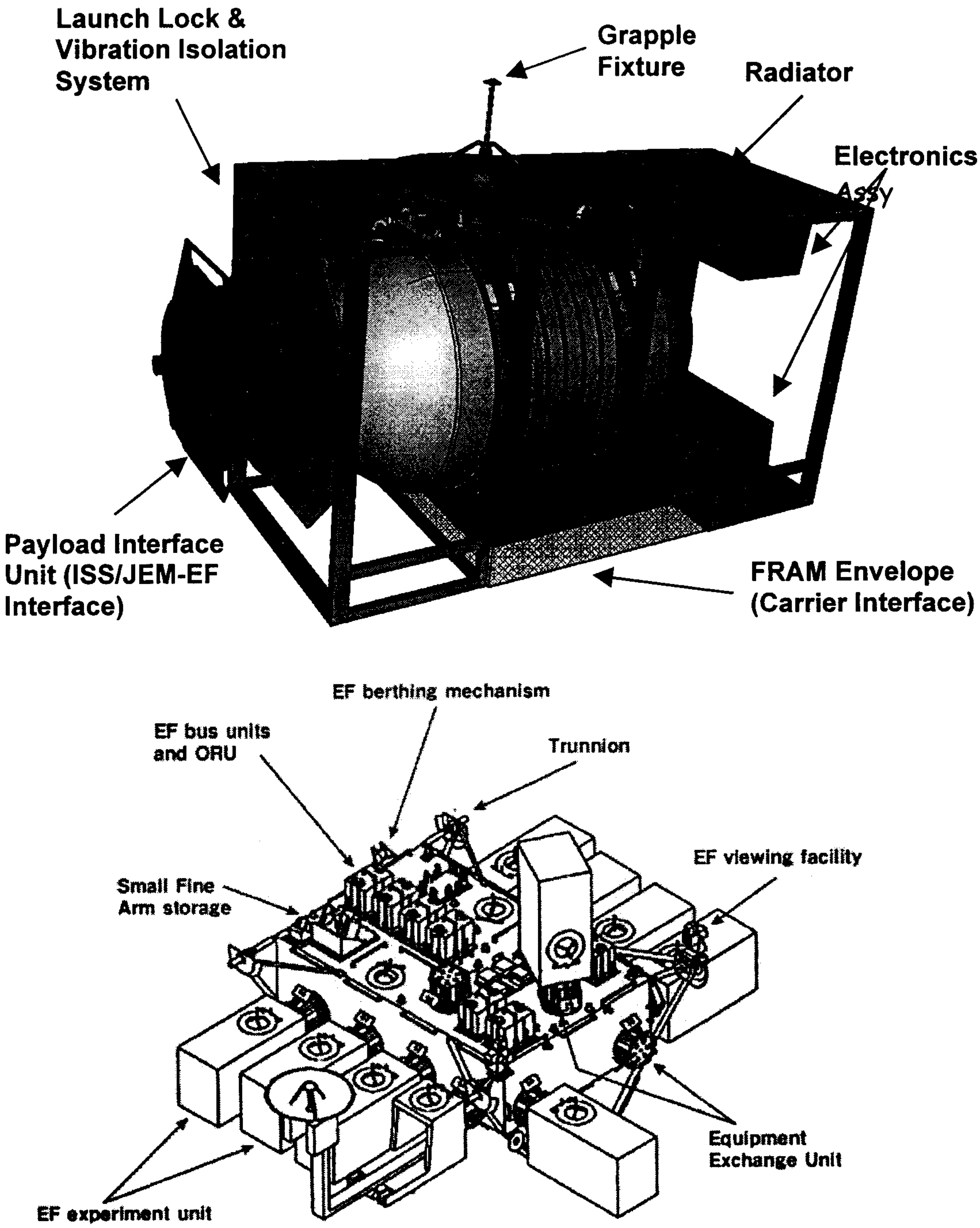


Figure 2 Concept drawing of LTMPF and JEM-EF

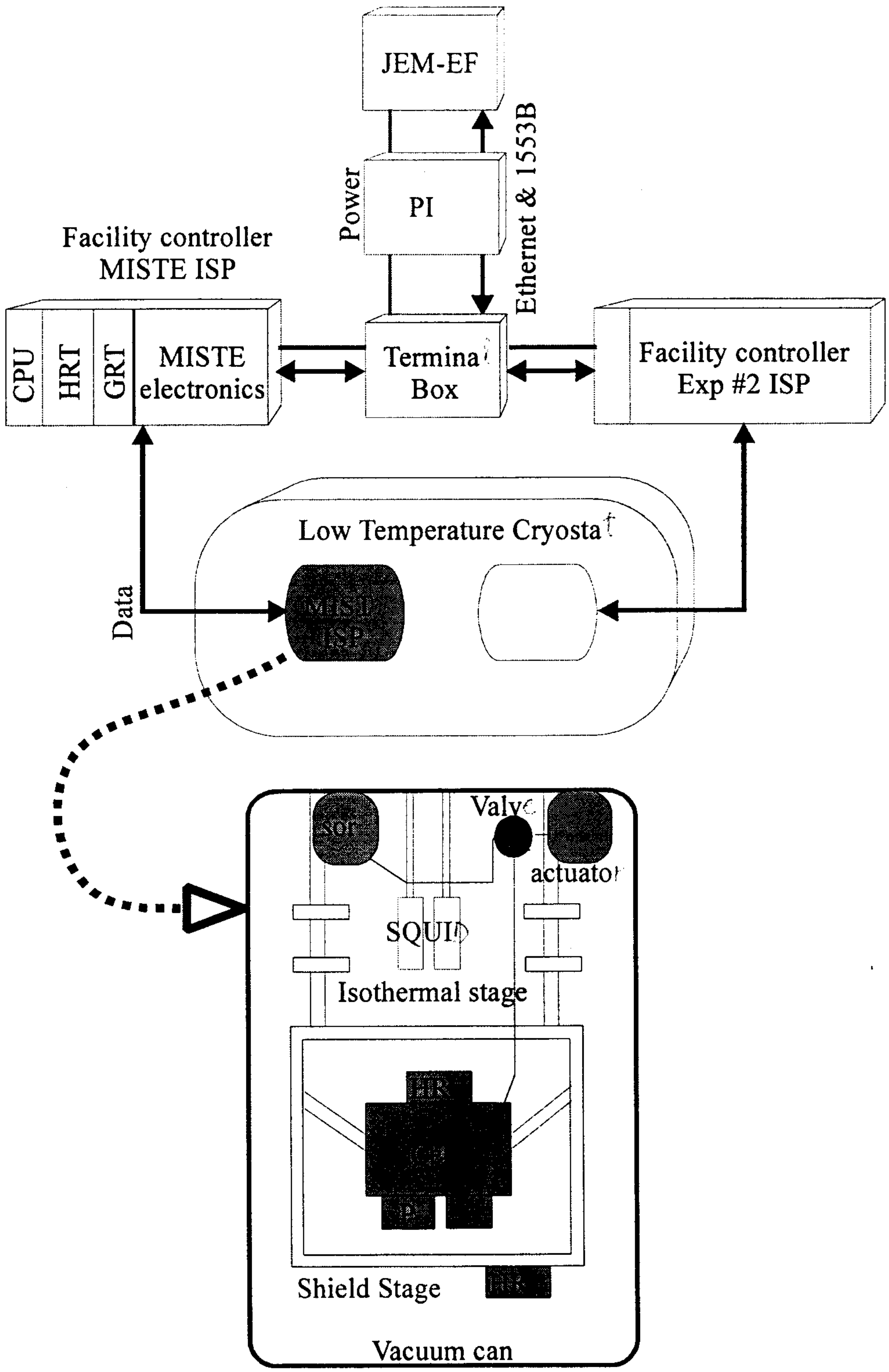


Figure 3 Block diagram of MISTE ISP and LTMPF electronics

4.4.3 Flight Interface

Integration and test of the ISP and LTMPF will be done at JPL. The MISTE science team will operate the instrument remotely via the Internet to verify the success of the integration, the performance of the instrument, and software functionality. After the successful ground testing, the LTMPF will be shipped to the launch site. During this period the temperature of the system will be maintained below 4.3 K. It may take as many as three days for the launch carrier to dock with ISS, and additional three more days for LTMPF to be attached to JEM-EF. During this period of time only minimum power will be available to maintain electronics facility and cryostat. After a successful attachment to JEM-EF, the instrument teams will perform a standard test to demonstrate instrument control and nominal performance. Science operation will be performed at P.I. institution, JPL in the case of MISTE.
===

Figure 4 shows command uplink and telemetry data downlink flow chart between P.I.'s lab and LTMPF in space. A command data issued by MISTE Lab computer using a internet based software will be passed to JPL telescience science support center (TSC). The processed command will be sent to ISS using S-band via Payload Operations Integration Center (POIC) at MSFC.
======= still working on it ===

