National Aeronautics and Space Administration

Potential Follow on Experiments for the Zero Boil Off Tank Experiment

Presentation to

30th ASGSR Annual Meeting

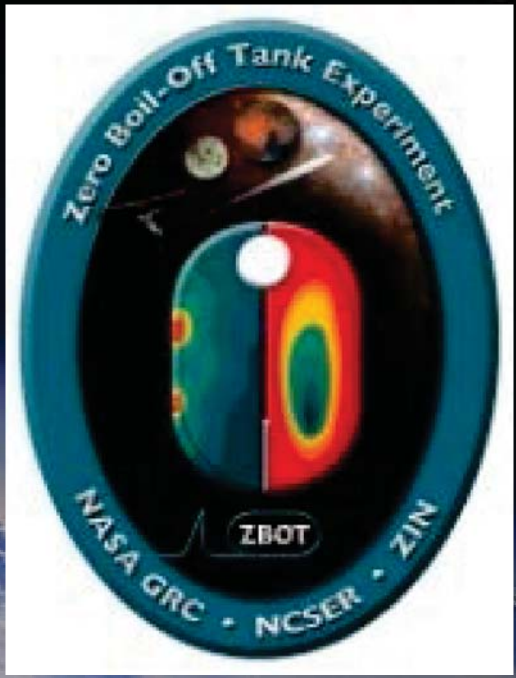
October 26th 2014

By

Dr. David . Chato

And

Dr. Mohammed Kassemi

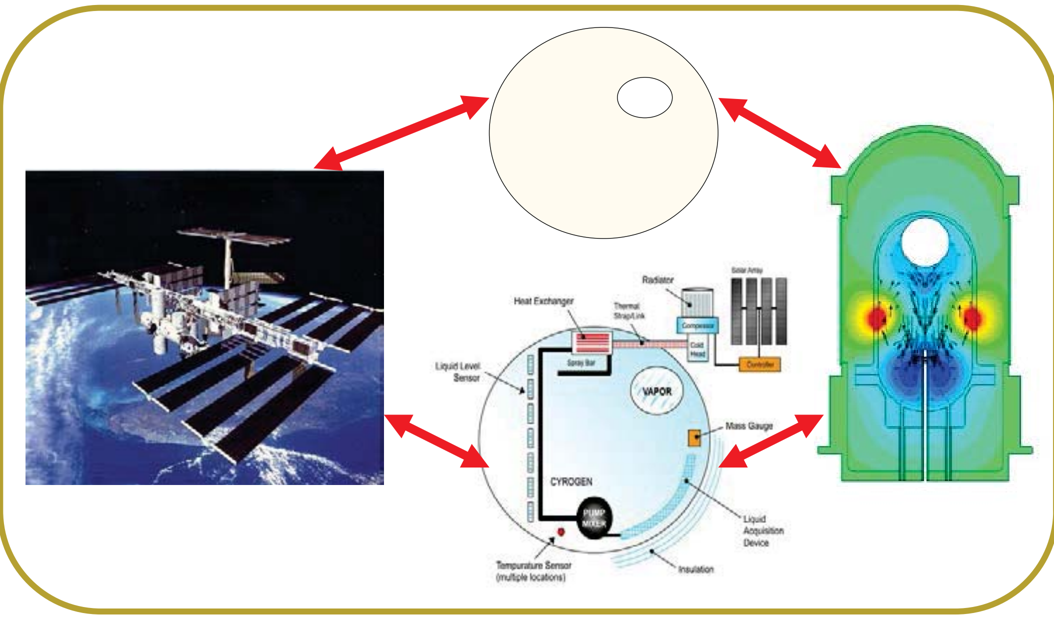


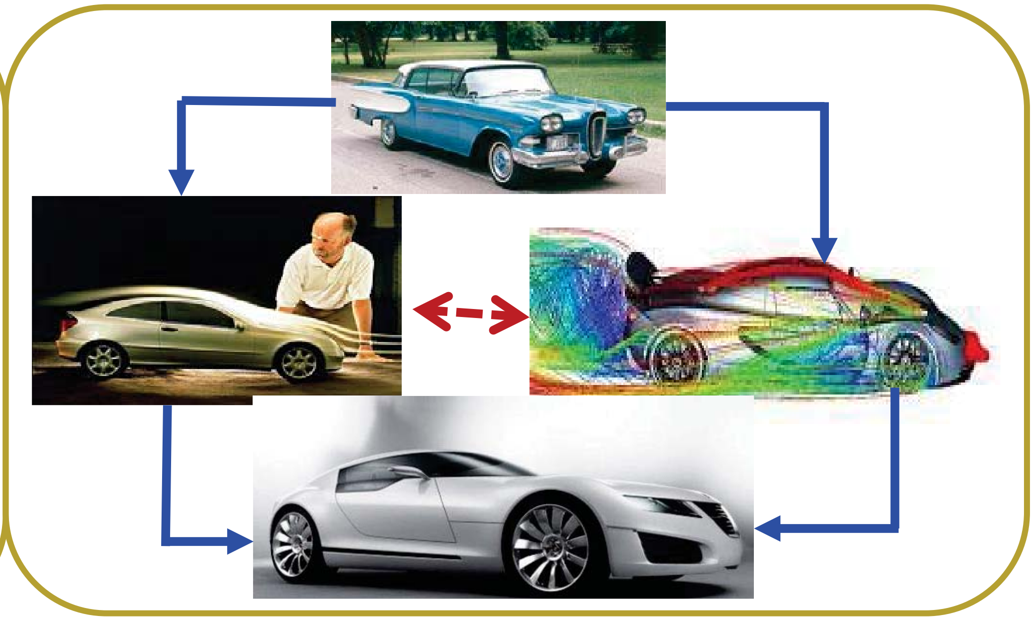
Zero Boil-Off Tank(ZBOT) Experiment Series

- **Principal Investigator:** Dr. Mohammad Kassemi, National Center for Space Exploration Research
- **Co-Investigator:** Dr. David J. Chato, NASA, GRC
- **Project Scientist:** John McQuillen, NASA GRC
- **Project Manager:** William Sheredy, NASA GRC
- **Engineering Team:** ZIN Technologies, Inc
- **Carrier**: Microgravity Science Glovebox

Background and Motivation

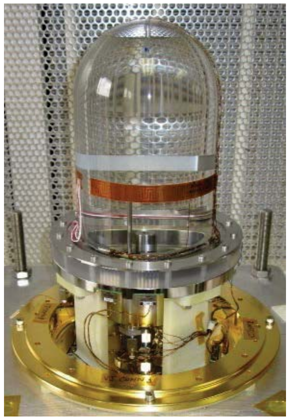
- Cryogenic Storage &Transfer are enabling propulsion technologies in the direct path of nearly all future human or robotic missions
- It is identified by NASA as an area with greatest potential for cost saving
- This proposal aims at resolving fundamental scientific issues behind the engineering development of the storage tanks
- We propose to use the ISS lab to generate & collect archival scientific data:
  - raise our current state-of-the-art understanding of transport and phase change issues affecting the storage tank cryogenic fluid management (CFM)
