# MISTE Flight Experiment Status

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The MISTE flight experiment has made significant scientific and technical progress in preparing for a future microgravity flight. We are collaborating with several theoretical modeling groups that have developed crossover (equation-of-state) models for predicting thermodynamic behavior near the liquid-gas critical point. Computer codes for these models are being prepared in preparation for analyzing future MISTE flight data. Several of these models have already been used to test experimental measurements of the heat capacity at constant volume, isothermal susceptibility, and coexistence curve in the crossover region near the $^3$He liquid-gas critical point. A brief description of these models and a representative fit to experimental data will be presented. An important technical advancement required for the successful completion of the MISTE flight experiment is the development of a low temperature valve that can be actuated multiple times. In collaboration with Mission Research Corporation, MISTE has been testing a new small pneumatic valve for use at low temperatures. The results of recent successful low temperature actuation tests will also be discussed.

## I. INTRODUCTION

The main objective of the MISTE flight experiment is to perform pressure, density and temperature measurements as well as heat capacity at constant volume and isothermal susceptibility measurements near the $^3$He liquid-gas critical point. This study is important because these thermodynamic quantities diverge and measurements very close to the transition can be used to unambiguously test critical phenomena scaling theories that apply to all simple fluids.

The MISTE experiments will determine the asymptotic critical amplitudes and exponents for $C_V$ and $\chi_T$ above and below the transition. To more clearly understand the meaning of this statement, Eq. (1) shows the theoretically expected behavior of the isothermal susceptibility along the critical isochore above the transition and along the coexistence curve below the transition.

$$\chi_T^{\pm *} = (P_c/\rho_c^2)\chi_T^{\pm} = \Gamma_0^{\pm}|t|^{-\gamma}[1 + \Gamma_1^{\pm}|t|^{\Delta_s} + ...], \tag{1}$$

where $\gamma \simeq 1.24$ is a universal critical exponent that define the strength of the susceptibility divergence and $\Gamma_0^{\pm}$ are system-dependent asymptotic critical amplitudes. In this expression, the + sign indicate above the transition and the - sign below. The asymptotic region is very close to the critical point where critical fluctuations dominate the behavior of the system. In this region, the susceptibility is expected to follow the power law behavior given by the leading power law term. The MISTE flight experiment will obtain values for the asymptotic critical amplitudes and critical exponent.

Farther away from the transition, the system enters the crossover region where it slowly changes from critical behavior to mean field behavior. In this region, correction-to-scaling terms, shown in the brackets of Eq. (1), become important. These terms are generally called Wegner correction terms, and the first correction term is shown within the brackets. $\Gamma_1^{\pm}$ are system dependent amplitudes and $\Delta_s$ is another exponent that describes crossover behavior. Ground-based measurements provide information about the crossover region.

There are similar expression like that shown in Eq. (1) for other thermodynamic quantities such as the heat capacity at constant volume and shape of the coexistence curve. A new flight guest experiment called Coexistence Boundary Experiment (COEX) is being considered to use the MISTE flight hardware. The COEX experiment will accurately determine the shape of the coexistence curve. By combining the MISTE/COEX flight measurements with corresponding ground-based thermodynamic measurements, we can test the predictions of critical phenomena theories both in the asymptotic region as well as the crossover region. These predictions will include the amplitude ratios and exponent scaling relations. The approach to be taken is to performed measurements primarily along the critical isochore or path of constant critical density, the critical isotherm or path of constant critical temperature and the liquid and gas sides of the coexistence curve.

## II. GROUND EXPERIMENTAL ACTIVITIES

We have spent considerable time and effort in upgrading the ground-based MISTE cryostat. A new donut shaped cell was fabricated. This design will permit the cell to withstand higher pressures than the previous cell design. We will now be able to perform measurements along the critical isochore to $\approx$ 11 K. This will allow a determination of the crossover to mean field behavior as well as the analytic background contributions.

We have also significantly improved the High Resolution Thermometer readout electronics. This was accomplished by developing a flux counter system that can read at least 60,000 flux counts/sec. This means that we will not loose count of temperature changes even for the fastest experimental temperature slewing rates.

This new measurement system is now being tested in preparation for a more precise set of thermodynamic measurements. Of particular significance is the ability to accurately measure the shape of the coexistence curve. The COEX approach for measuring the coexistence curve will also be used during this next run. Thus, for the first time, we will have a complete set of precision thermodynamic measurements within the crossover region obtained in the same apparatus. These combined sets of measurements will provide a stringent test of theoretical crossover models.

## III. THEORETICAL ACTIVITIES

During this last year, the main emphasis in this area has been to analyze existing ground-based measurements using the predictions of recent theoretical models. We have been developing collaborations with theoreticians to improve and test their models. Here are listed some of these collaborations and the progress that has been made.