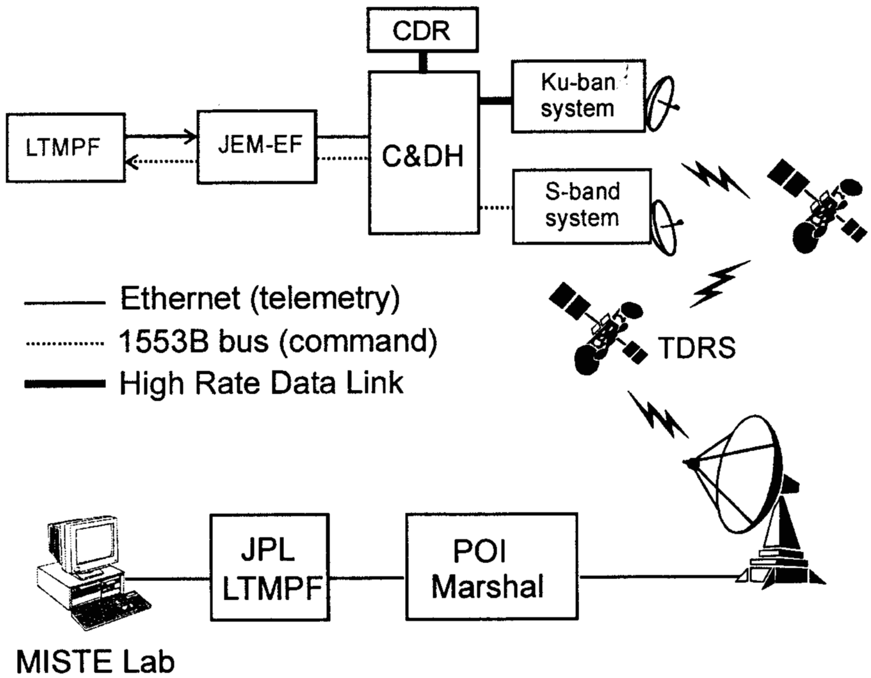


Figure 4 Flight experiment data flow schematic

4.4.4 Ground Support Equipment

The electronics GSE is used to generate commands to the flight instrument (probe and MISTE ISP, and custom electronics) and to receive, store, and display data for ground-based testing. It is necessary to perform the ground-based testing on MISTE ISP using a flight like electronics before final interface to

LTMPF. LTMPF project will provide a facility electronics simulator consists of GRT/HRT controller boards attached to a VME chassis, and cables and a breakout box. Also, the flight like CPU board with minimal set of software to control the probe will be connected to network such that the P.I. science team can perform the low temperature test on ISP. The ground based interface testing of MSITE ISP and LTMPF probe will be performed at JPL with collaboration LTMPF engineering team.

Gas handling rack is used to fill the cell with sample. Other standard cryogenic equipment like shake fixture, ground dewar, transfer lines, and leak detectors are used for the ground based testing.

5 Technical Approach

5.1 Prototype MISTE ISP

5.1.1 Thermometer

The HRT is a key element in the MISTE instrument. The required temperature resolution is 10^{-8}. The current thermometer resolution status is 10^{-9}. The temperature-sensing element is a paramagnetic salt ($GdCl_3$) slightly above its ferromagnetic transition. A pair of permanent magnets inside the thermometer provides an applied magnetic field. When the temperature of the salt changes, the magnetization of the salt changes due to the Curie-Weiss law behavior of its susceptibility. The magnetization is measured using SQUID magnetometer.
Figure 5 shows a schematic drawing of the HRT. MISTE plans to use the current design as a flight one. As a part of the LTMPF project in JPL, a shakable dewar was designed and fabricated to support the launch load test of low temperature components. This facility will be used to experimentally verify the launch load survivability of instrument components. The current LTMPF plan is to provide a total of up to 6 DC SQUID sensors and associated readout electronics. Therefore the MISTE team will not independently develop the flight electronics hardware for the SQUID's.

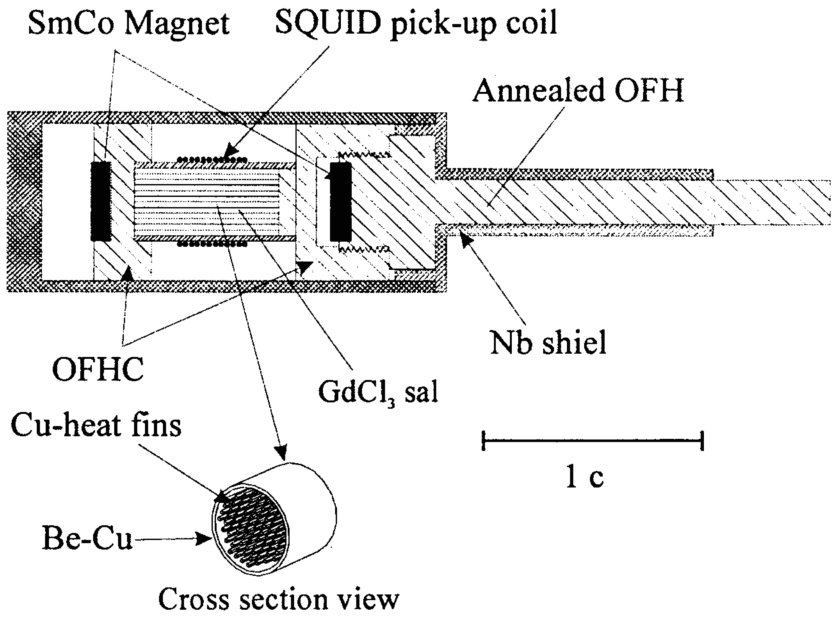


Figure 5 Schematic drawing of HRT

5.1.2 Pressure Gauge

The pressure sensor used in the MISTE experiment is a conventional Straty-Adams capacitive gauge. The principle of the capacitive pressure gauge is very simple. The pressure gauge uses a small portion of one wall as a flexible diaphragm that moves in response to pressure changes. A capacitor plate is attached to the diaphragm with a second plate held in close proximity. **Figure 6** shows a schematic drawing of the pressure gauge. The minimum requirement of pressure resolution is set to 1×10^{-7} for a wide range of susceptibility measurements along isochores and isotherms. A non-optimized ground based pressure gauge showed a resolution of $4\text{x}10^{-7}$. A new prototype will easily meet the sensitivity of

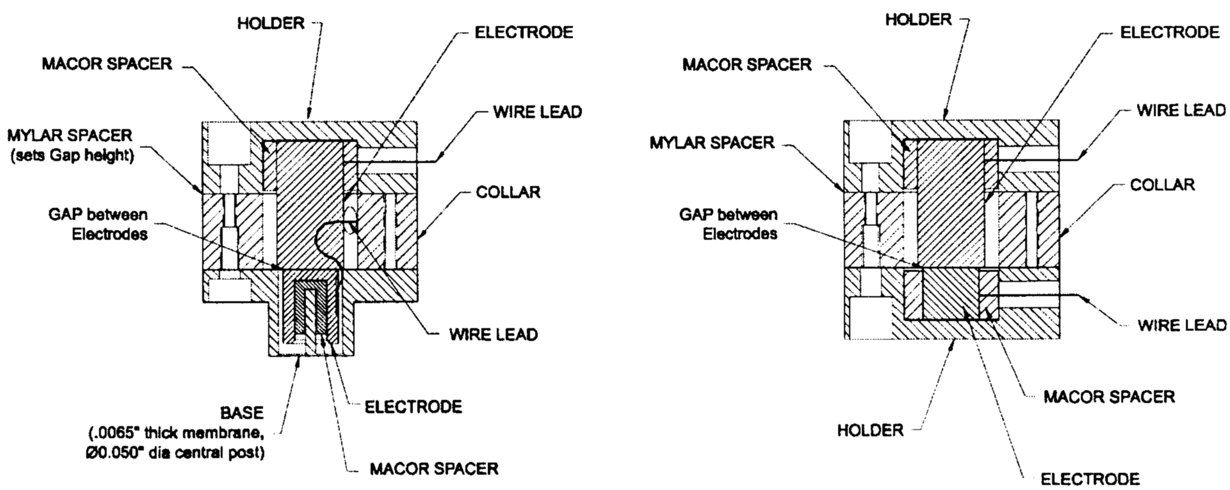


Figure 6 Schematic drawing of pressure gauge

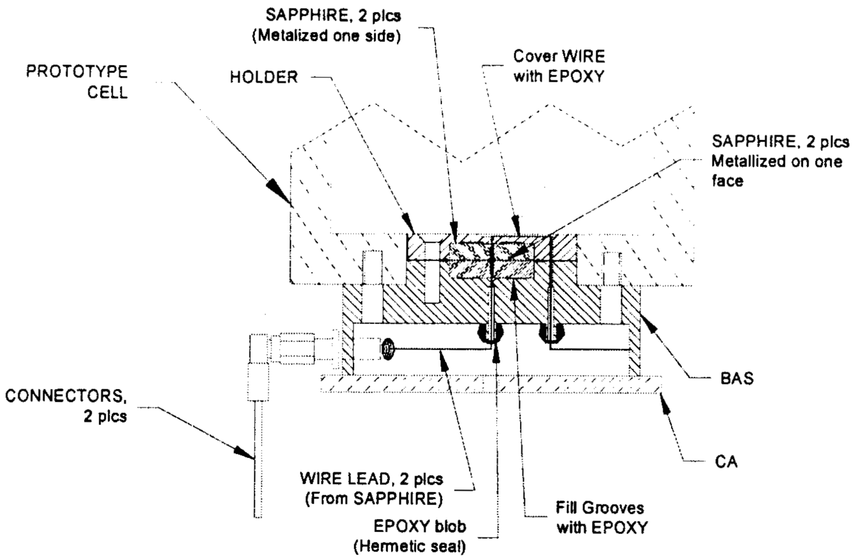


Figure 7 Schematic drawing of density sensor

the pressure measurement by reducing the pressure sensor capacitor gap to achieve a shorting pressure closer to the critical pressure of ^3He. The flight prototype pressure gauge is currently assembled together and low temperature testing is under progress. The shake test on the pressure gauge will be done before RDR.