  - develop and validate state-of-the-art CFD models to innovate, optimize, and advance the future engineering designs



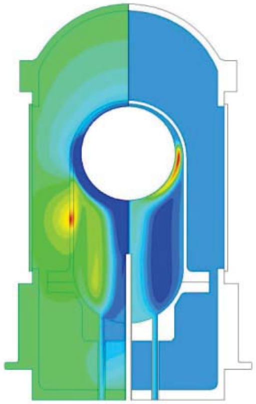


Zero-Boil-Off Tank (ZBOT) Experiment

- A small-scale ***simulant*-fluid (**Perfluoropentane [PnP]) experimental platform to be accommodated in the Microgravity Science Glovebox (MSG) unit aboard the ISS.
- **Obtain microgravity data** for tank stratification, pressurization, mixing, destratification, pressure reduction, ullage penetration, and droplet transport & phase change time constants during storage with and without noncondensables.
- Elucidate the roles of the various **interacting transport and phase change phenomena** that impact tank pressurization and pressure control in microgravity to form a scientific foundation for storage tank engineering.
- **Derive empirical** microgravity engineering correlations *for back-of-the-envelope design calculations* and implementation into the zonal-based engineering models
- **Develop a *state-of-the-art* CFD** two-phase model for storage tank pressurization & pressure control.
- **Validate and Verify** the CFD-based tank model with the microgravity data. Use the model and correlations to optimize and scale-up future storage tank design

