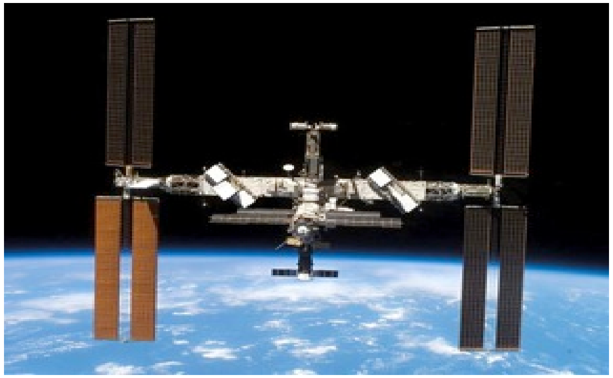
NASA Physical Sciences Research: Fluids Physics Focus

ITTW 2017 - 11th International Conference on Two-Phase Systems for Space and Ground Applications

Novosibirsk State University, Novosibirsk, Russia



Francis Chiaramonte, NASA HQ
Program Scientist for Physical Sciences
John McQuillen, NASA GRC
September 15, 2017

Physical Sciences Research Program – Research Areas

Combustion Science

- Spacecraft fire safety
- Droplets
- Gaseous – Premixed and Non-Premixed
- Supercritical reacting fluids
- Solid Fuels

Biophysics

- Biological macromolecules
- Biomaterials
- Biological physics
- Fluids for Biology

Fluid Physics

- Adiabatic two-phase flow
- Boiling, Condensation
- Capillary Flow
- Interfacial phenomena
- Cryogenics

Materials Science

- Metals
- Semiconductors
- Polymers
- Glasses, Ceramics
- Granular Materials
- Composites
- Organics

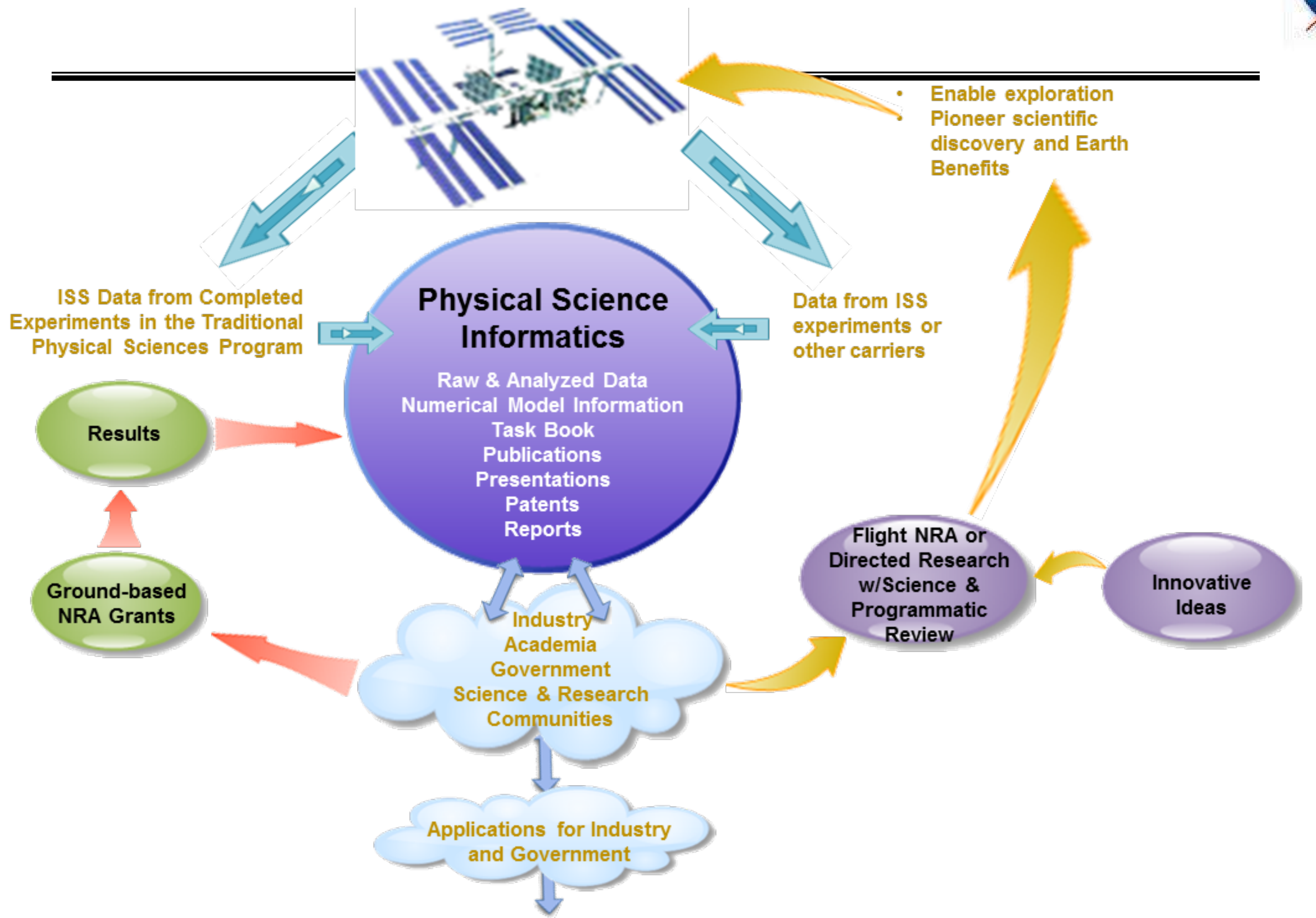
Fundamental Physics

- Space Optical/Atomic Clocks
- Quantum test of Equivalence Principle
- Cold atom physics
- Critical point phenomena
- Dusty plasmas

Complex Fluids

- Colloids
- Liquid crystals
- Foams
- Gels
- Granular flows

Physical Sciences Research Program – Research Flow



Outcomes:

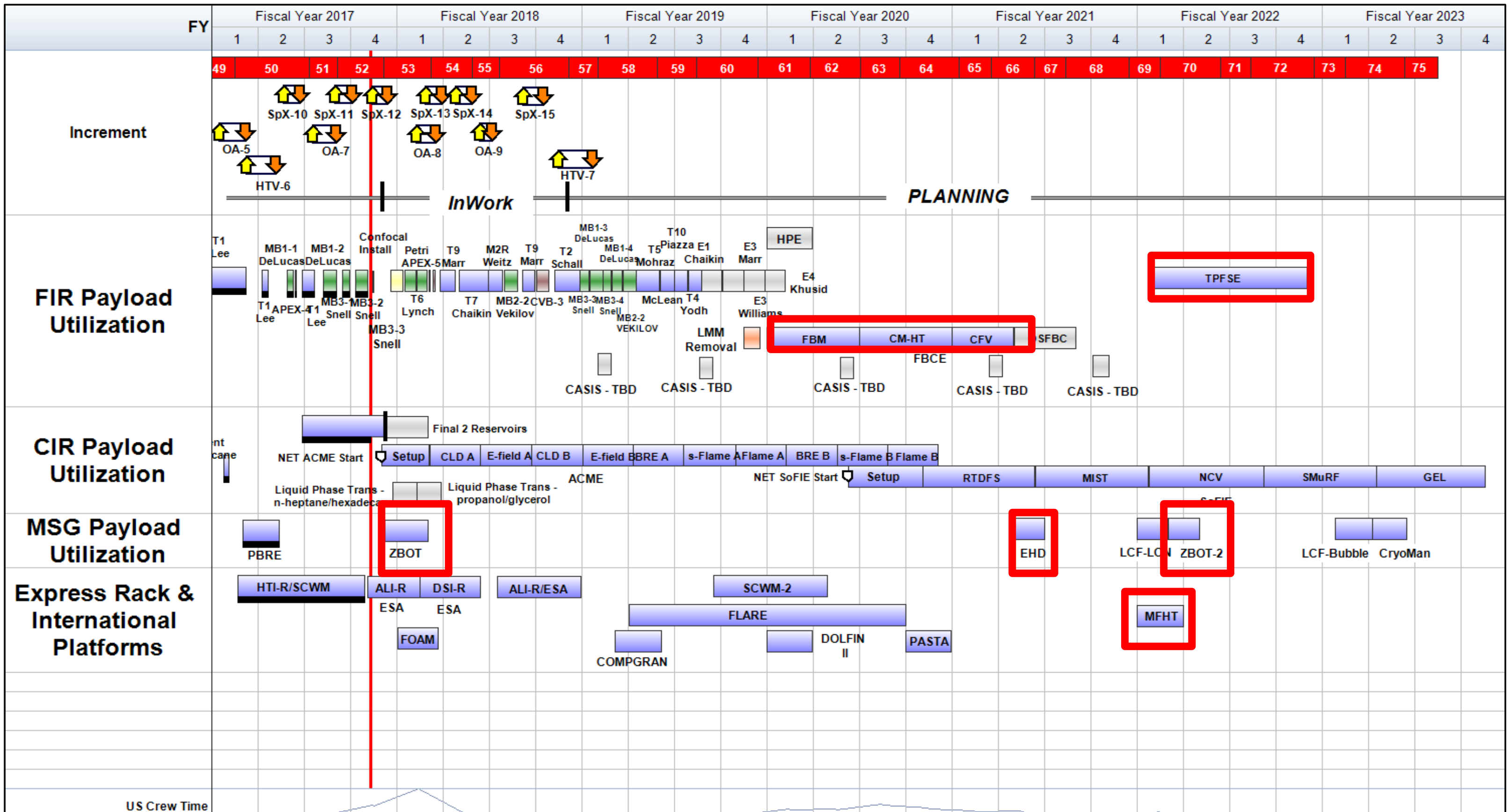
- ❖ Global access to cutting-edge research data
- ❖ Fuel innovation & discovery leading to increased economic growth
- ❖ Acceleration from ideas to research to products
- ❖ Enhancement and verification of numerical and analytical models
- ❖ Increased products, patents, and publications
- ❖ Advancement of fundamental research