==need a short description of new pressure gauge, difference from old design ====

5.1.3 Density Sensor

The density of the sample will be determined by measuring the ^3He dielectric constant using a capacitive sensor. This capacitive technique uses the Clausius-Mossotti relationship to determine the density of the sample in-situ. The current non-flight density measurement system shows a density resolution of 10^{-4} using 1 volt rms. It is important to know that the ultimate sensitivity of the density sensor is limited by the readout electronics, not by the sensor itself. Flight electronics to achieve the required capacitance resolution has been designed and analyzed, and will be presented in later section. A flight prototype density sensor has recently fabricated and test is under progress. The main change over an older design is that use of sapphire instead of macor as a support of the electrodes. This will minimize a potential density inhomogeneity due to the local cosmic ray heating effect.

5.1.4 In-Situ *Sample Handling System*

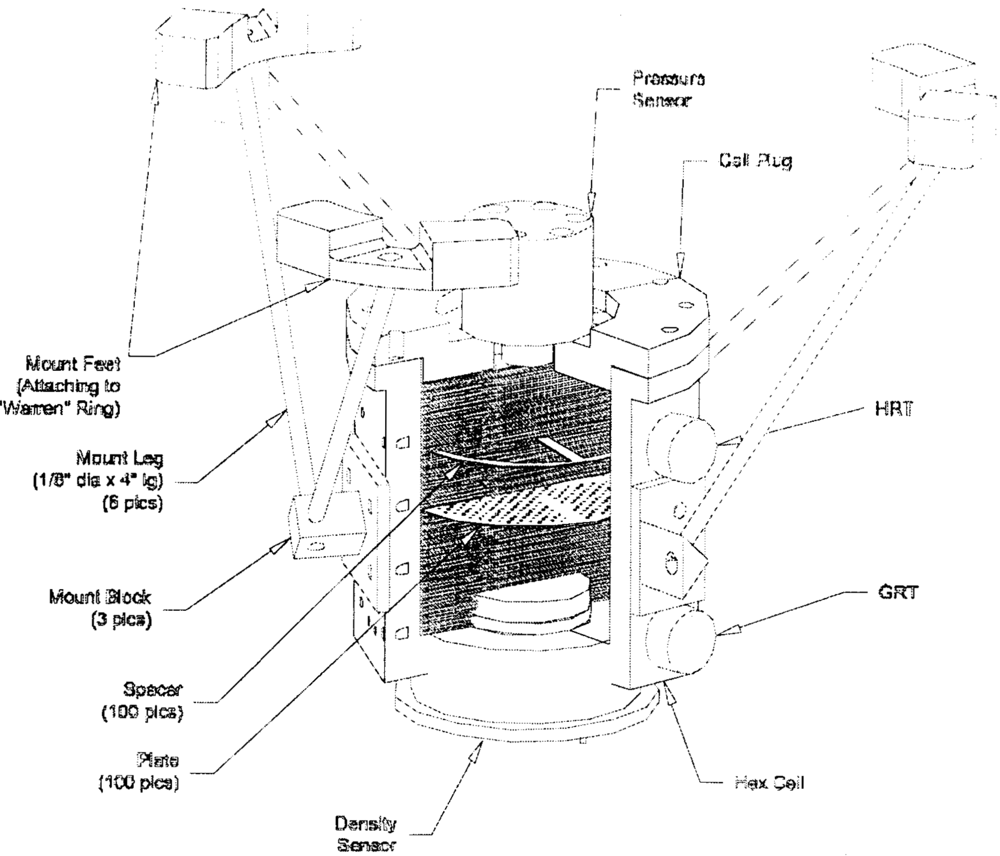
The MISTE experiment will require an *in-situ* sample transfer system to add or remove mass from the experimental cell. This mass transfer will be needed in order to perform measurements along several isochores around the critical isochore and along several isotherms near the critical isotherm. The system has a low temperature valve which is closed during constant density measurements or opened during density sweeps or other adjustments. With the valve open, the amount of helium in the cell can be controlled over a wide range (± 10%) by heating the sorption pump to a temperature up to about 30K. The regulated heat sink protects the carefully regulated lower stages from the hot gas that flows from the sorption pump. This heat sink and another on a small valve stage are both held above the cell temperature so as to avoid condensation and phase boundaries in the transfer lines. A prototype system of this kind has been used extensively in ground-based measurements and has performed well. (see the picture)

The in-situ system has one valve that needs to be remotely controllable on-orbit. This is the valve that isolates the cell from the sorption system for constant-volume specific heat and electrostriction measurements. It will be opened and closed at least 25 times during the flight. Our baseline plan is to use a pressure-actuated valve of the previously flown Lambda Point Experiment type. An alternative choice is a valve being developed in cooperation with Mission Research Corporation (MRC), which is a smaller version of an MRC valve planned for use in the LTMPF. (see the picture) The valve leak rate requirement is < 1×10^{-6} std-cc helium/sec in order to maintain the density constant to 0.02% over a one month maximum expected on-orbit time for runs at a given fixed density.
The pressure to actuate the valve will be provided by a hot-volume system filled with ^{3}He. The use of ^{3}He prevents superfluid thermal shorts to colder parts of the cryoprobe. Similar systems have been previously used to actuate low-temperature valves [17b] and as a backup procedure we can use the gas supply available on the LTMPF facility for the valve actuation. Another valve may also be used to isolate the low-temperature sample handling system from the fill line to room temperature. This valve would also be pressure actuated but it only needs to be actuated a few times on the ground for sample filling. The leak rate requirements on this valve are much less restrictive than on the cell valve since the isolation valve is only used to protect the system from fluctuations caused by bath temperature variations or other disturbances. This valve is not presently used in ground experiments and the need for it in the flight experiment is being evaluated.

===let's have the LPE valve drawing =======

5.1.5 Cell

For a cell ~ 5 cm tall, the reduced temperature for a 1% microgravity effect (at 2.8 μg) on the specific heat is $\sim7\times10^{-7}$. The current flight base line design is a right cylindrical cell (5 cm diameter x 5 cm height). Inside the cell there will be layers of copper spacer symmetrically situated to insure that the distance between conducting layers is equal to or less than 0.05 cm (the distance for the ground-based cell). These spacer are diffusion bonded together to increase thermal conductivity. Figure ### shows a picture of recently manufactured sample cell with sensors. Although it is a small improvement, it is still desirable to mount the cell such that its cylindrical systemic axis will be pointing toward the residual gravity vector at JEM-EF site. However, orienting the cell will required a careful interface plan to the LTMPF probe as well as ground-based testing issues. We are currently working on the technical issues with LTMPF team related to the mounting the cell at 45-degrees from the probe axis. If there is no major side effect on interfacing and testing in terms of tilting the LTMPF on the ground, the cell will be mounted angled. The only modification to the system for the mounting will be a new support structure and cell body. This is a very low risk modification to the baseline plan.



5.2 Flight ISP

The flight instrument will be composed of a common probe section and the MISTE ISP. The probe will be developed and tested by the LTMPF team and delivered to the MISTE team for integration with the ISP. The fabrication of the MISTE flight ISP will be conducted and/or contracted by the MISTE team. The flight ISP will be principally based on the prototype cell that is constructed and tested before RDR. For the final flight qualification JPL structural engineers will be consulted during the final flight ISP fabrication regarding launch survival issues. Further design and development will take place after RDR as needed, though the present prototype sensors are considered fairly mature and no major hurdles in the qualification of the flight cell are anticipated.

=== describe a plan to build flight one (in-house or Swales?)
=== Describe flight qualification. Safety, and environment testing and so on.
=== What is our plan to do that

5.2.1 Redundancy

Considering the six SQUIDs available on the LTMPF baseline probe, it is clear that there is ample opportunity for redundancy in the HRT system, which is one of the most important sensor systems. As a tentative approach, redundancy will be implemented in key sensors and in their controlling electronics to the extent that room is available. However, in current baseline plan for 2 ISP in one probe, there are not enough mass margins for full redundancy (e.g. 2 MISTE cells). The current baseline for the redundancy (double) is 1) 4-wire heater at the cell, 2) GRT at cell, 3) heater at shield, and 4) shield and cell HRT. This plan assumes 2 ISP in one probe configuration without knowledge on the exact final configuration of the other ISP. Therefore, the redundancy will be carefully revised after the RDR.