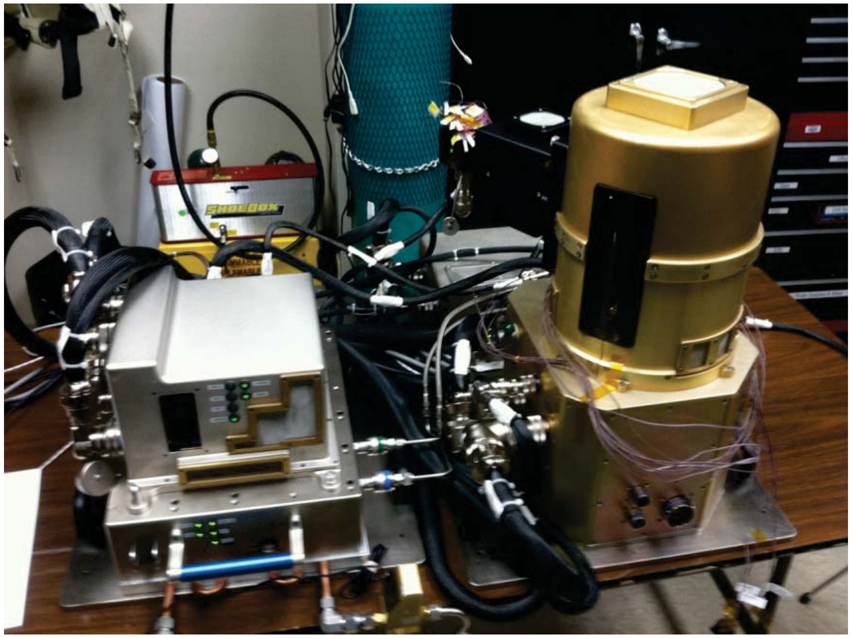


ZBOT EM Test Section



CFD Model Prediction: Temp & Flow Fields in Microgravity

- ZBOT Science Review Panel composed of six CFM experts from academia, aerospace industry, and NASA laboratories strongly endorsed the objectives of the experiment but recommended that they should be achieved in an incremental manner through a series of experiments with increasing complexity.
  - ✓ **ZBOT-1:**
    - o Pressurization, pressure reduction by mixing & destratification
    - o Model development and validation
  - ➢ **ZBOT-2:**
    - o Noncondensable effects on pressurization and pressure control
  - ➢ **ZBOT-3:**
    - o Different active cooling mechanism
    - o Droplet phase change & transport in microgravity