PSI website: http://psi.nasa.gov/index.html

Fluid Physics Experiments

- Packed Bed Reactor Experiment (PBRE)
  - PBRE-2
  - PBRE-Water Recovery, with NASA AES
- Two Phase Flow Separator Experiment (TPFSE)
- Flow Boiling and Condensation Experiment (FBCE)
- Multiphase Flow and Heat Transfer Experiment (MFHT), ESA led experiment, “Flow Boiling”
- ElectroHydro Dynamic Experiment (EHD)
- Zero Boil Off Tank (ZBOT) Experiments
  - ZBOT (data to be used by NASA STMD)
  - ZBOT 2+

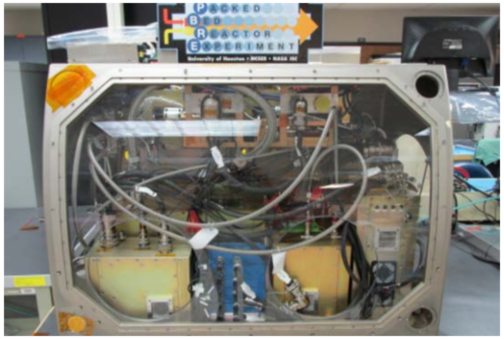
GRC ISS Microgravity Schedule



US Crew Time	10.2	11.4	24.4	46.9	86.5	25.4	24.8	25.3	16.5	24.0	26.0	25.6	36.1	36.1	49.1	38.8	30.7	31.4	8.5	8.7	29.5	23.0	15.9	13.7	17.4	25.0	8.9	4.7
Russian Crew Time	0.0	1.1	13.8	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CASIS Crew Time	0.0	8.0	10.0	7.0	20.4	3.7	11.9	0.8	23.1	6.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Packed Bed Reactor Experiment (PBRE) [completed]

GRC Project Manager: MSI/Bob Hawersaat
PI Team:Dr. Brian Motil, NASA GRC
Prof. Vemuri Balakotaiah, U. of Houston
Julie L. Mitchell (JSC)
GRC Project Scientist: Dr. Enrique Ramé, USRA
Engineering Lead: ZIN Technologies, Inc.
NASA Customer: HEOMD/Space Life and Physical Sciences



PBRE in an MSG Simulator

Objectives:

Investigate role and effects of gravity on hydrodynamics of gas-liquid flow through porous media.

Develop/validate scaling laws and design tools for future packed bed reactors in 0-g and partial-g environments, including start up and transient operations.

Identify strategies to recover single-phase beds from undesired trapped gas bubbles.

Relevance/Impact:

Directly aligns with high priorities from the NRC Decadal survey on Biological and Physical Sciences (1) and the NRC 2000 report on Microgravity Research in Support of Technologies for the Human Exploration and Development of Space and Planetary Bodies (2):

- AP-2: Provide study of a critical multiphase flow component for life support systems (1)
- TSES-6: Provide a fundamental study in porous media under microgravity conditions (1)
- T-6: Lack of understanding of partial g on life support systems (1)
- T-22: lack of closed loop water recovery (1)
- Multiphase flow and heat transfer: Recommendation: #1, 2 & 7 p. 181 (2)

Two-phase components are critical to life support and thermal control systems.

Status:

- **Ops for Test Section #1 (glass) completed June 2016.**
- **Proposed initial criteria to identify bubbly-to-pulse flow regime transitions.**
- **Ops for re-test of Test Section #1 and Test Section #2 (Teflon) completed early February 2017.**
- **Initial results show higher pressure drop for glass (vs Teflon) but only at higher liquid flow rates. At low to moderate L, pressure drop is essentially the same.**

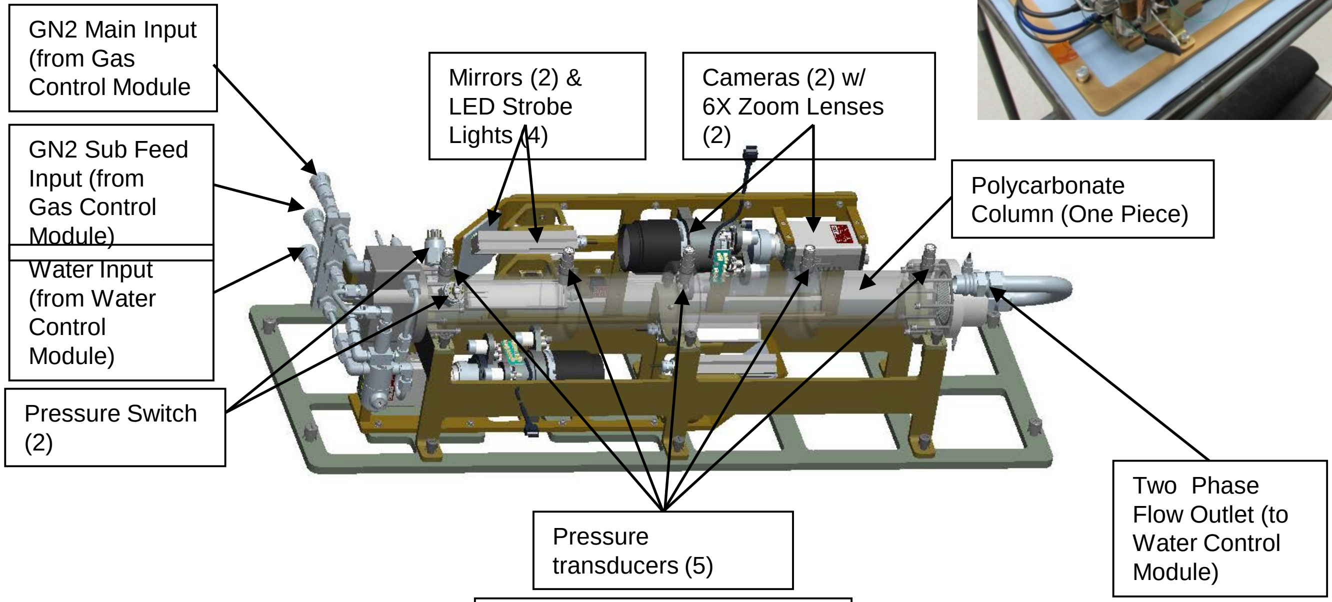
ISS Resource Requirements

Accommodation (carrier) (CIR,FIR, MSG, MWA,…..)	MSG
Upmass (kg) (Per Flight w/o packing factor)	147.4
Volume (m³) (w/o packing factor)	0.150
Power (kw) (peak)	0.75
Crew Time (hours) (Total)	22
Ops Activities & Detailed (Preparation, Installation, Operation, Change-outs,….)	Preps, install, ops, TM and SSD change-outs, disassemble and stowage.
Autonomous Ops (hrs)	200 hours
Launch/Operating Increment	SPACEX8/Inc 45
Unique Payload Requirements (Late Access (T/O (L-hours), Cold stowage, Temperatures,…)	At least 5ºF environment (cargo and stowage)
Down Mass of Samples/Data	Test Modules (TMs) and Solid State Drives (SSDs)

Packed Bed Reactor Experiment –Water Recovery

Test Module with Test Sections

[Wetting and Non-Wetting Columns]



Replace column with different test sections.