5.3 Flight Electronics

MISTE will develop only the flight electronics that is specific to the experiment. Facility maintenance electronics, a VME bus controller (main computer), telemetry supporting electronics, SQUID readout electronics, GRT readouts, and standard and precision heater systems are assumed to be provided by the LTMPF project without development work by the MISTE team. MISTE will breadboard non-trivial electronics for MISTE-specific requirements.

The principal MISTE-specific electronics is the capacitance measurement system. The choice of a measurement approach is a ratio transformer and a lock-in. Preliminary design has been developed and breadboard a prototype flight system is under progress. MISTE also requires electronics systems to control the on-orbit actuated low temperature valves. These boards are not anticipated to be particularly complicated, and will be similar to other Ball developed systems (either heater control boards or controls for the facility MRC cold valves or the warm IGV vent valve.) As a result, these systems will not be breadboarded at JPL and will probably be obtained from Ball as copies or slight modifications of existing systems.

To aid in the development of prototype flight electronics and flight software, the MISTE team will obtain in FY 2000 a VME bus system with the VXworks operating system from LTMPF team. We will also obtain a flight like GRT board and a SQUID readout board from LTMPF team. These boards will be non-flight copies of existing boards (from FACET) but they are assumed to be interface compatible with the LTMPF flight units. The MISTE Electronic Instrument Engineer will integrate these components and will slowly move the experiment to a flight-like electronic control system. This system will be in use by the middle of probe/ISP I&T.

5.3.1 Capacitance Bridge System (CBS)

5.3.1.1 Prototype

The MISTE electronics consists of the signal sources and measurement systems for two capacitance-bridge test cells. A block diagram is shown in figure 1. The signal sources consist of all the elements of the block diagram that are left of the test cells. The measurement electronics are all of the elements of the block diagram that are right of the test cells. The only electronics at liquid helium temperature are the resistors and capacitors in the test cells.
The signal sources and measurement systems are identical for both test cells. The signal sources and measurements systems are cross-linked with relays, so that, the electronics for test cell "A" can be used with test cell "B" and vice-versa. Although both test cells cannot be run simultaneously with one set of electronics, the cross-linking does permit some measure of redundancy for the experiment if some part of the electronics fails during the flight.

5.3.1.1.1 Sinewave and DC Sources

A stable local oscillator (STALO) provides a constant frequency to 2 sinewave generators. The sinewave generators are numerically controlled oscillators (NCO's) with programmable output frequency. The sinewave signal from the NCO is low-pass filtered to remove the reference switching frequency before being applied to an AGC amplifier. The AGC amplifier sets the amplitude of the signal. Either sinewave source can drive either ratio transformer.

The DC bias source consists of a DC/DC converter followed by 2 high-voltage digital-to-analog converters (HVDAC's). The DC/DC converter is low-power flyback type that steps-up the 28-volt DC input voltage to over 200 volts. An 8-bit DAC together with a high-voltage series-pass MOSFET form the high-voltage DAC circuit. The DC/DC converter's output voltage is not regulated, since the HVDAC will perform the regulation function. The 8-bit DAC will control the DC voltage to the test cell in steps of 0.784 volts up to a maximum of 200 volts. Either HVDAC can drive either test cell.

5.3.1.1.2 Ratio Transformer

The ratio transformer consists of an input step-up and isolation transformer followed by a binary weighed autotransformer. The step-up transformer has two primary windings and 8 secondary windings. The voltage step-up ratio can be either a factor of 4 or 8. The secondary windings are all placed in series. Two taps from the secondary winding will drive the binary weighed autotransformer. The autotransformer consists of 8 pairs of windings connected in series through a relay matrix. The 8 winding pairs have turns around the toroidal core with powers of 2. The turns for the 8 winding pairs are 128, 64, 32, 16, 8, 4, 2 and 1. By connecting one of the pair of windings either above or below a signal tap point, the signal at the tap can be adjusted to a binary fraction of the input signal from 1/1 to 1/255 to zero. The combination of the step-up transformer and the autotransformer gives a binary voltage divisor equal to 10 bits of resolution or approximately 1 part in 1024.
The signal placed across the ratio transformer is also applied across the test cell through the relay matrix. The phase of the signal to both sides of the test cell is adjusted with the programmable phase shifters. The phase is adjusted to remove the quadrature component of the test signal appearing at the input of the low-noise amplifier (LNA). Either ratio transformer can drive either test cell

5.3.1.1.3 Low-Noise Amplifier

The low-noise amplifier is a differential JFET-input design using specially selected transistors. The transistors are selected for low voltage noise and low current noise in the frequency range from 1 kHz to 10 kHz. The amplifier has a fixed gain of 10. Low-leakage protection diodes are placed at the input of the amplifier to clamp high-voltage spikes from the test cell. The amplifier is designed to operate at temperatures from 120°K to 300°K. Lower noise performance can be achieved by placing the LNA in the cryostat and operating at lower temperatures, but the heat load on the cryostat will be increased.

5.3.1.1.4 Synchronous Demodulator

The input to a synchronous demodulator can be from either test cell, provided the reference signal comes from the ratio transformer that drives the same cell. A selectable-gain preamplifier drives an AD630 integrated circuit from Analog Devices. The AD630 is a square-wave demodulator, where the input signal is multiplied with a square-wave reference signal. The output of the demodulator is a DC voltage proportional to the amplitude and phase of the input signal at the reference frequency. A square-wave demodulator will also produce a DC voltage if the input signal contains odd-order harmonics of the reference signal, such as, the third and fifth harmonic. Therefore, the excitation signal for the test cell must be free of these harmonics and the amplifiers before the demodulator must not produce these harmonics.
The programmable phase shifter switches the demodulator from in-phase to quadrature detection modes. It contains a fine adjustment to tune out small phase shifts in the ratio transformer and the test cell.

The output of the demodulator is low-pass filtered and amplified before being applied to the ADC. The low-pass filter has 3 or more selectable bandwidths. The post amplifier has programmable gain and low output impedance to drive the ADC.

5.3.1.1.5 ADC and Auto-Zero Circuits

The ADC is a 16-bit successive approximation type with an input track-and-hold amplifier. The conversion time is less than 100 microseconds. The output of the ADC is latched into an output buffer that is read over the VME bus. The auto-zero circuits monitor the ADC output. The auto-zero circuits will automatically change the tap of the ratio transformer when the ADC signal goes above or below predetermined signal levels. The auto-zero circuit can be disabled with a command over the VME bus.

5.3.1.1.6 Control and Housekeeping Circuits

Power supply voltages, power supply currents, board temperatures and all instrument states are monitored with the housekeeping circuits. Control signals from the VME bus are conditioned and applied to the various parts of the electronics. The instrument is operated in a semi-automatic mode, where the instrument states are programmed over the bus and data is read from the bus. A small state-machine can be added to the control circuitry at a later date if fully automatic test sequences are desired.

5.3.1.1.7 VME Interfaces

The VME interfaces contain all the circuitry to communicate over the VME bus. The operating modes and output data for the experiments are all accessed by register addressing. A master reset signal from the bus will remove all signals from the test cell and place the instrument in a known safe mode.
Note that reads and writes over the VME bus will be asynchronous with the clocks and data acquisition times in the instrument. Even with double buffering the ADC data can be accessed while it is changing. Software routines for the electronics that access the data will be necessary to eliminate ambiguous data.

5.3.1.1.8 Power Conditioning

The power conditioning circuits filter and convert the DC voltage power supply voltages into the MISTE electronics. To reduce noise from ground loops, the LNA runs off an isolated DC power bus generated from the input power sources. The digital power grounds and analog power grounds are isolated to reduce digital interference. The power circuits for the two synchronous demodulators must be heavily filtered (or isolated) to prevent crosstalk between the two systems.

5.3.1.2 Flight Model

To develop the flight final flight electronics, the prototype block diagram described above will be analyzed further to see that it will meet the requirements, and the key analog systems will be breadboarded. At this point the GSE to test and calibrate the system will be defined and mass, power and volume constraints will be considered. This will lead on to the detailed design phase when full hardware and software specifications and designs will be made. The electronic engineer will perform failure mode analysis and develop environmental test requirements.

===Describe how we build the flight-qualified electronics. (breadboard to PDR, CDR, Thermal-vac test..)

=== What's is main issue, assumptions, part selection, calibration, charged particle effect, and so on.