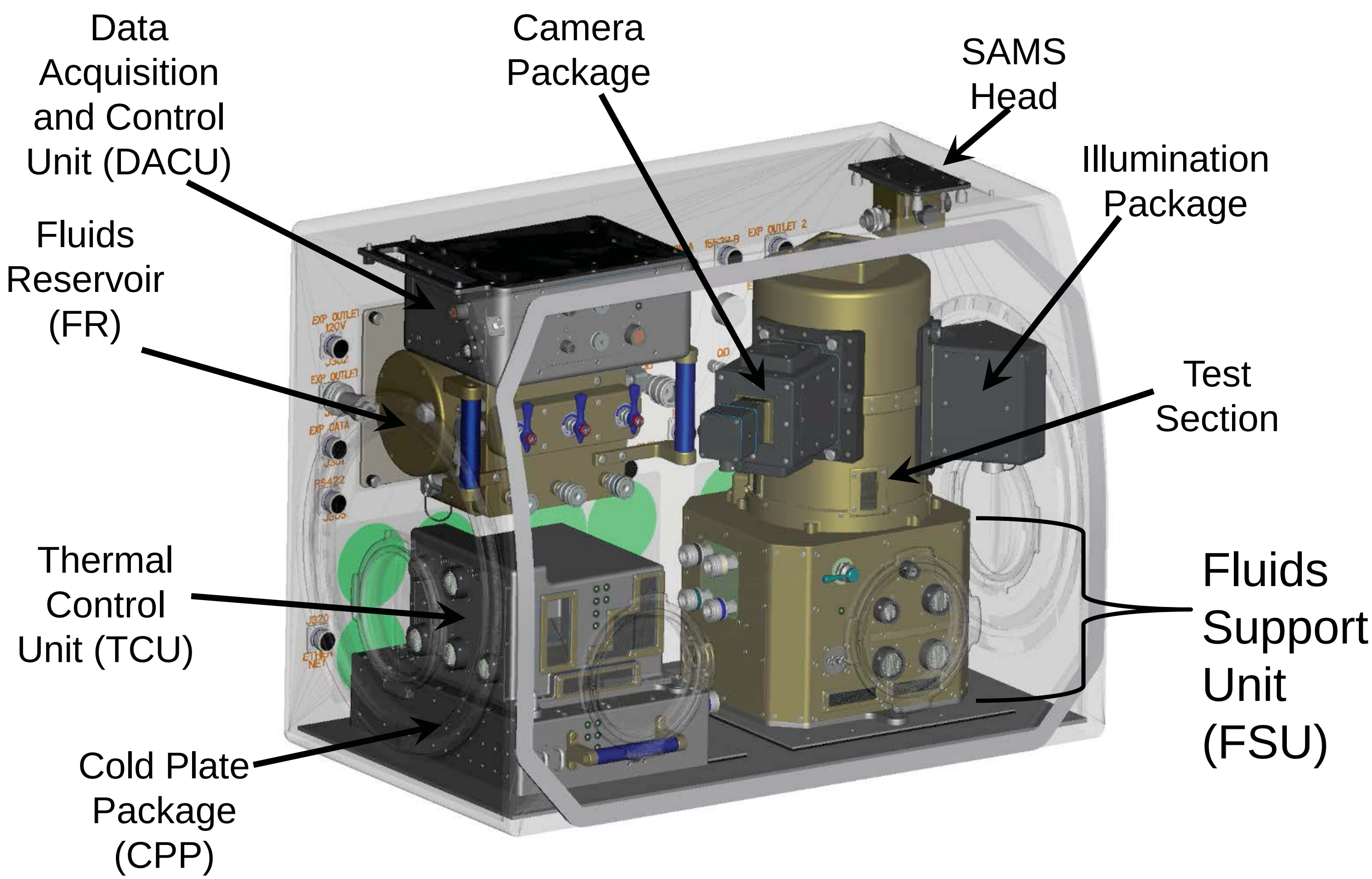
- The follow-on experiments will benefit greatly from heritage developed by ZBOT-1

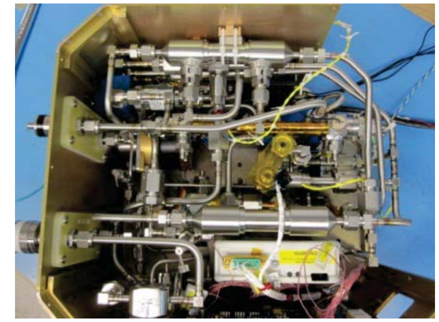
Broad Scientific Goals of ZBOT

- Perform hand-in-hand experimentation, theoretical analysis, and computational modeling to:
  1. Gain a fundamental understanding of the phase change and transport phenomena associated with tank pressurization and pressure control
  2. Determine the time constants associated with pressurization, mixing, destratification, and pressure reduction for different gravitational environments
  3. Determine the effects of noncondensables on evaporation and condensation and transport phenomena
  4. Delineate the different microgravity transport/phase change mechanisms associated with different mixing/cooling strategies
  5. Investigate the nature of microgravity superheating and its effect on boil-off
  6. Validate and verify a state-of-the-art two-phase CFD model for cryogenic storage
- Produce archival data and simulations that will not only benefit the cryogenic storage tank design but a multitude of other two-phase flow operations and processes in space