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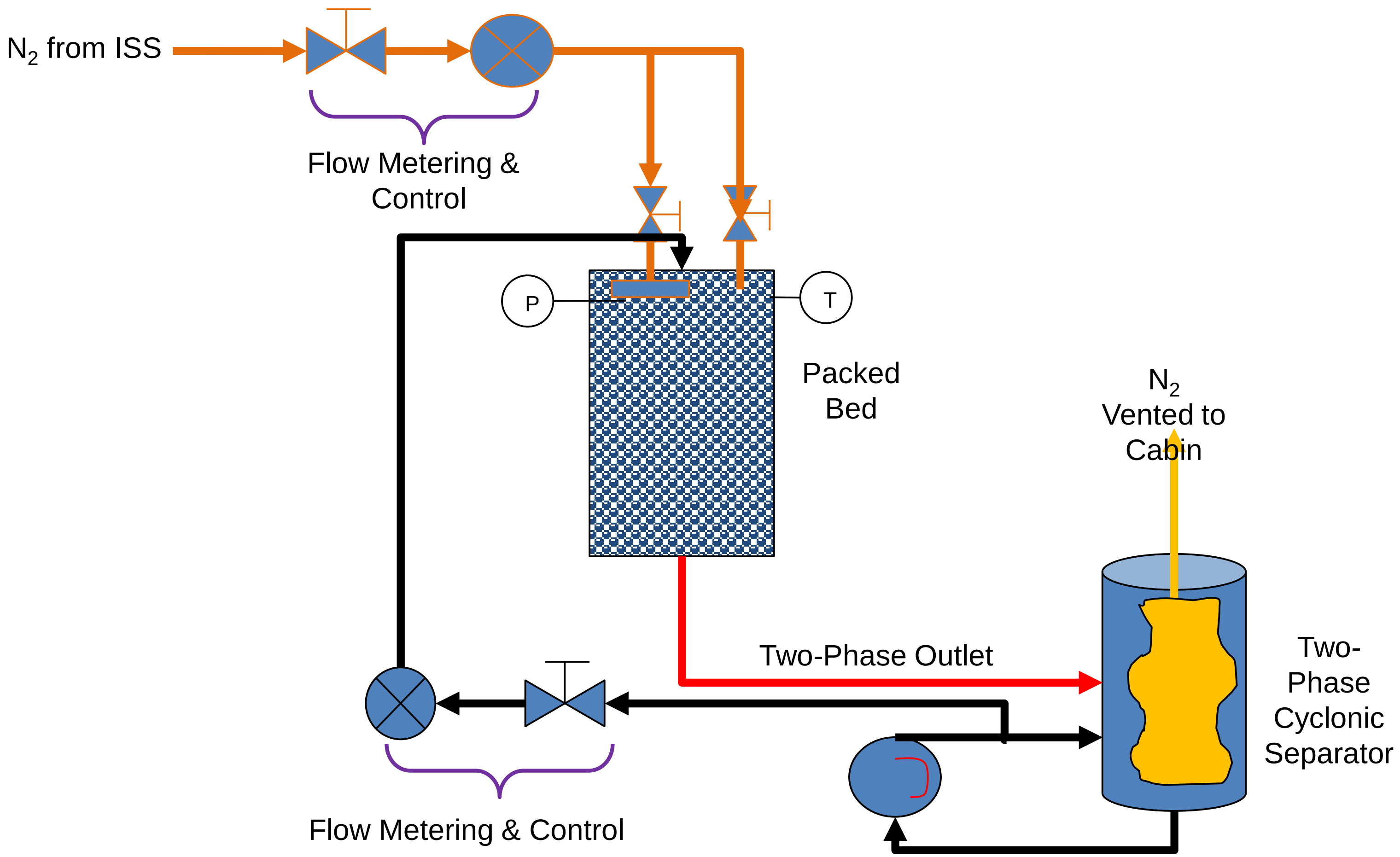
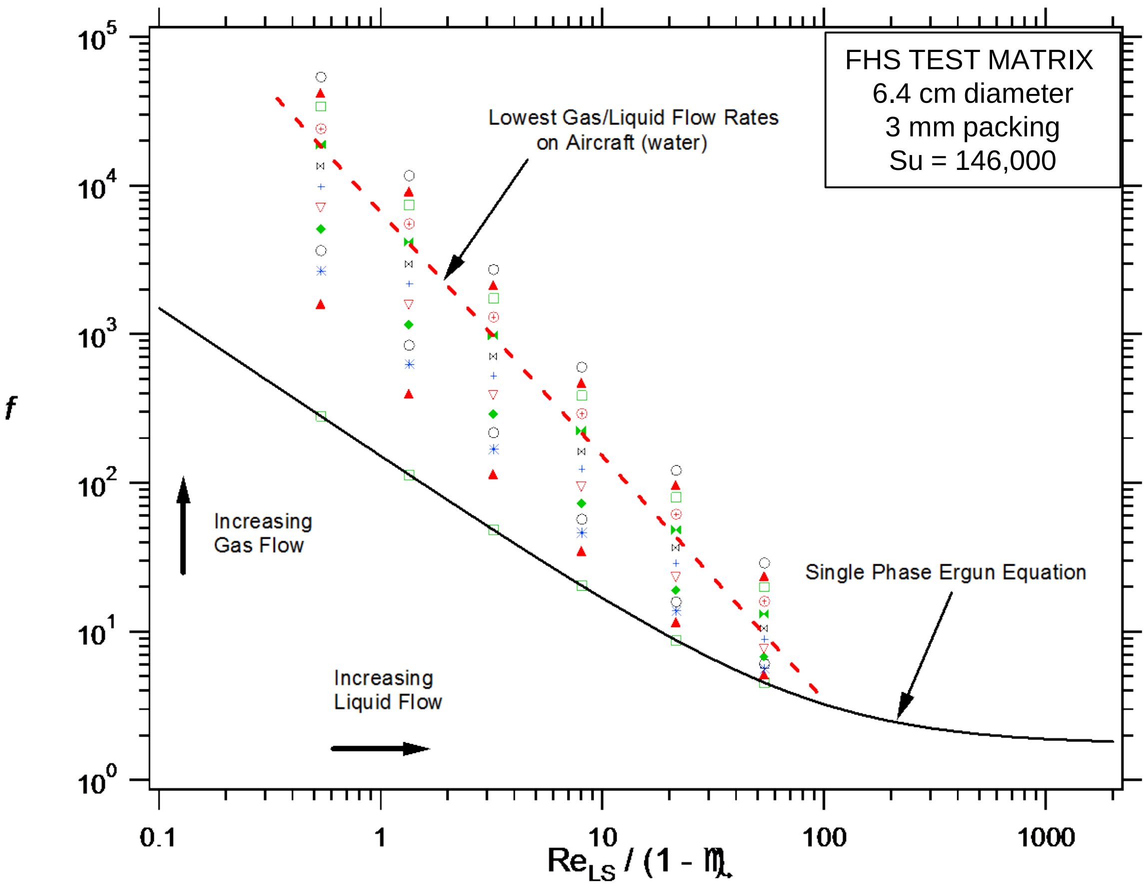
PBRE Simplified Flow Schematic

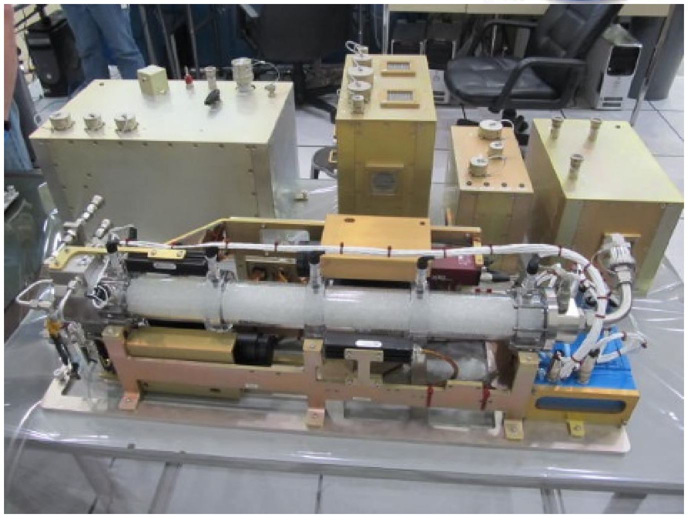


PBRE Test Matrix



Packed Bed Reactor Experiment (PBRE)-2

GRC Project Manager: MSI/Bob Hawersaat
PI Team: Dr. Brian Motil, NASA GRC
Prof. Vemuri Balakotaiah, University of Houston
Julie L. Mitchell (JSC)
GRC Project Scientist: Dr. Enrique Ramé, USRA
Engineering Lead: ZIN Technologies, Inc.
NASA Customer: HEOMD/Space Life and Physical Sciences



PBRE Hardware Synopsis:

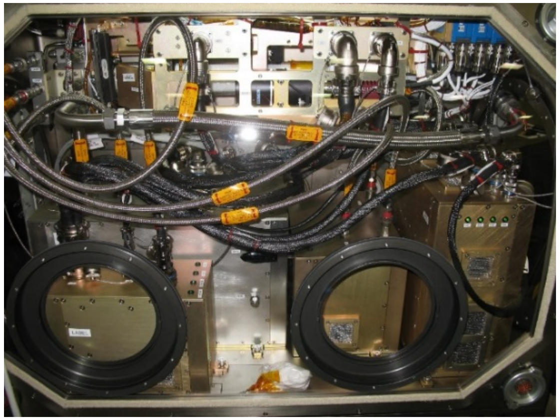
- PBRE was successful except for:
  - High Gas Flow:
    - Requirement of 3 kg/hr of N2 was not met by ISS (actual was 1.1 kg/hr)
    - Did not allow for high pressure flow conditions.
  - High Speed Video:
    - High speed cameras (2) unable to meet requirement of 100 fps.
    - Actual rate varied, but in general experiment could run at ~50 fps for 8 seconds (each).