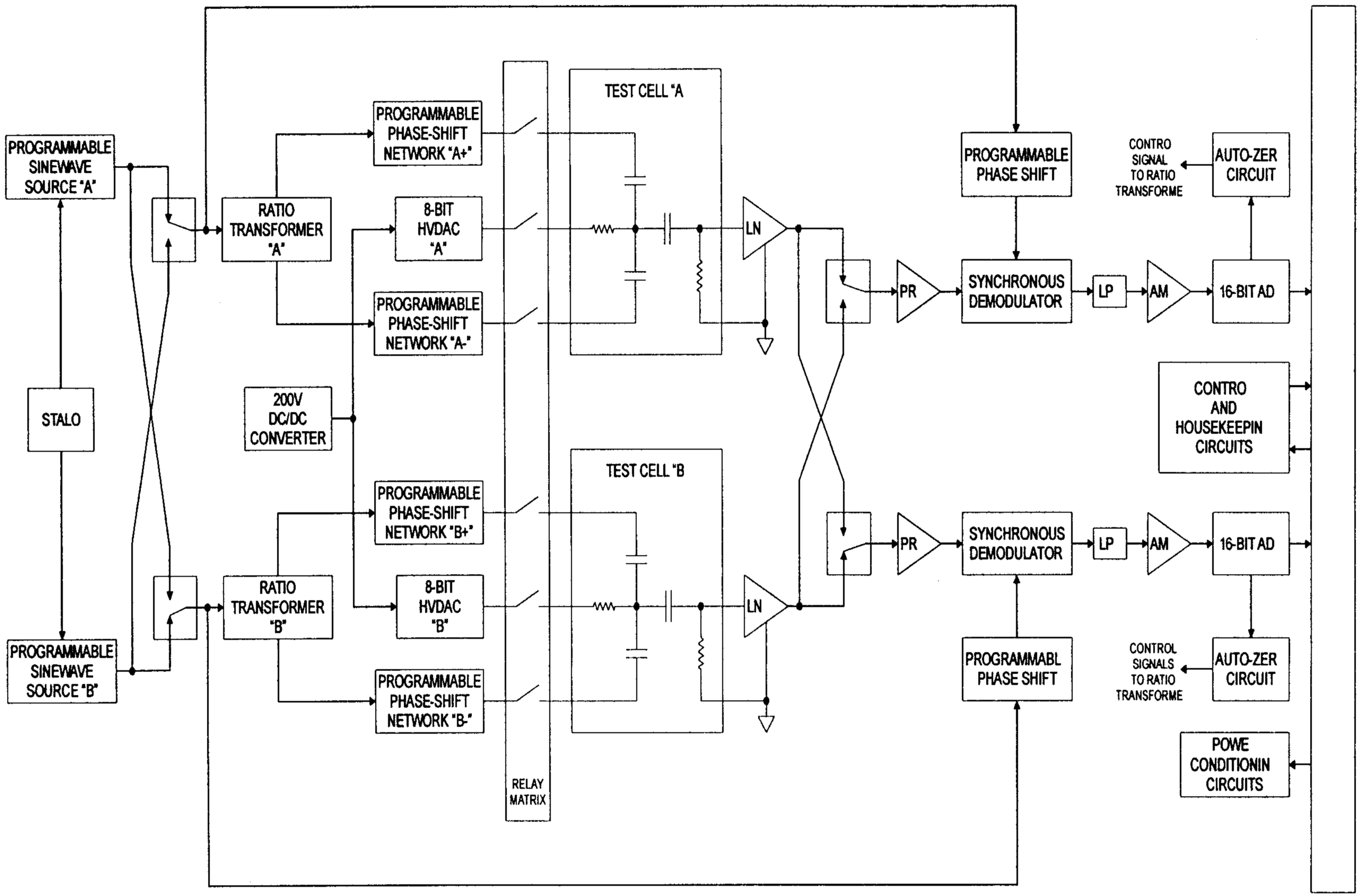


Figure 8: MISTE Electronics Block Diagram

5.4 Flight Software

5.4.1 Science sequence

We are assuming at this point that the MISTE team will define the experiment control and data acquisition sequence for flight. This will be developed and tested on the ground VXworks/VME bus system provided by LTPMF for the probe&ISP interfacing test. Guidelines for the development of the software and specifications of LTMPF software interfaces to telemetry and to drivers for common electronic systems (SQUID readouts, etc) will be required from the LTMPF team. Parts of the required information will be contained in the PI Integration Handbook which will be delivered by the LTMPF software team in June 2000. The remaining details will follow as the flight electronics matures. In the process of software development a fairly detailed software specification will be written, based on the algorithms used in the LabView ground software. This specification will serve both as a guide to our own development and as a basis for external verification. We assume that the LTMPF project team, with MISTE support, will handle the final integration of the experiment control software into the flight system.

5.4.2 Device Driver for CBS

MISTE will provide a basic interface routines to communicate with CBS. This device driver will be acceptance tested to the requirements specified in the LTMPF Software Requirements Document.

5.5 Integration and Testing

In this section we will describe activities related to test MISTE instruments (ISP, and CBS) with LTMPF probe. It is important to note that this integration and testing will be done using a LTMPF delivered probe and GS, not using a flight LTMPF. It is also anticipated that this activity will be developmental due to the complexity of the two-ISP arrangement. After the successful developmental test, the probe with a MISTE ISP and 2^{nd} ISP will be integrated into LTMPF.

5.5.1 Probe and MISTE ISP integration

Current probe design is optimized for a single ISP mounting. LTMPF team is working on new configuration to adopt 2 ISP in a single probe. Integration of the ISP into the probe will be done at JPL with LTMPF engineering team.

5.5.2 Ground Support Equipment

For the functional test of MISTE instrument both at room and cold temperature, it is essential to have ground support test equipment, and facility support. Current plan is to utilize a laboratory facilities at JPL (79-100). The following table lists items necessary to test MISTE instrument with a LTMPF probe. This list is only for the activities involved in testing MISTE instruments with LTMPF probe, not including required GSE for LTMPF.

Ground Support Equipment	***From***	***Status***	***Comments***
Cryogenic equipment			
Dewar	LTMPF	Ready	
Pumping Station	LTMPF	R	
1K-pot pump	LTMPF	R	
Leak detector (3He capable)	LTMPF/MISTE	R	
Lab use transfer tube	MISTE	R	
Sample Gas handling system	MISTE	R	
Probe support gas handling system	LTMPF	R	
Probe			
Cold flange & can	LTMPF	R	
Isothermal stages	LTMPF	R	
SQUID stages	LTMPF	Not Ready	
1K-pot	LTMPF	NR	
vacuum pumping line	LTMPF	NR	
Warm flange	LTMPF	NR	
Valves and Fittings	LTMPF/MISTE		
He level detector	LTMPF		
Probe hanging structure	LTMPF	NR	
General lab tools	LTMPF	R	
Working bench	LTMPF	R	
Electronic/Electric Equipment			
SQUID (at least 4)	LTMPF	NR	
Coaxial cable and feedthru	MISTE	NR	
GRTs and Heaters	LTMPF	NR	
Wiring (cold to warm flange)	LTMPF	NR	
Data Acquisition System (VME style)			
VME chassis	LTMPF	NR	
DY4 CPU board	LTMPF	NR	
Interface (1553B,Ethernet)	LTMPF	NR	
GRT board	LTMPF	NR	
HRT board	LTMPF	NR	
CBS board	MISTE	NR	
Host computer (sever type)	LTMPF	NR	
Display and Storage	LTMPF	NR	
Breakout box and Cables	LTMPF	NR	
Equipment Rack	LTMPF	NR	
Power supply with UPS	LTMPF	NR	
Dewar monitoring			
Computer	LTMPF	NR	
Paging system	LTMPF	NR	

5.5.3 Testing

5.5.3.1 Cooldown and Leak Checking

5.5.3.2 Initial Instrument Testing

5.5.3.3 Software Testing

5.5.3.4 Sample Filling

5.5.3.5 Preliminary ground-based data taking

5.6 Interfaces to LTMPF

Since the MISTE team is producing mainly an ISP for use within the LTMPF, the relationships between LTMPF-designed systems and the MISTE-specific systems are very important. The interaction between these systems is defined by: 1) MISTE experimental requirements (i.e. facilities that we are requiring LTMPF to provide to support our science objectives), 2) Constraints placed on the MISTE systems by LTMPF and others, and finally 3) the detailed specification of interfaces to which MISTE systems must mate.

5.6.1 MISTE Requirements on LTMPF

We are assuming that the probe will meet the specifications listed in the SRED and the Probe/Dewar Interface Requirements Document. These specifications are expected to be defined more precisely in the LTMPF FRD (functional requirements document) which is now in a preliminary version. In addition to the standard facilities and capabilities of the LTMPF. Four coaxial lines and 2 triaxial lines and the capability to mount a cold amplifier on the innermost vapor cooled shield (with allowed power dissipation TBD) are also required. These additional items are listed in the current MISTE-specific requirements in the probe interface document. Note that MISTE will probably not require all of these additional elements, but the complete list covers several possible scenarios in order to allow some freedom of implementation.