ZBOT-1	ZBOT-2	ZBOT-3
Fluid Mixing	NonCondensable	Active Cooling

ZBOT Hardware Overview

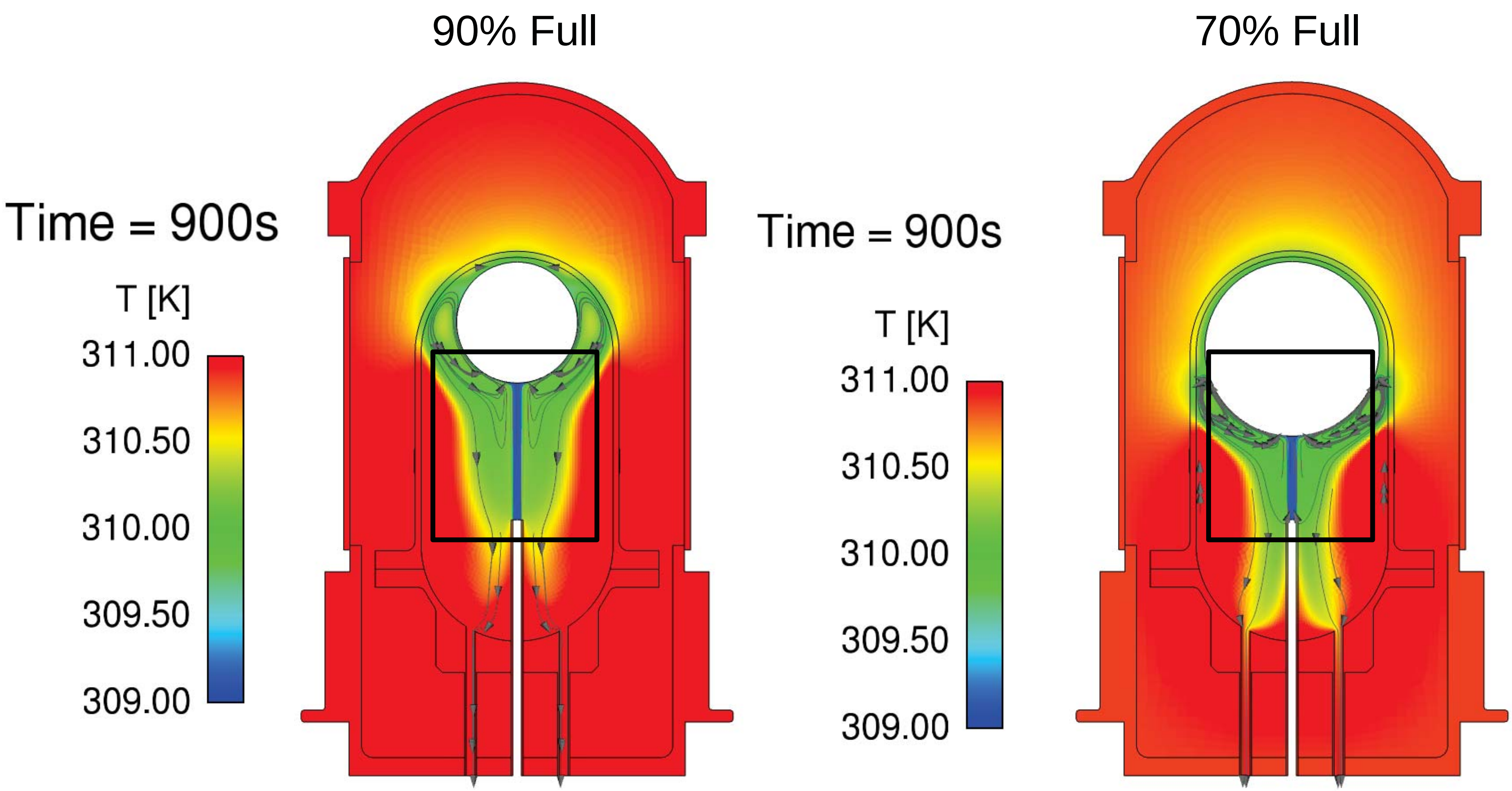




- ZBOT Engineering Model Fluids Support Unit (FSU)