Proposed Hardware Adjustments:

- By decreasing packing size, high pressure flow conditions can be tested at the lower gas flows.
- Video issues are believed to be related to low voltage in DACU.

Benefits:

- Reflight allows for investigators to obtain full test matrix with high speed video and extend range of data to validate model.



PBRE Flight hardware

Packed Bed Reactor Experiment –Water Recovery

GRC Project Manager: MSI/Bob Hawersaat
PI Team: Layne Carter, NASA MSFC, AES
Dr. Brian Motil, NASA GRC
John McQuillen, NASA GRC
GRC Project Scientist: TBD
Engineering Lead: ZIN Technologies, Inc.
NASA Customer: HEOMD/Space Life and Physical Sciences

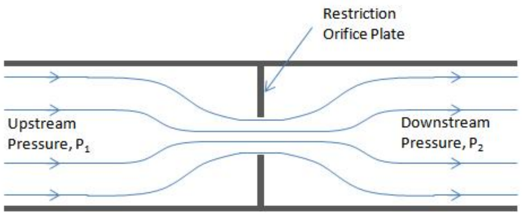
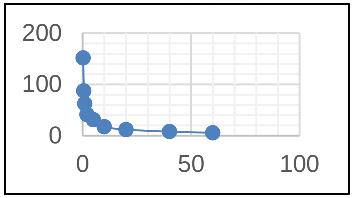


Diagram of orifice flow ΔP



Plot of average bubble pt (mmHg) vs filter micron rating (data from Porvair)

Objectives:

Evaluate Pressure Drop of Two Phase Flow in m-Gravity using PBRE

- Test for differences between 1-G and m-G bubble point values for filters with varied micron ratings. Bubble point is the pressure at which free gas in two-phase flow is forced through a filter.
- Test for differences between 1-G and m-G pressure drop values across various packed beds and flow restrictors
- Develop correlation for difference between bubble point and pressure drop behavior in experiments 1-G vs m-G systems on the ISS.

Packed bed material for ISS WRS, Catalytic Oxidation Reactor (Alumina or Zirconium beads)

Impact/Applications:

- Anomalies on ISS indicate the bubble point and pressure drop across restrictions is higher in m-G than 1-G. This test program will quantify the effect of m-G on the bubble point and pressure drop across restrictions.
- This information will provide clarification on the unexpected accumulation of gas that has occurred on Water Recovery System (WRS) filters during ISS operations, and therefore provide better understanding of anomalous behavior and support further troubleshooting activities.
- Improves understanding of pressure drop in m-G so future space exploration missions avoid further issues related to filters and restrictions in gas/liquid systems.

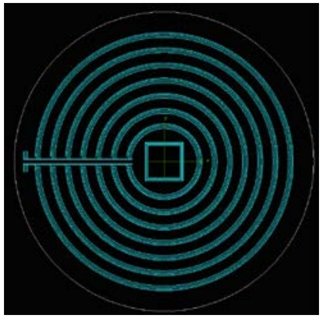
Filter in the ISS Urine Processor

Status:

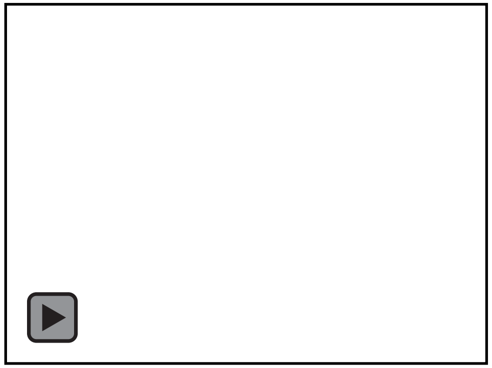
- Planning Stages.

ElectroHydroDynamic (EHD) Experiment

GRC Project Manager: MSI/Bob Hawersaat
GRC Project Scientist: LTZ/Dr. Mojib Hasan
PI Team: PI Prof. Jamal Seyed-Yagoobi, Worcester Polytechnic Institute
Co-I: Jeffery Didion, NASA GSFC
Engineering Lead: Mike Bohurjak, ZIN Technologies, Inc.
NASA Customer: HEOMD/Space Life and Physical Sciences



EHD Test Chamber silicon disk and heater layout, heater in center



Objective:

- Characterize the effects of gravity on the interaction of electric and flow fields in the presence of phase change specifically pertaining to:
- The effects of microgravity on the electrically generated two-phase flow.
- The effects of microgravity on the electrically driven liquid film boiling (includes extreme heat fluxes)
- Electro-wetting of the boiling section will repel the bubbles away from the heated surface in microgravity environment.

Relevance/Impact:

- Provides phenomenological foundation for the development of electric field based two phase thermal management systems leveraging EHD.
- This will permit the optimization of heat transfer surface area to volume ratios as well as achievement of high heat transfer coefficients resulting in system mass and volume savings.
- The EHD replaces buoyancy or flow driven bubble removal from a heated surface.

Project Development Approach:

- The development approach is drop tower rig, breadboard, engineering unit and flight unit. The flight unit test chamber will be defined at PDR.
- The reviews planned are RDR, PDR, CDR, PSR.
- The planned carrier is MSG, and the engineering is contracted to ZIN through SPACEDOC.
- The EHD project will use the PBRE project data acquisition system if practical to reduce development costs.

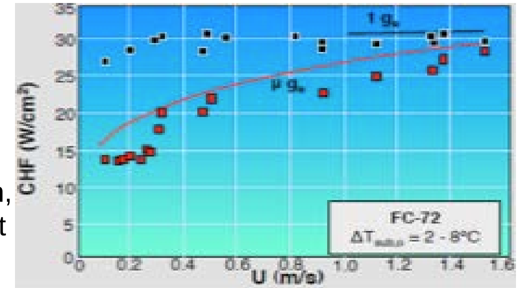
ISS Resource Requirements

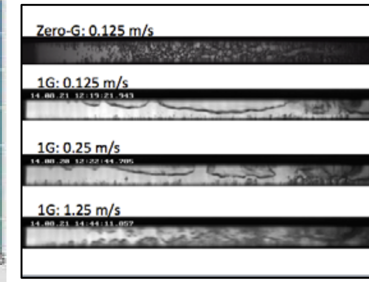
Accommodation (carrier)	Microgravity Science Glovebox (MSG)
Upmass (kg) (w/o packing factor)	100
Volume (m^3) (w/o packing factor)	0.10
Power (kw) (peak)	0.50
Crew Time (hrs) (installation/operations)	5 hours to install
Autonomous Operation	700 hours
Launch/Increment	Jan 2021 / Inc 66

Award	SCR	RDR	PDR	CDR	FHA
9/15/2013	7/10/2014	9/22/2017	9/12/2018	10/22/2019	10/30/2020

Flow Boiling and Condensation (FBCE)

GRC Project Manager: Andrew Suttles, NASA GRC
GRC Deputy Project Manager: Hunt Hawkins, NASA GRC
PI Team: Dr. Issam Mudawar, Purdue University
Dr. Mojib Hasan, NASA GRC
GRC Project Scientist: Dr. David Chao, NASA GRC
Chief Engineer: William Taylor, NASA GRC
Chief Safety Officer: Dave Bittner, NASA GRC
Benefactors/Adopters (Push): AP1, TSES1, Nuclear Power/Propulsion, Thermal Control/Life Support, Chilldown for Cryo Propellant Management





Left: Critical Heat Flux (CHF) data and model predictions for microgravity and Earth gravity for flow boiling
Right: Flow Regimes as Function of Acceleration

Objective:

- Develop an integrated two-phase flow boiling/condensation facility for the International Space Station (ISS) to serve as primary platform for obtaining two-phase flow and heat transfer data in microgravity.