5.6.2 ISS/JEM-EF/LTMPF/Probe Constraints

The SRED and Probe Interface Document also place certain constraints on the ISP (power dissipation, size, mass, etc). We expect to receive more detailed information in the LTMPF FRD, and final information on these constraints by a date TBD (baseline 11/01/99). We are assuming the LTMPF team will collect and pass along to us all pertinent constraints due to ISS, JEM-EF, and STS, with possible modifications based on, for instance, the vibration transfer function for the dewar. We therefore expect to have a concise and central reference for the constraints and requirements on the ISP and MISTE-specific hardware elsewhere in the facility (e.g. flight electronics) without having to search through numerous NASA / ISS / JEM-EF / STS / NASDA documents.

5.6.3 Interface Specifications

In order to be able to start designing systems that will actually mate with LTMPF hardware, we will require detailed interface documentation (ICD's - interface control documents) for several LTMPF subsystems. As a baseline date we assume all these interfaces (with the exception of flight ops) will be finalized by 01/00 (the system PDR date). Preliminary interface information should be passed on to us as it becomes available to the LTMPF team. We have identified the following interfaces between MISTE systems and LTMPF that need to be defined:

5.6.4 Mechanical Interfaces

There are two: the probe-ISP mechanical interface (including plumbing) needs to be defined, including information on allowed mounting points on the IGV can flanges. Our interface to the warm end of the dewar plumbing also needs to be specified, so that we can mount possible low temperature valve actuation controls, etc. This is an area that is very unclear at the moment. Orientation of the cell aligned with residual gravity direction at JEM-EF site requires also well defined probe orientation in advance. However the absolute orientation of the probe and 2 ISP configuration in a probe is very unclear at the moment.

5.6.5 Electronics Interfaces

We anticipate that the cold electronics (and SQUID) interfaces will be fairly straightforward, but they will need to be defined explicitly. Of more concern to us is the interface for MISTE-specific flight electronics. We will build a VME bus interfaced capacitance bridge system. Cabling requirements for MISTE-specific sensors are total 7 coaxial line and 1 triaxial line without redunduncy.

5.6.6 Software Interface

We assume that LTMPF will provide a standard software package to control temperature of isothermal stages, and HRT reading and control. This involves remote commanding, displaying output, and storing. MISTE team will provide a science sequence for the experiment (algorithm, not actual flight qualified source code), and device-driver (actual source code) for the MISTE specific capacitance bridge electronics. Actual flight sequence will be generated by LTMPF software engineering team with algorithm input from MISTE science team. After the successful compilation, the MISTE science team will test software systems during the low temperature run. As all telemetry from the experiment will be routed through the LTMPF flight computer, we assume that our interface to telemetry is a subset of the software interface.

5.6.7 Flight Operation Interface

The SRED describes a JPL/LTMPF Telescience Support Center (TSC) which will serve as an intermediary between the experiment PI's and the Payload Operations Integration Center (POIC) at MSFC. We assume that the PI interface to the TSC will be defined by 1/02 so that necessary interface software can be written. This interface is also discussed in section 4.4.3.

5.7 Assumptions in Mission

5.7.1 Orbit

The altitude of the ISS orbit is 370-460 km. The inclination of the orbit is 51.6° (driven by the latitude of the Russian launch site). The orbital period for circling the Earth will be constant at approximately 90 min. The most important fact about the orbit is that the charged particle radiation environment is a function of the altitude and inclination. Effects at higher flux levels are to some extent unknown. Estimates of the flux level have been made assuming linear extrapolation from available data and models. The radiation environment will clearly degrade the quality of the experimental data. However, this problem can be overcome by flying a longer mission and restricting critical measurement to periods near the equatorial band where the radiation is smallest.

5.7.2 Experiment Timeline

The planned experiment timeline is described in section 4.3.5. The assumptions that are implicit in that timeline are 1) MISTE will fly after ISS assembly completion. 2) no power or telemetry will be available until after turn-on on the JEM-EF. 3) LTMPF staff will handle initial facility health checks and then the experiment will be turned over to nominal MISTE control until cryogen depletion at least 4.5 months later, after which telemetry and power will be cut and the facility will enter survival mode till its return.

5.7.3 Orientation of ISS

The effect of gravity is still an important factor in designing the experimental cell for the MISTE flight experiment. The orientation of the cell relative to the microgravity field can have significant consequences on the performance of this experiment. At this time the MISTE experimental probe is planned to be inserted along the axis of the LTMPF. The LTMPF in turn will be attached to one of the ports of the Japanese JEM-EF Module. An analysis of the expected gravity vector has been performed for all of the potentially available ports on the JEM-EF Module. To illustrate one possible scenario we have considered port 2 of the JEM-EF Module during a specific time period corresponding to flying in the first quarter of 2004. The magnitude of the gravity vector for port 2 is ~ 2.6 μg with a stability of 0.1 μg. Assuming the axis of the LTMPF is along the port 2 axis, the net acceleration vector will point in a given direction that is ≈ 45° with a stability of 3.2° from the axis of the MISTE probe. The predicted magnitude of the gravity vector varies somewhat for the other available JEM-EF ports, but the angle and the variation is very similar. This information is encouraging in that the gravity magnitude and direction will be relatively constant throughout a short duration experimental run. However, the direction of the gravity vector relative to the MISTE cell axis can complicate the data analysis. This direction varies with the altitude of the ISS which will be constantly varying. The magnitude of this variation is now being investigated.

There are several possible scenarios for minimizing the effect of gravity on the MISTE experiment. Ideally, the flight cell should be oriented so the shortest fluid length is along the net acceleration vector. If the orientation of the net acceleration vector remains approximately constant during the LTMPF mission, the MISTE cell axis should be oriented at a fixed angle relative to the probe axis. An off-axis orientation could seriously complicate the ground based testing and integration of the flight cell. At this time, the MISTE preliminary science requirements are based upon a flight cell design that could achieve the proposed experimental objectives independent of the cell orientation.

5.7.4 Activities of ISS

After completion of ISS assembly, there is a requirement that there be 180 days per year of microgravity operations in increments of a least 30 days. There are no requirements on the length of time that microgravity operations are achieved during assembly. It is expected that ISS activities like docking, assembly and reboosts will perturb the microgravity environment. Building the ISS requires more than 50 flights over a 4.5 to 5 year period. This means that ISS will meet the Shuttle almost every 30 days. Approximately 10 days of activity is required before the ISS can reestablish the microgravity operation mode. The impact of these activities to the experiment is not well understood. If the experiment has to idle during these periods, the total available microgravity time would be 2/3 of currently planned LTMPF schedule. It is also unknown at this point when the experiment will actually fly relative to the ISS assembly schedule.

5.7.5 Experiment Data

In order to optimize data collection during the mission it is important to maintain continuous real time command and data telemetry with the experiment as much as possible. Unfortunately, the coverage of the relevant Ku communication band for the ISS is expected to be much lower than similar coverage for the shuttle, approximately 70% per orbit, on average. Therefore, it is extremely important to establish the optimum data collection and command strategy for the experiment as early as possible during the mission. For space shuttle experiments (LPE, CHeX) the decisions regarding the data acquisition strategy could be made by evaluating data inputs after about three days of flight time. It is obviously impossible to simulate everything about the mission because proposed functionality of the ISS is still in transition and may not be available before the flight. In the MISTE experiment we plan to optimize the command and telemetry sequence for the data collection after about one week of flight time. This early flight study will provide appropriate inputs regarding ISS telemetry capabilities/coverage and the regions of the orbit where environmental effects are minimum. We believe that this strategy is quite adequate for the MISTE experiment on ISS because of the allowed long duration (at least 4.5 months).

5.7.6 Environmental Data

It is very important to obtain environmental data during each orbit. Charged particle data should be monitored during the experiment to optimize the data acquisition plan and to look for sources of heat input to the experimental cell. It will also be necessary to perform checks of the acceleration environment to look for possible adverse effects on the experiment, such as vibration heating effects during the heat capacity measurements. In addition to a full spectrum of the vibration environment, it is desirable to have the real time peak acceleration vector amplitude data transmitted to the MISTE instrument computer system to be correlated with the main science data. These capabilities are SRED requirements and the data will be provided to the MISTE team.

5.7.7 Orbiter Data

For the post-flight data analysis activity it will be required to have data on the ISS location and attitude as a function of mission elapsed time. It is also important to know the actual direction and magnitude of the gravity vector at the LTMPF as a function of time. Also a record should be kept on the time of high acceleration events such as a docking events on the ISS and attitude control rebooting events. These events will need to be cross-correlated with the main science data.

6 Schedule

The subheadings in this section describe in more detail the tasks on the MISTE schedule in Appendix A.

6.1 Prototype Instrument Fabrication and Integration

After SCR, design and fabrication of prototype flight-like sensors and a flight-like cell was begun. Consultation with structural experts and possible component shake testing will be performed to validate flight-like design concepts. All of the sensors will be integrated into a prototype ISP by approximately the RDR date.

6.2 Prototype Instrument Testing

Testing of the prototype instrument will be preformed in the existing MISTE ground science dewar using conventional laboratory electronics and LabView computer control. This integrated prototype system will be operated in a simulated flight scenario to demonstrate that the requirements of all the sensors are being met.