The Minimal Renormalization $\phi^4$ model was initially developed by Volker Dohm and co-workers[1][2] to make predictions for the lambda point. The MISTE team has applied this approach to the $O(1)$ universality class that includes the liquid-gas critical point. There are three articles already published[3]-[5] that use our $C_V$ and $\chi_T$ data to test this approach, and a detailed description of this application to the $O(1)$ universality class is in preparation[6].

Another field theoretical approach called the Massive Renormalization $\phi^4$ model was also developed by Bagnuls and Bervillier several years ago[7][8]. They have recently extended their model to cover the complete classical-to-crossover region[9]. We recently developed computer fitting routines for their various models and have fit heat capacity, susceptibility and coexistence curve $^3$He data using these models. The results of this analysis is now being prepared for publication[10].

We have worked closely with Professor Anisimov and co-workers in testing their new crossover parametric model (CPM)[11]. A joint article was initially published comparing their model against $^3$He heat capacity and susceptibility measurements[3]. These data were also used in their paper that gave a complete description of this model[11]. We have just finished developing a computer code for the complete equation-of-state form of their model and are now prepared to use this code to also include coexistence curve measurements in the analysis.

The most recent advancement is a new field-theoretical parametric crossover model (PCM) developed in collaboration with Joseph Rudnick who is a co-investigator on MISTE. This is a complete equation-of-state model that satisfies the most accurate field theoretical predictions of Guida and Zinn-Justin[12] in the asymptotic limit and also satisfies the mean field predictions[13] far away from the transition. The model has the critical exponents and amplitude ratios fixed at the latest theoretical values. A computer code is now being developed and testing against $^3$He measurements is in progress[14].

As an example of our analyses of recent theoretical models, Fig. 1 shows a fit of $^3$He susceptibility data to the PCM model. The susceptibility data were scaled by the leading power-law behavior in order to provide a more sensitive test of the theory. For this initial fit to the theory, we manually adjusted the three model parameters to give a reasonable fit to the data. The parameters $u$ and $\tau$ are the fundamental model parameters and must be the same for fitting any other $^3$He thermodynamic parameter. The parameter $A_s$ adjusts the susceptibility amplitude. We see that this manual fit is reasonably good and we can extract estimates of the leading and first Wegner critical amplitudes both above and below the transition. Of course we plan to perform more thorough non-linear least square fits in the near future. It should be noted that these are gravity free data that only approach the transition to a reduced temperature of $|t| \cong 10^{-4}$. The MISTE microgravity experiment should be able to extend these data another two decades closer to the critical point.

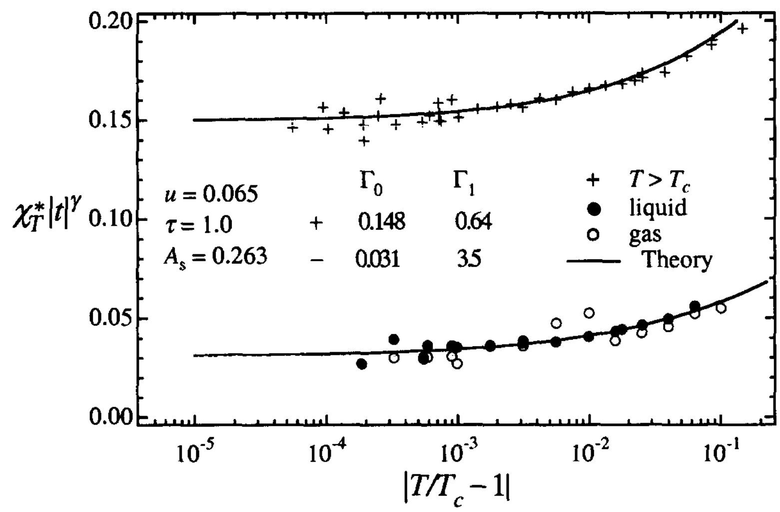


FIG. 1: Manual fit of the PCM model to $^3$He susceptibility data both above and below the critical point. The parameter $\tau$ was held constant and the parameters $u$ and $A_s$ were adjusted.

## IV. FLIGHT ENGINEERING ACTIVITIES

In order for the flight experiment to be successful, we need a low temperature mini-valve that can be actuated many times in-situ. We have been collaborating with Mission Research Corporation (MRC) and have recently successfully tested a prototype mini-valve. The valve body is approximately 1.5″ in diameter by 1.75″ long. A more detailed description of this valve design has already been published[15]. The leak rate determined during the actuation study is shown in Fig. 2. The valve was actuated over 200 times with the leak rate being generally below $2 \times 10^{-7}$ std cc/s. The requirement for the MISTE flight is $1 \times 10^{-6}$ std cc/s for 25 cycles. Thus, this valve satisfies these requirements and further tests of a flighr-like valve are planned.