Relevance/Impact:

- The Rankine cycle is one of the most viable options for space application because of its high power output per unit mass or unit volume.
- The Rankine cycle is one of the most viable options for space application because of its high power output per unit mass or unit volume.
- TSES1: Conduct research to address issues for active two phase flow relevant to thermal management.
- AP1: Reduced-gravity multiphase flows, cryogenics and heat transfer database and modeling, including phase separation and distribution (i.e.. flow regimes), phase-change heat transfer, pressure drop and multiphase system stability.

Project Development Approach:

- Protoflight unit approach – Flight-functional ground unit as time/funding permit.
- Fluids Integrated Rack (FIR) Subrack Payload Facility.
- Developed, integrated, and operated in-house by GRC Engineering
  - Flow Boiling Module
  - Condensation Heat Transfer Module
  - Condensation Flow Visualization Module

ISS Resource Requirements

Accommodation (carrier)	Fluid Integrated Rack (FIR)
Upmass (kg) (w/o packing factor)	225 kg (estimated)
Volume (m³) (w/o packing factor)	0.3 m³ (estimated)
Power (kw) (peak)	2500W (estimated)
Crew Time (hrs) (installation/operations)	20 hrs for install (estimated) runs autonomous / Inc 61-63
Autonomous Operation	6 months
Launch/Increment	9/2019 / Inc 61

Award	SCR	RDR	PDR	CDR	FHA
6/15/2011	11/2011	2/2014	3/2015	11/2017	8/2019

Multiphase Flow and Heat Transfer (MFHT) in coordination with ESA

GRC Project Manager: MSI/Nancy R. Hall
GRC Project Scientist: LTZ/John McQuillen
NASA PI: Prof. Jungho Kim, University of Maryland
ESA Science Team Coordinator: Catherine Colin, Institut de Mécanique des Fluides de Toulouse
Benefactors/Adopters (Push): Nuclear Power/Propulsion, Thermal Control/Life Support, , Thermodynamic Vent System and Chilldown for Cryo Propellant Management
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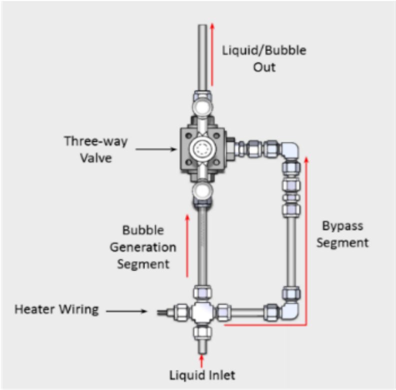


Left: Single Bubble Generation Concept
Right: Thermal Sensitive Paint (TSP glows a reddish/orange color when excited by UV.

Objective:

- Develop models needed to predict the behavior of two-phase flows in geometries relevant to advanced heat exchangers in variable gravity environments.
- High speed thermography will measure local heat transfer to investigate effect of gravity and tube size on microgravity flow boiling.
- Develop a mechanistic understanding of flow regime characteristics affect heat transfer coefficients.

Relevance/Impact:

- Enhance the development of two-phase thermal management systems, which provide isothermal control. By reducing the temperature difference between the heat source and radiator, the higher operating temperature for the radiator significantly reduces the area and weight of the radiator. Flow boiling transports the heat from its source to its sink in two-phase thermal management systems.
- Chilldown of transport line in cryogenic systems results in vaporization and needless loss of propellants.
- Relative increase in the effect of surface tension forces and reduction in buoyancy forces impacts bubble departure size, convective flows and heat transfer.

Development Approach:

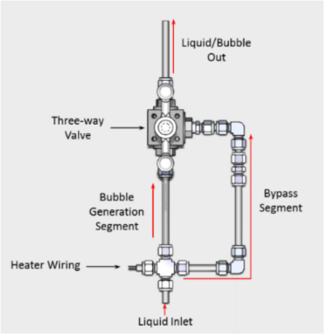
- NASA review through SCR then reviews will follow ESA review cycle.
- A collaborative effort that will utilize the European Space Agency's Heat Transfer Host within the EDR-2 rack to operate this experiment.
- ESA will provide hardware for PI. Launch vehicle not known yet.

ISS Resource Requirements

Accommodation (carrier)	ESA Thermal Platform
Upmass (kg) (w/o packing factor)	NA
Volume (m³) (w/o packing factor)	NA
Power (kw) (peak)	NA
Crew Time (hrs) (installation/operations)	NA
Autonomous Ops Time (hrs)	NA
Launch/Increment	NA

Award	NASA SCR	ESA SCR	ESA Design Rev	ESA SRR	ESA PDR	ESA CDR	ESA FHA
??	7/2016	5/2017	3/2018	1/2019	9/2019	9/2020	9/2021
ESA Heat Transfer Host		ESA TP SRR	ESA TP PDR				
		4/2017	10/2018				

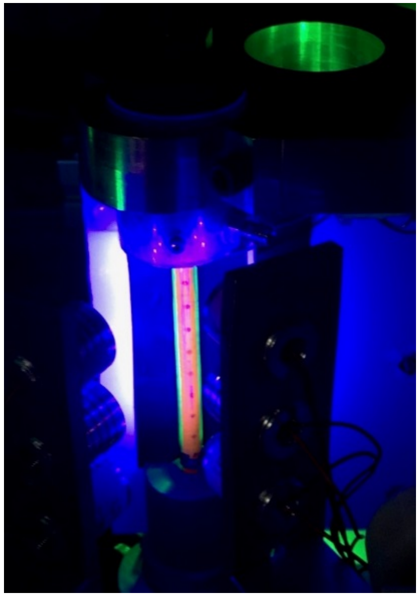
Multiphase Flow and Heat Transfer (MFHT)



Single Bubble Generation Concept

Taylor bubble moves slowly upward since the buoyancy force opposes the downward flow of liquid. The heat transfer decreases significantly during bubble passage due to laminarization of the liquid trapped between the bubble and the wall. Even though there is a strong downward flow of liquid, the film temperature likely approaches the wall temperature, decreasing the heat transfer. Between 4.5 to 5.5 s, due to bubble nucleation at specific sites on the wall, there is the formation of high heat transfer streaks within the film.

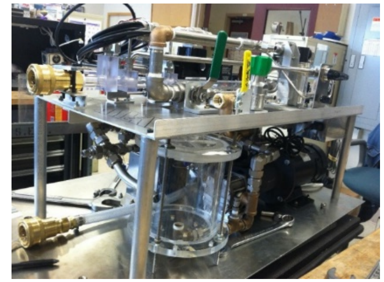
The heat flux in this movie was only 0.74 W/cm2 resulting in much more noise in the data since the temperature variations are much smaller.



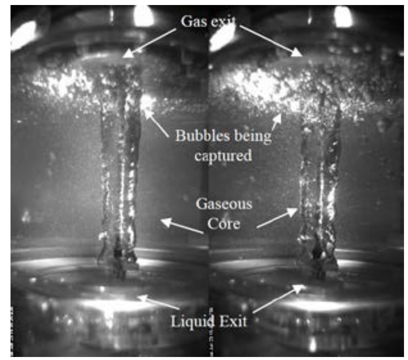
TSP glows a reddish/orange color when excited by UV. The TSP is attached to the inner surface of the sapphire at the wall/fluid interface causing the tube to glow. There is an insulator between the TSP and the dots (also TSP, but on the insulator sapphire interface). These temperature measurements provide for measurement of the local heat transfer. The tube is heated from the outside using a transparent heater.

Two-Phase Flow Separator Experiment (TPFSE)

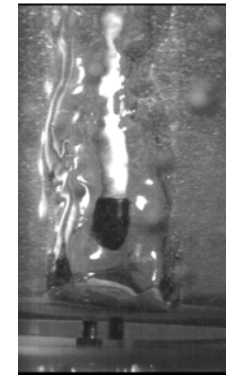
GRC Project Manager: MSI/William Sheredy
GRC Project Scientist: Dr. Enrique Ramé, USRA
PI Team: PI: Dr. Georges Chahine, DynaFlow, Inc.
PI: Prof. Yasuhiro Kamotani, Case Western Reserve U.
Co-I: Prof. Jaikrishnan Kadambi, Case Western Reserve U.
Engineering Lead: Mike Bohurjak, ZIN Technologies, Inc.
NASA Customer: HEOMD/Space Life and Physical Sciences
Benefactors/Adopters (Pull): AES/Advanced Life Support. Initiated discussions with STMD (Molly Anderson) & AES (Layne Carter) Workshop held this summer.



TPFSE Breadboard Model



Dynaflow Separator



Gas Core surrounding Extraction Port

Objective:

- Address the design and performance of passive two-phase flow separator technologies.
- Determine range of flow rates for acceptable performance.
- Quantify the effect of fluid properties and separator geometry.
- Determine separator response and stability envelope to startup, shutdown and liquid slugging conditions.