- ZBOT Engineering Model in the Microgravity Science Glovebox (MSG) Work Volume Mockup

Flight ZBOT-1 Simulations with DPIV Area Marked for 90% & &70% Fill Levels

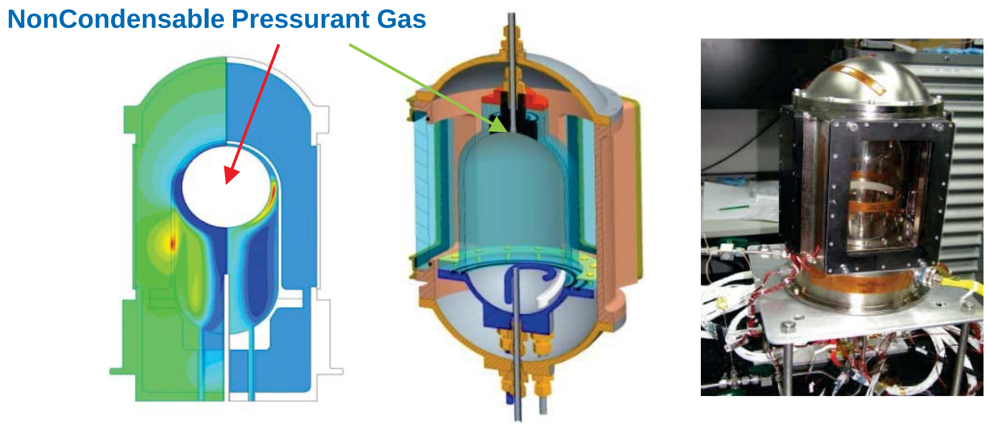


*Time from start of Axial Jet Mixing

Zero Boil-Off Tank Experiment-2 (ZBOT-2): Noncondensable Gas Effects

Objective:

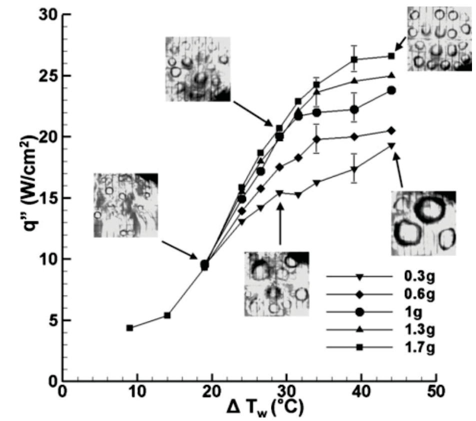
- Aid the design of NASA's space-based cryogenic storage systems by investigating the effects of noncondensable gases on tank pressure control
- Characterize and assess the effects of noncondensables on evaporation and condensation by obtaining microgravity two-phase flow and heat transfer data in a ventless Dewar
- Gather high quality microgravity data under controlled conditions for validation of storage tank CFD models and development of empirical engineering correlations