6.3 Flight ISP Design and Fabrication

This task starts after RDR. To the extent that experimental subsystems are judged at RDR to be in a mature, flight-like state, we propose to begin fabricating some components of the flight ISP. Other components will probably still require analysis and engineering evaluation before a final design is reached and fabrication can begin. All fabrication procedures and component drawings will be documented in the MISTE report system and through JPL engineering data management as appropriate. If there is a restriction that flight hardware shall not be fabricated before CDR, then we believe that the date of CDR should be made earlier by at least 3 months or possibly to a date shortly after the Probe CDR.

6.4 Flight Software Development

As the MISTE team does not have previous flight software experience, we plan to start this activity immediately after RDR. We will produce a specification based on the ground software then implement it on the ground prototype system. This will continue until ISP/probe I&T when we will test and improve the software control system.

6.5 Flight ISP Integration with Probe

The integration of the flight ISP and probe will nominally start on 5/16/01. The flight ISP will be integrated with the completed and tested probe provided by the project. This mating will occur at JPL, and be performed by MISTE with support by the project probe engineer. After initial mechanical and electrical integration the composite instrument will be functionally tested. We assume that testing of the integrated ISP/Probe instrument will be performed in a 10" dewar test bed including an appropriate probe support structure, radiation baffles, wiring to room temperature. We are assuming that this test bed will be provided by the project and will available at JPL by the integration start date. The test bed should allow testing in an environment as much like the flight facility dewars as feasible; e.g. the top flange of probe should be maintained at 1.6-2.0 K. At present we are assuming that the MISTE project will be constructing the room temperature MISTE-specific gas handling system required to operate the ISP in this test bed. By the end of this period, the experiment will be controlled by the MISTE VME bus data acquisition system with flight-like electronics and prototype flight software.

6.6 Instrument and Software Testing with LTMPF

This activity starts with the beginning of the integration of the instrument with the facility dewar, baselined on 12/05/01. Initially the integration between flight dewar and the flight probe with ISP will be performed mainly by the probe engineers and MISTE designated engineers. As cold testing begins the MISTE team will use flight electronics and flight software for extensive functional and performance tests before, during and after environmental tests. After all environmental tests, a period of ground science operations will be used for calibrations and for the final filling of the cell to near the critical density.

6.7 Environmental Testing

This task will be conducted concurrently and/or intermixed with the instrument and software testing, the exact time breakdown is TBD. Since the facility as a whole will be undergoing tests, environmental testing will be principally orchestrated by the LTMPF project team, with MISTE team providing ISP function/performance test support.

6.8 Launch Slip Waiting Period

The 11 month slip in the launch of the HTV which will carry MISTE has been incorporated into the schedule as a simple waiting period. This is per instructions from the LTMPF project management. All MISTE deliverables are still scheduled for the dates baselined before the launch slip.

6.9 Launch Campaign

For the purposes of this schedule we count the launch campaign from the date of delivery to Tanegashima Space Center in Japan. There will be some MISTE team interaction in functional tests after shipment. After that point we assume the responsibilities of the MISTE team will be minimal and the LTMPF project will handle housekeeping tasks for the facility. Experiment systems are assumed to be powered down during this time so little action is possible. We reiterate the MISTE requirement (which is incorporated in the SRED) that the ISP must not warm above 4.3 K during this period in order to avoid excess pressure stresses on the ISP sensors.

6.10 Mission Operations

6.10.1 Startup Tasks

We assume that events from launch to after LTMPF-JEM-EF attachment are not the responsibility of MISTE team. Any data that is collected during launch (launch load accelerations, heating, etc.) will be handled by the LTMPF engineering team. Initial power-on sequences and checkouts for the LTMPF systems (computer, power, dewar health checks, etc) will be handled by the Project, and then the MISTE team will be given command access for nominal performance verification tests. We expect that any anomalies that might influence the health of the experiment, which occur during the tasks from launch through turnover to MISTE control will be reported to the MISTE team. LTMPF will confirm the availability of all other required resources (SAMS data, etc.) and then turn the control of the experiment over to the MISTE team.

6.10.2 MISTE Science Operations

Using the telescience system, the MISTE team will first do performance checks, calibrations, and evaluation of on-orbit perturbations (e.g. charged particle heating). These tests will occur during the first week or so and be used to formulate a revised operation scenario and timeline. Data

collection will then begin in earnest with the measurements along the near-critical isochore set by the ground cell fill density. This will ensure significant science return even in the event of total failure of the on-orbit valve actuation. MISTE will perform data storage and redundant backup, data reduction and data analysis concurrently with operations. We expect to receive the following support data from LTMPF: data from LTMPF/probe charged particle and accelerometers, ISS data on altitude, attitude, position, and acceleration (SAMS-II) as well as notification of disturbances (docking, reboots, construction, exercise times, etc.). Implicit in this list is the assumption that the LTMPF engineering team will control and monitor the probe-level environment sensors (CP and acceleration). We assume that LTMPF will provide us with information about scheduled ISS events disrupting the microgravity environment to the extent that they are known.
Concurrently with MISTE science operations there will be continuous facility health monitoring by LTMPF engineering team. We need a defined interaction between the MISTE team, LTMPF engineering team and also the other M1 PI team regarding pertinent data about the health of the system and/or anomalies affecting the system.

6.10.3 Shutdown

It would be desirable if LTMPF engineers could estimate the remaining dewar lifetime so that MISTE can knowledgeably schedule end-of-run tasks such as final calibrations. Depending on the plumbing configuration of the final flight system, we may perform a final vent of the sample helium to space to avoid burst-disk blowout when the system warms up. After the cryogen is exhausted we will leave the system in a predefined state and turn control over to LTMPF engineering team for system shutdown and housekeeping until return.

6.11 Data Analysis

Starts concurrently with data acquisition. During science operations we will use dedicated computer systems for the telescience operations control, initial data reduction and evaluation. More detailed analysis will be performed in parallel on other computer systems in supporting the preparation of the final report

6.12 Shutdown, Return and ISP De-integration

In the baseline schedule, the return of the facility to JPL could take place up to 1 year after the launch date. Any final calibration checks, etc. will be performed on-orbit due to the unavoidable post-operations warm-up of the system. Some final ground checks might be necessary to investigate unexpected behavior. The probe/ISP should be available to the PI for some period (TBD) after de-integration to allow these tests.

6.13 Final Report

This is baselined as due 12 months after launch, as it was with the previous shuttle experiments which only flew for short durations. We believe that this deadline should be extended to 12 months after the end of the science operations.

7 Program Management

A full time lead engineer and assistant lead engineer of the project will coordinate the instrument development program. The MISTE science team and JPL low temperature science and engineering group staff will provide support.

7.1 Schedule Management

The schedule milestones will be reviewed and reported to the LTMPF project weekly. For items that are not completed on time, those that may impact the overall program will be identified and corrective plans will be initiated. The preliminary WBS structure is shown in Appendix B. At this time only a top-level budgeting is shown in the Appendix C.

7.2 Roles and Responsibilities

PI (M.Barmatz)
PI will insure the best possible chances of meeting the science objectives of the experiment within cost and schedule constraints. The PI will inform the sponsor if the risk of not achieving the science objectives appears unreasonably high. The PI also reports experimental progress at monthly management reviews.

Co-I (J. Rudnick, I. Hahn, U. Israelsson)
Provide guidance to PI and represent him at other institutions. Assist with the progress of the research and the collection of the science related data elements. Present the science tasks and objectives at reviews and meetings.

Lead engineer and assistant lead engineer (I.Hahn, M. Weilert)
Handle daily activities involving the technical aspect of the instrument development. Coordinate technical inputs to planning and status of the instrument development. Provide internal technical progress reporting. Coordinate managerial, technical interface with LTMPF project.