Relevance/Impact:

- Advanced gas-liquid separators are targeted for use in Advanced Life Support (ALS) Fluids degassing and power generation applications.
- Provides highly reliable low power gas liquid separation.
- Promote enhanced phase change by removing second phase and to promote contact with heat transfer surface.

Development Approach:

- Design and build experiment package that can meter air and water into test articles.
- Two different design concepts (one specified by each PI team) for cyclonic separators will be tested.
- Early unique diagnostic instruments demonstrations to assess and refine science requirements and to reduce technical risks proceeding to flight development phase.
- Contract to ZIN.

ISS Resource Requirements

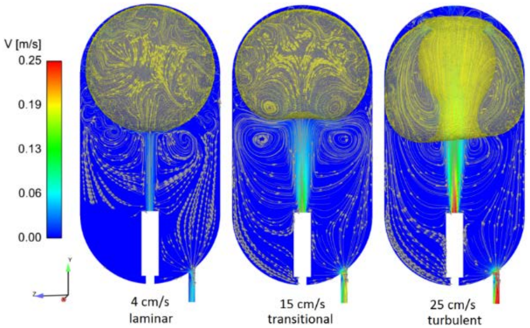
Accommodation (carrier)	Microgravity Science Glovebox (MSG)
Upmass (kg) (w/o packing factor)	210 (prelim est.)
Volume (m^3) (w/o packing factor)	0.25 (prelim est.)
Power (kw) (peak)	2.1 (prelim est.)
Crew Time (hrs) (installation/operations)	10 (prelim est.)
Autonomous Operation	200
Launch/Increment	11/2021

Award	SCR	RDR	PDR	CDR	FHA
5/2009	5/14/2015	12/2017	3/2019	3/2020	9/2021

Zero Boil-Off Tank (ZBOT)

GRC Project Management: MSI/William Sheredy
GRC Project Scientist: LTZ/John McQuillen
PI Team: Dr. Mohammad Kassemi, USRA
Engineering Lead: Ray Pavlik, ZIN Technologies, Inc.
Benefactors/Adaptors (Pull): STMD/Cryogenic Propellant Management. Letters on File.

ZBOT Flight System in the MSG Engineering Unit at MSFC



3D Simulation ZBOT-Flight Jet Mixing – Different Ullage Penetrations

Objective:

- Develop a small-scale simulant-fluid ISS flight experiment to study storage tank pressurization & pressure reduction through fluid mixing in microgravity.
- Gather high fidelity microgravity data under known/controlled conditions for verification and validation of storage tank CFD models.
- Formulate much-needed microgravity empirical correlations for thermal stratification, pressurization, liquid mixing, pressure reduction, and interfacial heat and mass transfer.
- Assess the engineering feasibility of dynamic Zero-Boil-Off (ZBO) pressure control for microgravity applications.

Relevance/Impact:

- Reduce propellant launch mass (cost) and decrease risks for future space missions by aiding the development of dynamic pressure control schemes for long-term storage of cryogenic fluids.
- Increase design reliability by providing archival data for benchmarking and improving CFD models/codes used by the Cryogenic Fluids Management Community (CFM) and the Aerospace Companies for future (ground-tested-only) tank designs.

Development Approach:

- Flight Phase: Develop ISS experiment/hardware and obtain microgravity data for tank pressurization and pressure reduction. Engineering performed by contractor
- Modeling: Develop a state-of-the art two-phase CFD model for tank pressurization and pressure control.
- Validation: Validate and Verify the CFD model with microgravity and 1g data.
- Scale-Up: Use the validated CFD model and empirical correlations derived from the 1g and microgravity data for scale-up tank design.

ISS Resource Requirements

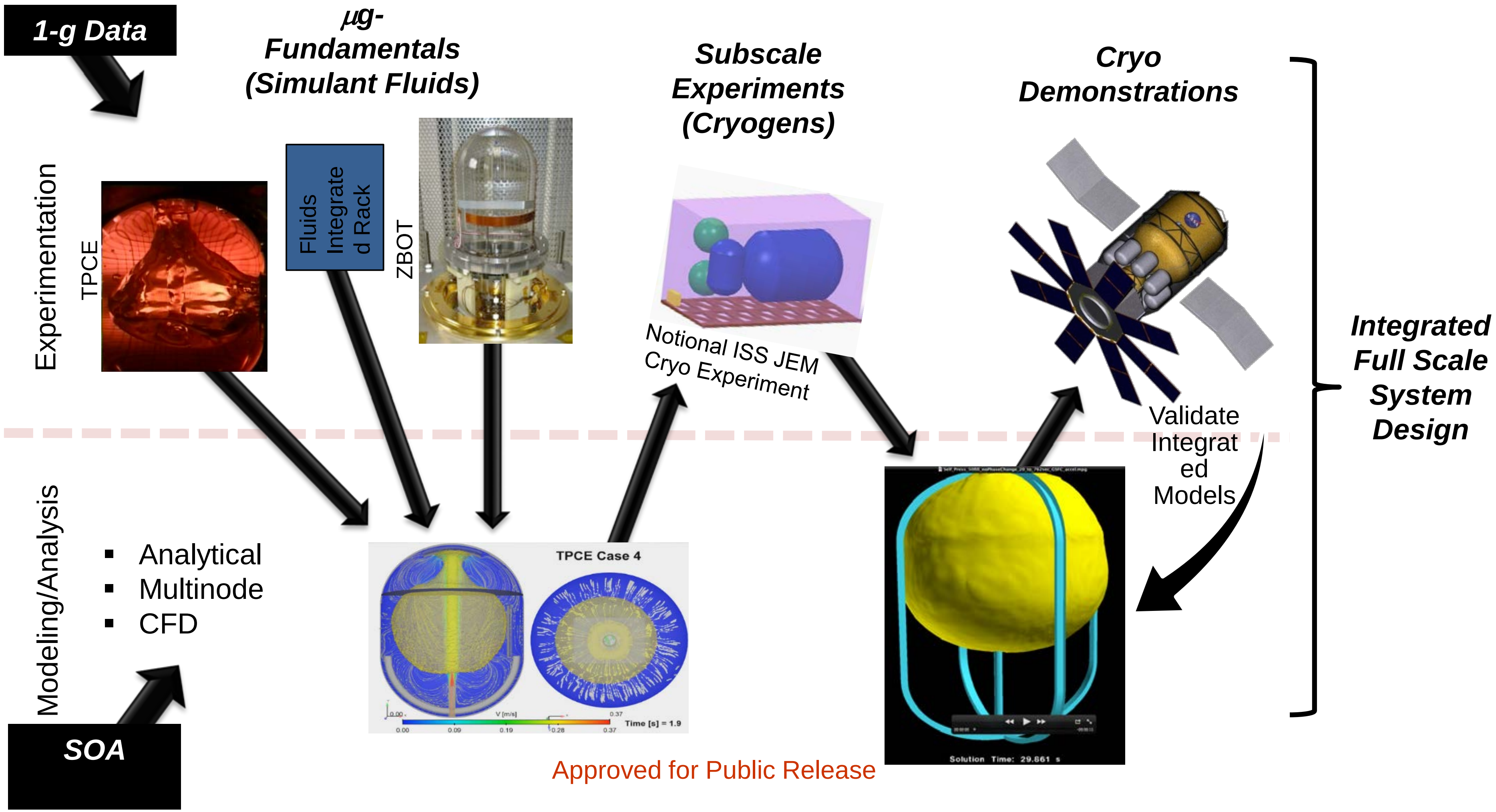
Accommodation (carrier)	Microgravity Science Glovebox (MSG)
Upmass (kg) (w/o packing factor)	115
Volume (m^3) (w/o packing factor)	0.23
Power (kw) (peak)	0.445 (0.135 off-peak normal)
Crew Time (hrs) (installation/operations)	14
Autonomous Operation	730 hours
Launch/Increment	OA-7/Inc 52 & 53 (ops)

17

Award	SCR	RDR	PDR	CDR	FHA	OPS
2006	7/06	6/18/08	2/26/10	12/10/2012	1/17/2017	9/18/2017

ZBOT Simulations

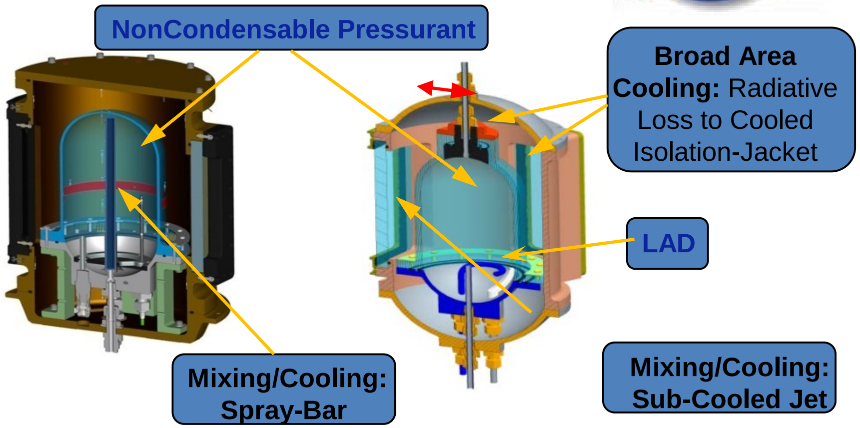
Notional Pathway to Mature Understanding of CFM Fluid Physics



Multiple demonstrations at various scales may be needed to accommodate future mission needs.