Hand-in-Hand Microgravity & 1G Experimentation and Computational Modeling

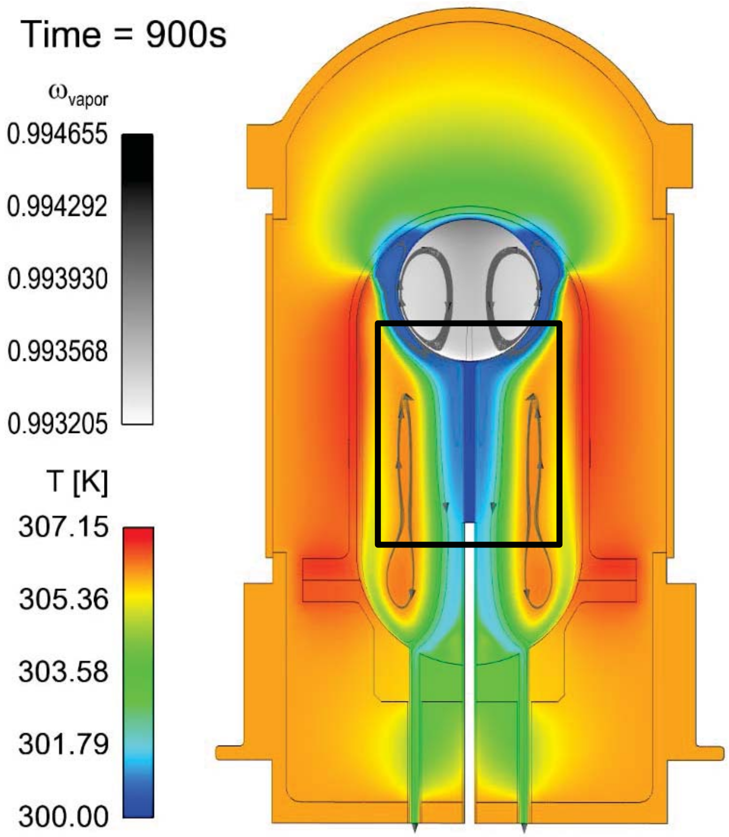
Non-Condensable Effects

- Noncondensable gases can significantly affect zero boil-off storage tank pressurization and pressure control, especially, in microgravity
- Non-condensable effects
  - Partial pressure variations on vapor side of interface → Marangoni convection on the liquid-side of the interface.
  - Build up of non-condensables in Knudsen layer retards condensation
- The objective of this research is to investigate the important effects of noncondensables on the transport and phase change phenomena that control tank pressure.

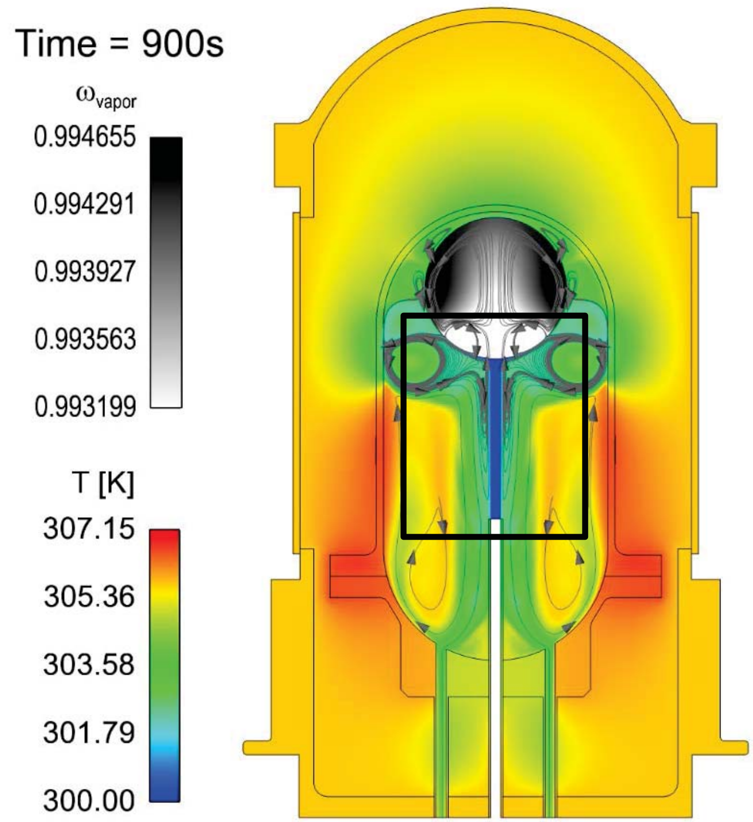


*Pool boiling curve at various acceleration levels for the high dissolved gas concentration case (~1216 ppm) with superimposed bottom view images at 0.3 g and 1.7 g.