Progress has also been made in developing the MISTE flight cell. It consists of a 5.9 cm inner diameter by 3.2 cm height cylindrical cell body that contains the $^3$He fluid. The cell will have approximately 60 copper plates and 60 copper spacers each being 0.025 cm thick. The plates will have a large number of small holes to permit fluid to communicate between adjacent local 0.025 cm thick cells. These plates and spacers are introduced to reduce the thermal equilibration time which becomes very long near the critical point. There will also be two sets of temperature, density and pressure sensors attached to the cell. These cell components are now being fabricated.

The MISTE flight cell and associated sub-systems will be situated on the Low Temperature Microgravity Physics Facility (LTMPF) probe. This entire assembly will be sealed in a vacuum can and inserted in the LTMPF dewar. Figure 3 shows an assembly drawing of the MISTE instrument sensor package integrated with the probe support structure. The MISTE cell is at the top of the probe and the probe is attached to the dewar cold plate. The cold plate is 25 cm in diameter and the height of the assembly shown here is approxi-

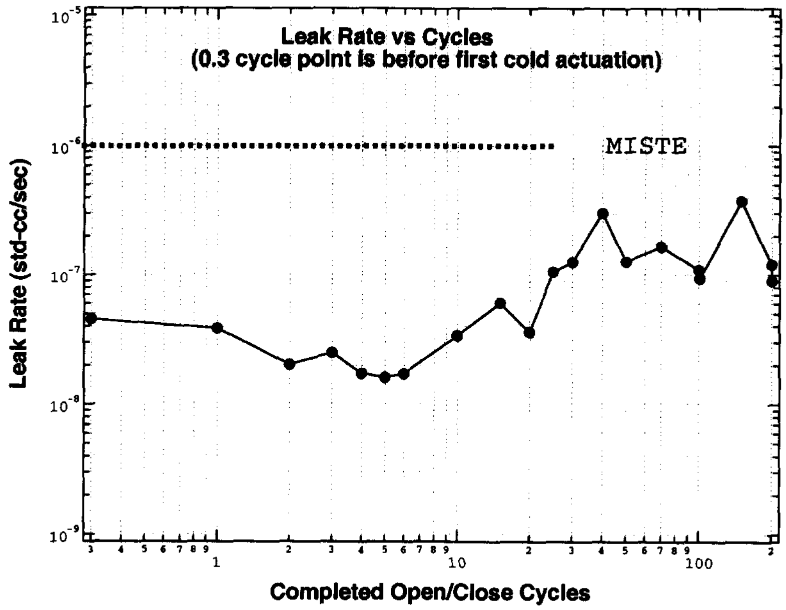


FIG. 2: Leakrate of MRC valve versus number of actuation cycles. Leakrate remained below the MISTE requirement of $1 \times 10^{-6}$ std cc/s for 200 actuation cycles.

mately 40 cm. The probe support consists of three isolation stages. Each stage has better than a 1000:1 isolation from the previous stage. With this level of isolation, a temperature resolution of better than a nano-Kelvin at the MISTE cell can be attained. In the final assembly, the shield stage will have a copper radiation shield that will surround the MISTE cell to improve thermal isolation. A vacuum can, that surrounds this entire assembly, will be sealed at the cold plate.

In conclusion, a new MISTE cell has been fabricated and will be use to perform a complete set of thermodynamic measurements in the critical region ($PVT$, $C_V$, $\chi_T$, coexistence curve shape). Computer fitting routines for several recent theoretical critical point models have been developed and these models are being tested using ground-based measurements. All of the MISTE flight hardware components have been designed and are now being fabricated for testing.

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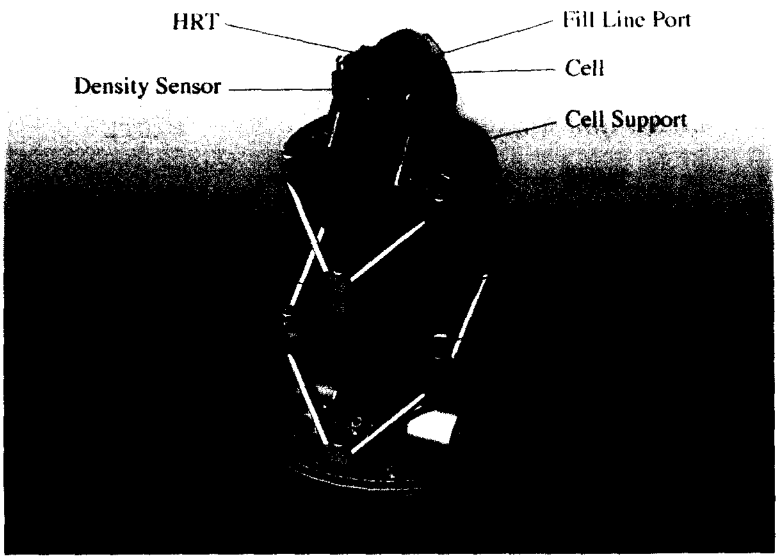


FIG. 3: The MISTE instrument sensor package integrated with the LTMPF probe support structure.

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