7.3 Deliverable Items

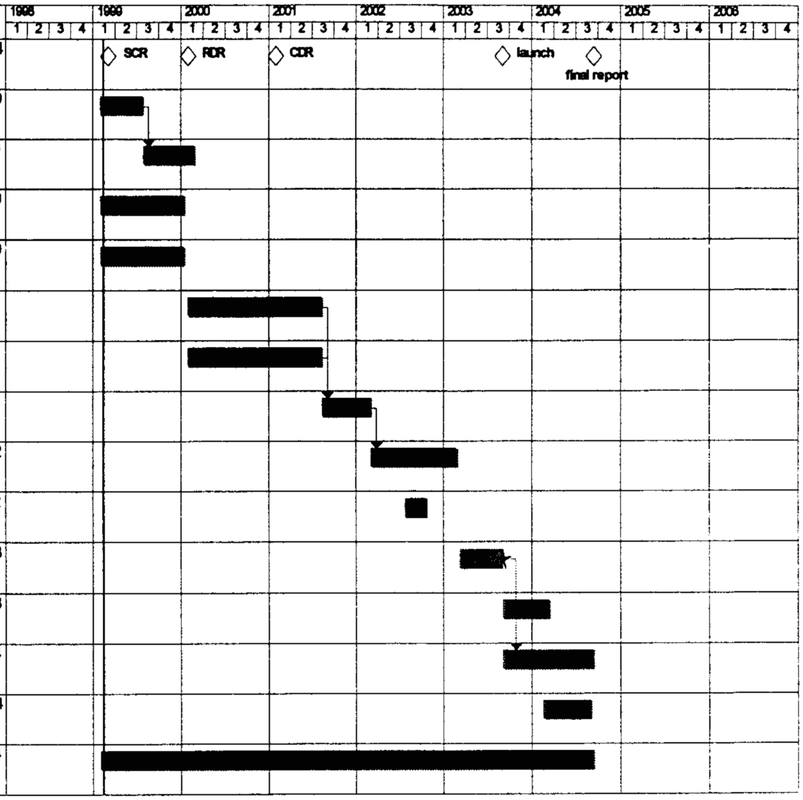
Table 1

Science Requirement Document	11/99
Experiment Implementation Plan	11/99
Flight ISP	7/01
Flight CBS board	7/01
Integration Test Software	7/01
Flight Instrument integration LTMPF	5/02
Flight Software	10/02
Final Report	7/04
Progress Report	Monthly

8 Appendix A

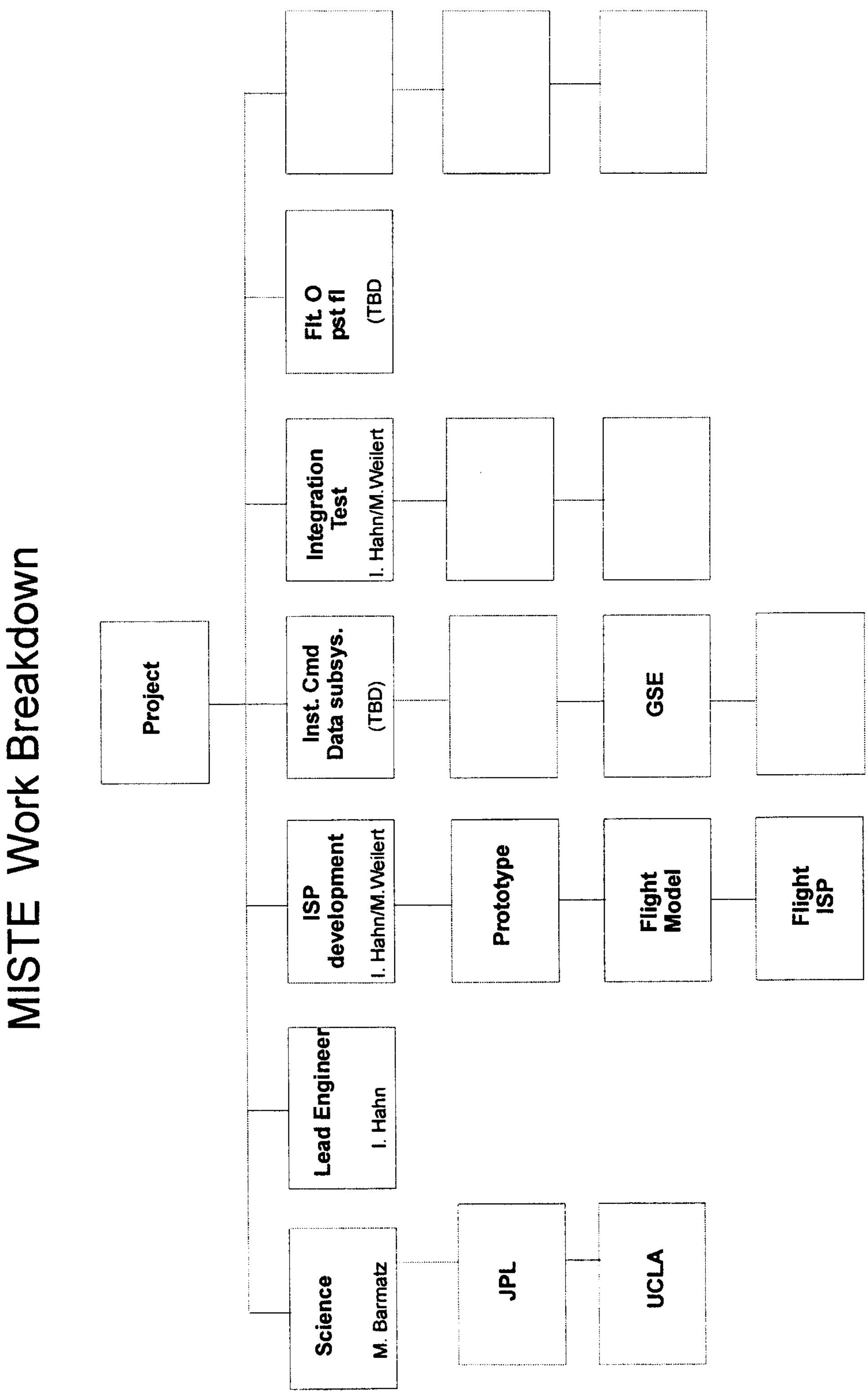
Schedule

ID	Task Name	Start	Finish
1	**reviews & milestones**	**Fri 12/4/98**	**Tue 6/15/04**
7	Prototype Instrument Fabrication and Integration	Wed 11/4/98	Fri 4/30/99
8	Prototype Instrument Testing & Flight Instrument Des.	Mon 5/3/99	Tue 11/30/99
9	Implementaion Plan	Wed 11/4/98	Mon 10/18/99
10	Science Requirement Document	Wed 11/4/98	Mon 10/18/99
11	Flight ISP Design and Fabrication	Tue 11/2/99	Mon 5/14/01
12	Flight Sotware Development	Tue 11/2/99	Mon 5/14/01
13	Flight ISP Integration with probe	Wed 5/16/01	Tue 12/4/01
14	Instrument and Software Testing with LTMPF	Wed 12/5/01	Fri 11/29/02
15	Environmental Testing	Fri 4/26/02	Thu 7/25/02
16	Launch Campaign	Mon 12/9/02	Wed 6/4/03
17	Flight Operations	Mon 6/9/03	Mon 12/15/03
18	Data Analysis	Mon 6/9/03	Tue 6/15/04
19	shutdown, return and ISP de-integration	Fri 11/21/03	Fri 6/4/04
20	Ground Science Activities	Wed 11/4/98	Tue 6/15/04



Appendix B

Work Breakdown Structure



Appendix C

old Top-Level MISTE Budgeting (98)

This is still here for the comparison

Year	99	00	01	02	03	04
Total (K)		1691	2087	772	712	503

Total 5.76M

New Top-Level MISTE Budgeting (99)

Year	99	00	01	02	03	04
Total (K)		905	1500	950	851	112

Total 4.318M

Appendix D

Acronym List

BATC Ball Aerospace and Technology Corporation
CDR Critical Design Review
CHeX Confined Helium Experiment
CO-I Co-Investigator
Facet Fast Alternative Cryogenic Experiment Testbed
FRD Functional Requirements Document
FY Fiscal Year
GRT Germanium Resistance Thermometer
HRT High Resolution Thermometer
I&T Integration and Test
ICD Interface Control Document
IGV Instrument Guard Vacuum - the vacuum space surrounding the Instrument
ISP Integrated Sensor Package
ISS International Space Station
JEM-EF Japanese Experiment Module - Exposed Facility
KSC Kennedy Space Center
LPE Lambda Point Experiment
LTMPF Low Temperature Microgravity Physics Facility
MISTE Microgravity Scaling Theory Experiment
MRC Mission Research Corporation
MSFC Marshal Space Flight Center
PI Principal Investigator
POIC Payload Operations Integration Center
RDR Requirements Definition Review
SAA South-Atlantic Anomaly
SAMS Space Acceleration Measurement System
SCR Science Concept Review
SRD Science Requirements Document
SRE SQUID Readout Electronics
STS Shuttle Transport System - The Space Shuttle
SQUID Superconducting Quantum Interference Device
TBD To Be Determined
TSC Tele-Science Support Center
VCS Vapor-Cooled Shield
VME Versa Module Europa, an open standard bus system
WBS Work Breakdown Structure, a graph of who is doing what.

Other Terms

Probe The LTMPF team designed common support structure and thermal control system onto which the ISP mounts. The probe contains up to six squids and provides other common resources to the ISP as defined in the Probe interface document.

Instrument The cryogenic experiment system that is made of the ISP integrated with the probe. This mounts into the dewar.

Project The LTMPF team/program/budget, as distinct from the MISTE or other PI team/program/budget.

Facility Short for LTMPF, and specifically the parts of the LTMPF excluding the instrument, i.e. the dewars, electronics, external plumbing, support structure, and the interface to the JEM-EF.

Dewar The liquid helium reservoir and associated vapor cooled shields and outer can in which the instrument is housed. This includes wiring and plumbing from outside the dewar to the probe. There are two dewars in the facility.