90% Full, No Marangoni



90% Full, w/ Marangoni



ZBOT-2 Approach

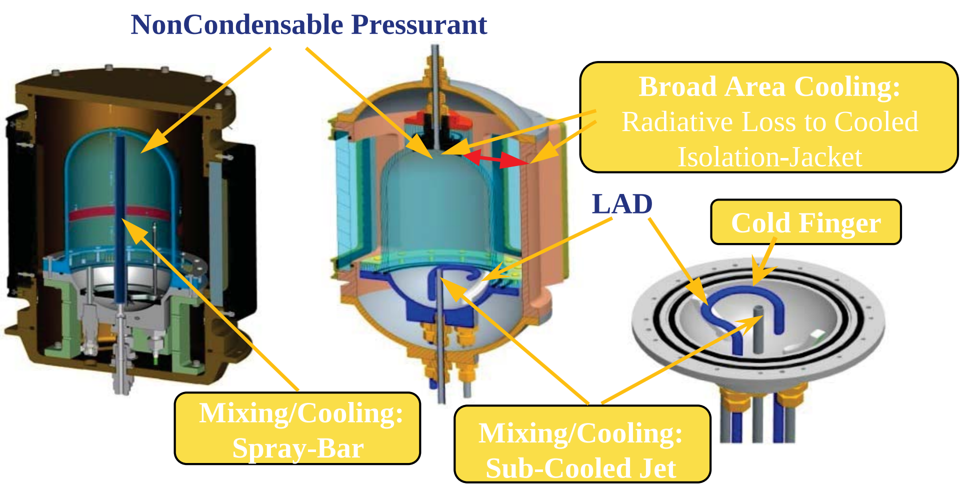
- **Obtain microgravity data** to determine the effect of the noncondensable pressurant on tank pressurization, thermal destratification, and pressure reduction through mixing in microgravity
- **Expand** the ZBOT-1 two-phase CFD model to incorporate the non-condensable gas effects
- **Additional science testing** will include:
  1) 100% and 50% of saturation for dissolved gas concentrations.
  2) Expanded test matrix based on initial results,
  3) Impact of jet subcooling
  4) Heat transfer in different flow regimes,
  5) Impact of tank drainage rates on phase change
- **Hardware changes** expected to include:
  - Addition of a non-condensable gas injection system
  - Development of diagnostic tools to evaluate the level of non-condensable in the system
- **Trade studies** are required to determine proper non-condensable gases:
  - Gases which produce measurable changes such as Ph level when absorbed versus low absorption gases
  - High molecular weight gases versus low molecular weight gases

Zero Boil-Off Tank Experiment-3 (ZBOT-3): Active Cooling

Objective:

Aid design of NASA's cryogenic storage systems by studying ***different active cooling strategies*** for future Zero-Boil-Off (ZBO) tank pressure control designs:

- Obtain microgravity flow and heat transfer data to characterize tank thermal destratification and pressure reduction for: (i) sub-cooled jet mixing (ii) spray-bar mixing; and (iii) broad area cooling with intermittent mixing
- Provide high quality microgravity data under controlled conditions for development, validation and verification of tank pressure control models, CFD codes, and empirically-based correlations
- Perform a quantitative comparison among different ZBO active pressure control strategies using microgravity data and model simulations



ISS Resource Requirements

ZBOT-3 Approach

- **Modify** the ZBOT-1/2 hardware to incorporate spray bar and broad area cooling technologies and diagnostics for these studies. Obtain microgravity data to determine the effectiveness of the different active pressure control strategies in microgravity.
- **Determine** interaction of ullage bubble with different strategies and impact on pressure control.
- **Hardware changes** expected to include:
  - Addition of a Spray Bar Injection system
  - Addition of an active cooling loop close coupled to the tank itself
- **Design trades** include:
  - Sizing the number and location of Spray bar holes
  - Determine the best cooling approach between cold finger and cooling shields for active cooling

Other ZBOT possibilities

- **Use Clear tank** to further explore liquid acquisition:
  - Add Vane PMD
  - Add Screen Channel LAD
- **Explore Tank Filling**:
  - Add tests to examine dynamic response during level change
  - Increase bellows capacity (or decrease tank size) to allow for levels ranging from empty to 90% full
- Examine other **tank inlet** configurations:
  - Opposed axial jet
  - Swirl Injectors like those in cyclone phase separators

Above can be accomplished mostly with changing test section and leaving rest of hardware intact

- Examine **Tank Chilldown** Phenomena (may require change of test fluid)