Assembly and Integrated Systems Testing for the Flow Boiling and Condensation Experiment (FBCE)

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Flow Boiling and Condensation Experiment (FBCE)

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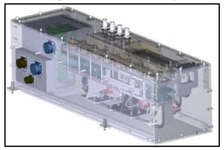
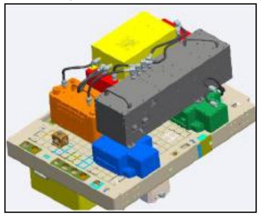
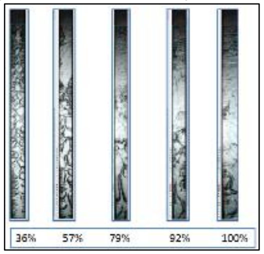
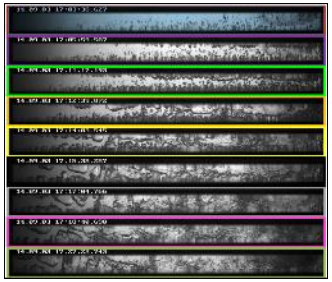
Customers/Adopters (Push): AP1, TSES1, Nuclear Power/Propulsion, Thermal Control/Life Support, Chilldown for Cryo Propellant Management

Right to left: Flow Boiling Imaging (Horizontal orientation,1g); Flow Boiling Imaging (vertical up-flow orientation, low g-Aircraft); Integrated FBCE system on FIR optics bench; Flow Boiling Module Teat Assembly









Flight FBM test module in assembly

Objectives

- 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.
  - Obtain flow boiling and flow condensation databases in long-duration microgravity environment.
  - Develop experimentally validated, mechanistic model for microgravity flow boiling critical heat flux (CHF) and flow condensation and dimensionless criteria to predict minimum flow velocity required to ensure gravity-independent CHF.

Experimental Approach

- Study influence of microgravity on two-phase transport phenomena.
- Control variables: temperature, pressure, flow rate.
- Diagnostics: Pressure transducers, thermocouples, high-speed imagery.

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.
- 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 flight hardware – Flight-functional ground unit for development testing.
- Fluids Integrated Rack (FIR) Subrack Payload Facility.
- Developed, integrated, and operated in-house by GRC Engineering.

ISS Resource Requirements

Accommodation (carrier)	Fluid Integrated Rack (FIR)
Upmass (kg) (w/o packing factor)	165 kg (estimated - dry)
Volume (m^3) (w/o packing factor)	0.2 m^3 (estimated)
Power (kw) (peak)	2500W (estimated)
Crew Time (hrs) (installation/operations)	8 hrs for install (estimated) runs autonomous / Inc 65-69
Autonomous Operation	12 months
Launch/Increment	**First Available in Increment 62**

Award	SCR	RDR	PDR	CDR	FHA	Ops
6/15/2011	11/2011	2/2014	3/2015	1/2018	12/2019	9/2020

FBCE Science Objectives

The proposed research aims to 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.

Key objectives are:

1. Obtain **flow boiling database** in long-duration microgravity environment
2. Obtain **flow condensation database** in long-duration microgravity environment
3. Develop experimentally validated, **mechanistic model** for microgravity flow boiling **critical heat flux (CHF)** and **dimensionless criteria** to predict **minimum flow velocity** required to ensure **gravity-independent CHF**

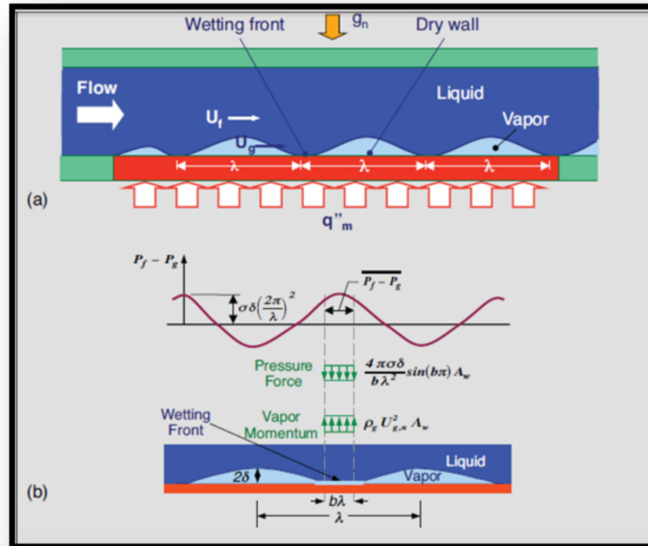
$$\frac{Bo}{We^2} = \frac{(\rho_f - \rho_g)(\rho_f + \rho_g)^2 \sigma g_e}{\rho_f^2 \rho_g^2 U^4} \le 0.09.$$