Zero Boil-Off Tank-2+ (ZBOT-2+)

GRC Project Management: MSI/William Sheredy
GRC Project Scientist: LTZ/John McQuillen
PI Team: Dr. Mohammad Kassemi, USRA
Engineering Lead: Ray Pavlik, ZIN Technologies, Inc.
Benefactors/Adopters: STMD/Cryogenic Propellant Manageme



Objective:

- This research will investigate three important effects of noncondensables on the transport and phase change phenomena that control tank pressure. These effects can be best studied when they are readily unmasked in microgravity: 1) The effect of noncondensable on microgravity vapor transport in the ullage during pressurization. 2) The creation of thermocapillary convection induced by noncondensable and its effect on mixing, stratification and destratification in the liquid. 3)The penetration of noncondensbles into the Knudsen layer and its impact on condensation during microgravity pressure control.
- Long-duration ventless storage of cryogenic liquids through active cooling design strategies have been tested in terrestrial environment, but require validation in microgravity: 1)Provide a sound understanding of the fluid flow, heat transfer, and phase change characteristics associated with the different active cooling mechanisms in microgravity. 2) Examine an array of different active cooling strategies, including jet mixing and spray-bar mixing designs, together with internal or broad-area cooling strategies. 3) Establish a microgravity foundation for comparison and optimization of the different active cooling strategies for future storage pressure control design.

ISS Resource Requirements

Accommodation (carrier)	Microgravity Science Glovebox (MSG)
Upmass (kg) (w/o packing factor)	50 (ZBOT-2+ new hardware only)
Volume (m^3) (w/o packing factor)	0.1 (ZBOT-2+ new hardware only)
Power (kw) (peak)	0.445 (0.135 off-peak normal)
Crew Time (hrs) (installation/operations)	14
Autonomous Operation	730 hours
Launch/Increment	12/2021 / TBD

Relevance/Impact:

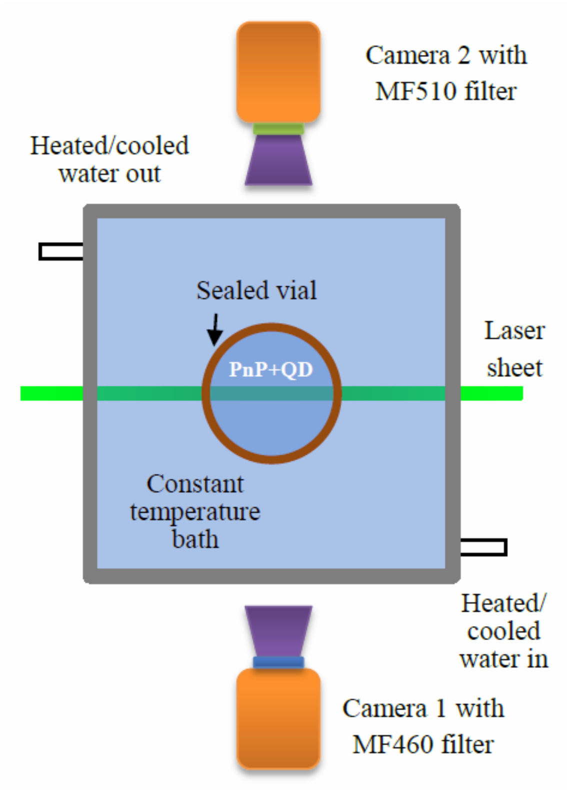
- Expand the state-of-the-art knowledge for two-phase phenomena associated with Cryogenic Fluid Management (CFM) in 1g and microgravity.
- Decrease the risks and costs of future space missions by aiding the design and implementation of robust ZBO tank pressure reduction/control.
- Increase design reliability by providing archival microgravity data for benchmarking/improving CFD models used by the CFM community and the aerospace companies for future (ground-tested-only) tank designs.

Project Development Approach:

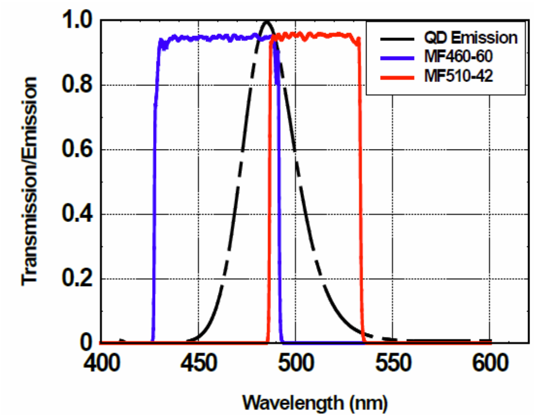
- Flight Experiment: Modify the ZBOT-1 hardware and diagnostics for non-condensable gas and cooling studies.
- Theoretical Work: Expand the existing ZBOT-1 two-phase CFD model by incorporating 1) non-condensable gas kinetics, species transport, and Marangoni convection submodels and 2) spray-bar lagrangian/eulerian droplet phase change and broad area cooling submodels. Validate the expanded two-phase CFD model and submodels.

Zero Boil-Off Tank-2+ (ZBOT-2+)

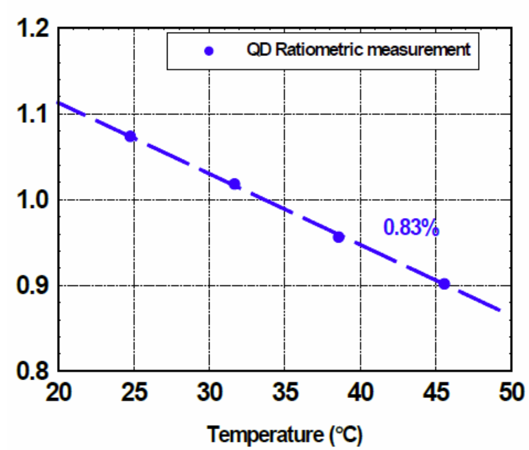
Ratiometric Temperature Measurement Using Quantum Dots



Experimental Setup



Emission Spectrum of QD's and Bandpass Filters For Thermal Imaging

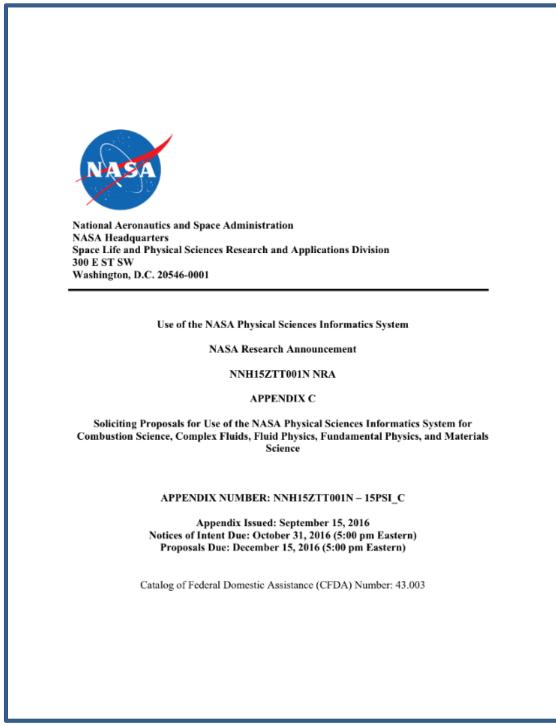


NRA plan

Research Opportunities -

- Physical Sciences Informatics System
- Fluid Physics

2017 Physical Sciences Informatics NRA - Appendix D



National Aeronautics and Space Administration
NASA Headquarters
Space Life and Physical Sciences Research and Applications Division
300 E ST SW
Washington, D.C. 20546-0001