$$\frac{1}{Fr} = \frac{(\rho_f - \rho_g) g_e D_h}{\rho_f U^2} \le 0.13$$

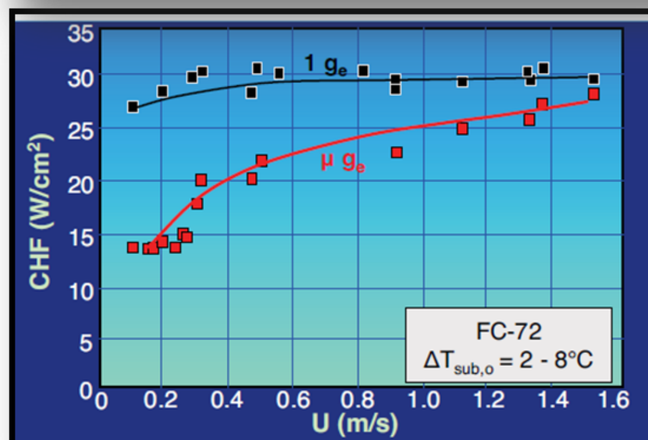
4. Develop experimentally validated, **mechanistic model** for microgravity annular condensation and **dimensionless criteria** to predict **minimum flow velocity** required to ensure **gravity-independent annular condensation**; also develop correlations for other condensation regimes in microgravity

Applications include:

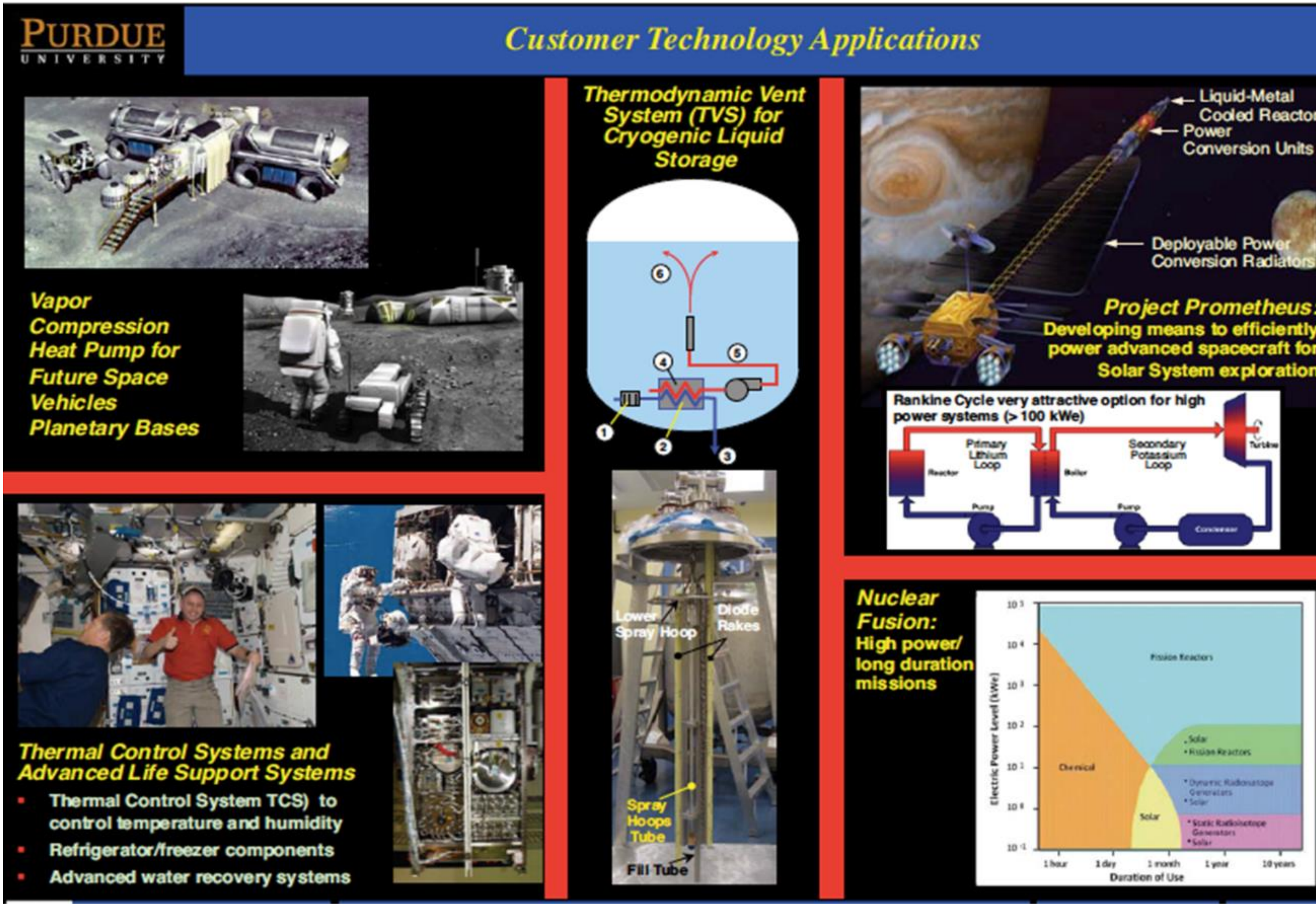
1. Rankine Cycle Power Conversion System for Space
2. Two Phase Flow Thermal Control Systems and Advanced Life Support Systems
3. Gravity Insensitive Vapor Compression Heat Pump for Future Space Vehicles and Planetary Bases
4. Cryogenic Liquid Storage and Transfer