Use of the NASA Physical Sciences Informatics System

NASA Research Announcement

NNH15ZTT001N NRA

APPENDIX C

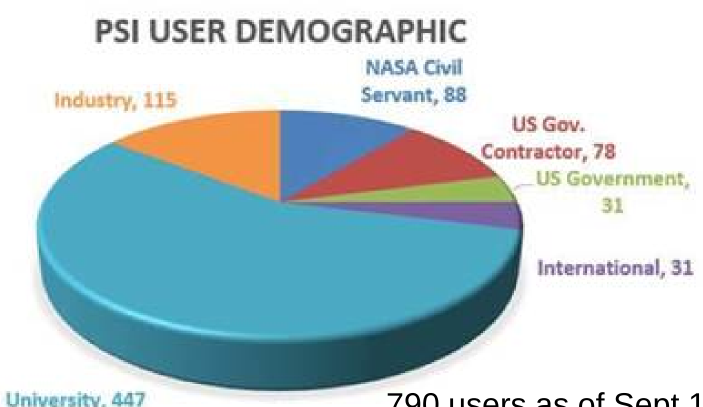
Soliciting Proposals for Use of the NASA Physical Sciences Informatics System for Combustion Science, Complex Fluids, Fluid Physics, Fundamental Physics, and Materials Science

APPENDIX NUMBER: NNH15ZTT001N – 15PSI_C

Appendix Issued: September 15, 2016
Notices of Intent Due: October 31, 2016 (5:00 pm Eastern)
Proposals Due: December 15, 2016 (5:00 pm Eastern)

Catalog of Federal Domestic Assistance (CFDA) Number: 43.003

- Release: September 15, 2017
- NOIs Due: October 31, 2017
- Proposals Due: December 15, 2017
- 48 eligible experiments
- WebEx Oct. 17, 2017
- PSI Appendix D solicits ground-based research proposals from established researchers and graduate students to generate new scientific insights by utilizing experimental data residing in the PSI system.
- 48 experiments uploaded to PSI from the following five Research Areas: **Combustion Science, Complex Fluids, Fluid Physics, Fundamental Physics** and **Materials Science.**
- The NRA will be available at: http://tinyurl.com/NASA-15PSI-D
- Five selections are planned (one or two in fluid physics)
- For additional information on the entire PSI database, visit: http://psi.nasa.gov



790 users as of Sept 1, 2017

2017 PSI NRA – Schedule summary*

2017 PSI NRA	Release Date	Proposals Due	Selection Announcement
Appendix D	Sept. 15, 2017	Dec.15, 2017	May, 2018
Appendix E	Sept. 15, 2018	Dec.15, 2018	May, 2019
Appendix F	Sept. 15, 2019	Dec.15, 2019	May, 2020
Appendix G	Sept. 15, 2020	Dec.15, 2020	May, 2021
Appendix H	Sept. 15, 2021	Dec.15, 2021	May, 2022
Appendix I	Sept. 14, 2022	Dec.15, 2022	May, 2023

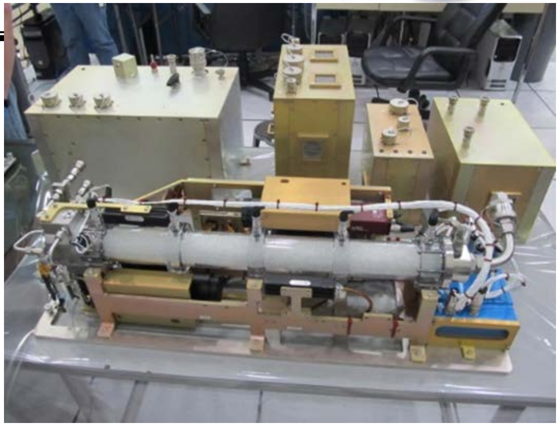
*Five selections planned per year (one or two in Fluid Physics)

NRA for ISS experiments - planning

Fluid Physics NRA is in the planning phase and will be exploration focused.

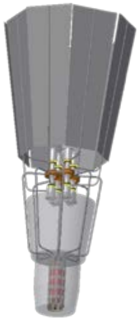
Possible topics include:

1. Adiabatic Two Phase Flow for ECLSS systems using PBRE hardware
2. Capillary studies for plant, root zone water management
3. Flow Boiling and Condensation for power generation using FBCE hardware
4. Heat Pipes for Exploration

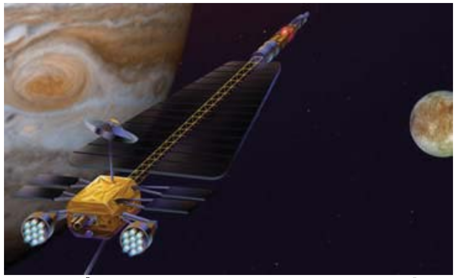


PBRE unit

Increment 40 crew member, Alex Gerst, performing the fourth operation of the Interior Corner Flow 5 (ICF5) vessel for the Capillary Flow Experiment 2 (CFE-2) on June 19, 2014.



Power generation system concept using Stirling engine and heat pipes



Nuclear Power Conversion System concept

Back -Up

PSI - Uploaded Experiments

- Combustion Science
- BASS (Burning and Suppression of Solids)
- DAFT (Dust and Aerosol Measurement Feasibility Test)
- DAFT-2 (Dust and Aerosol Measurement Feasibility Test-2)
- FLEX (Flame Extinguishment Experiment)
- SAME (Smoke Aerosol Measurement Experiment)
- SAME-R (Smoke Aerosol Measurement Experiment Reflight)
- SPICE (Smoke Point in Coflow Experiment)
- SLICE (Structure and Liftoff In Combustion Experiment)
- Complex Fluids
- ACE-M1 (Advanced Colloids Experiment-Microscopy 1)
- BCAT-3 (Binary Colloidal Alloy Test 3)
- BCAT-4 (Binary Colloidal Alloy Test 4)
- BCAT-5 (Binary Colloidal Alloy Test 5)
- BCAT-6 (Binary Colloidal Alloy Test 6)
- InSPACE (Investigating the Structure of Paramagnetic Aggregates from Colloidal Ellipsoids)
- InSPACE-2 (Investigating the Structure of Paramagnetic Aggregates from Colloidal Ellipsoids-2)
- InSPACE-3 (Investigating the Structure of Paramagnetic Aggregates from Colloidal Ellipsoids 3)
- InSPACE-3+ (Investigating the Structure of Paramagnetic Aggregates from Colloidal Ellipsoids 3+)
- PCS (Physics of Colloids in Space)
- PHaSE (Physics of Hard Spheres Experiment)
- SHERE (Shear History Extensional Rheology Experiment)
- SHERE II (Shear History Extensional Rheology Experiment II)
- SHERE-R (Shear History Extensional Rheology Experiment Reflight)

PSI - Uploaded Experiments

- Fluid Physics
- CCF (Capillary Channel Flow) – EU1 – Critical Velocities
- CCF (Capillary Channel Flow) – EU2 – Critical Velocities
- CCF (Capillary Channel Flow) – EU2 – Phase Separation
- CFE (Capillary Flow Experiment)
- CFE-2 (Capillary Flow Experiment-2)
- CVB (Constrained Vapor Bubble)
- CVB-2 (Constrained Vapor Bubble-2)
- MABE (Microheater Array Heater Boiling Experiment)
- NPBX (Nucleate Pool Boiling Experiment)
- PBE (Pool Boiling Experiment)
-
- Fundamental Physics
- DECLIC-ALI (DEvice for the study of Critical LIquids and Crystallization - Alice Like Insert)
- GRADFLEX (Gradient Driven Fluctuation Experiment)
- PKE and PK-3+ (PKE-Nefedov and Dusty Plasma 3+)
-

PSI - Uploaded Experiments

- <u>Materials Science</u>
- CSLM (Coarsening in Solid-Liquid Mixtures)
- CSLM-2 (Coarsening in Solid-Liquid Mixtures 2)
- CSLM-2R (Coarsening in Solid-Liquid Mixtures 2 Reflight)
- CSLM-3 (Coarsening in Solid-Liquid Mixtures 3)
- DECLIC-DSI (DEvice for the study of Critical LIquids and Crystallization - Directional Solidification Insert)
- IDGE-STS-62 (Isothermal Dendritic Growth Experiment) - Second United States Microgravity Payload on Columbia (USMP-2)
- IDGE-STS-75 (Isothermal Dendritic Growth Experiment) - Third United States Microgravity Payload on Columbia (USMP-3)
- IDGE-STS-87 (Isothermal Dendritic Growth Experiment) - Fourth United States Microgravity Payload on Columbia (USMP-4)
- ISSI (In-Space Soldering Investigation)
- MICAST/CSS (The Microstructure Formation in Casting of Technical Alloys under Diffusive and Magnetically Controlled Convective Conditions/Comparison of Structure and Segregation in Alloys Directionally Solidified in Terrestrial and Microgravity Environments)
- PFMI (Pore Formation and Mobility Investigation)
- SUBSA (Solidification Using a Baffle in Sealed Ampoules)
- TEMPUS (Electromagnetic Containerless Processing in Microgravity)