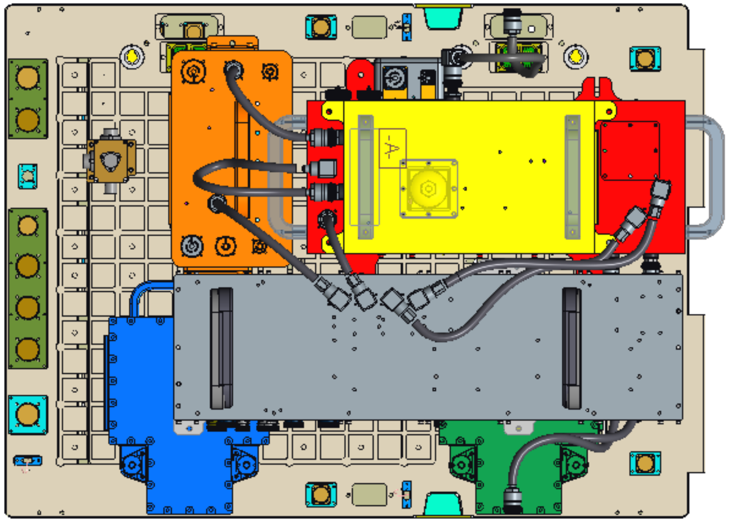
Interfacial Lift-off Model: (a) schematic representation of wavy vapor layer. (b) Balance of vapor momentum and interfacial pressure difference at moment of wetting front separation.

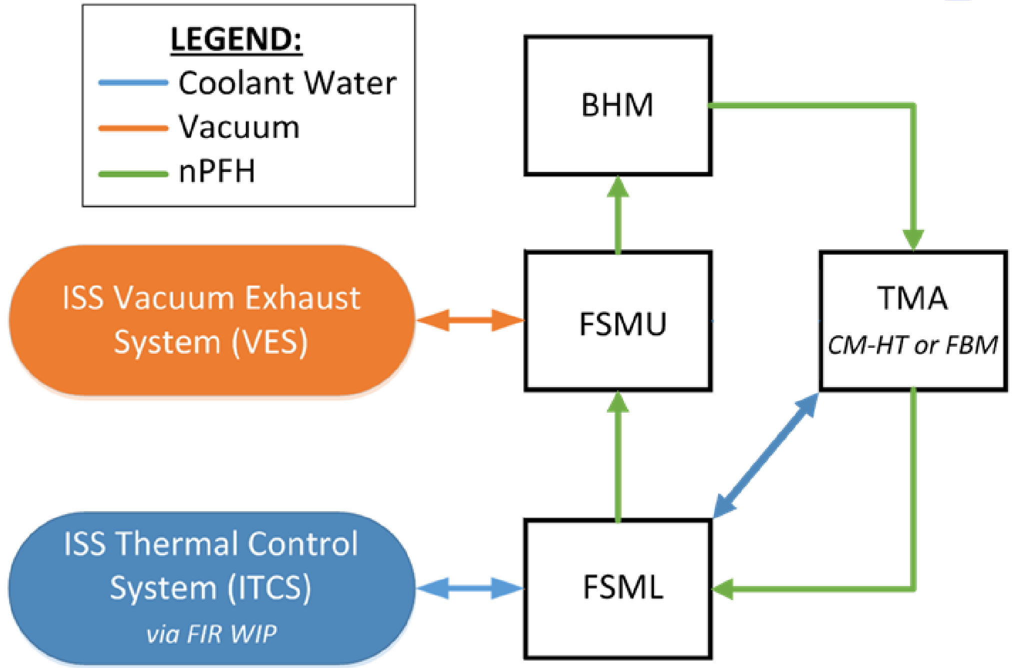


FBCE Mission Relevance for NASA



FBCE Design Overview





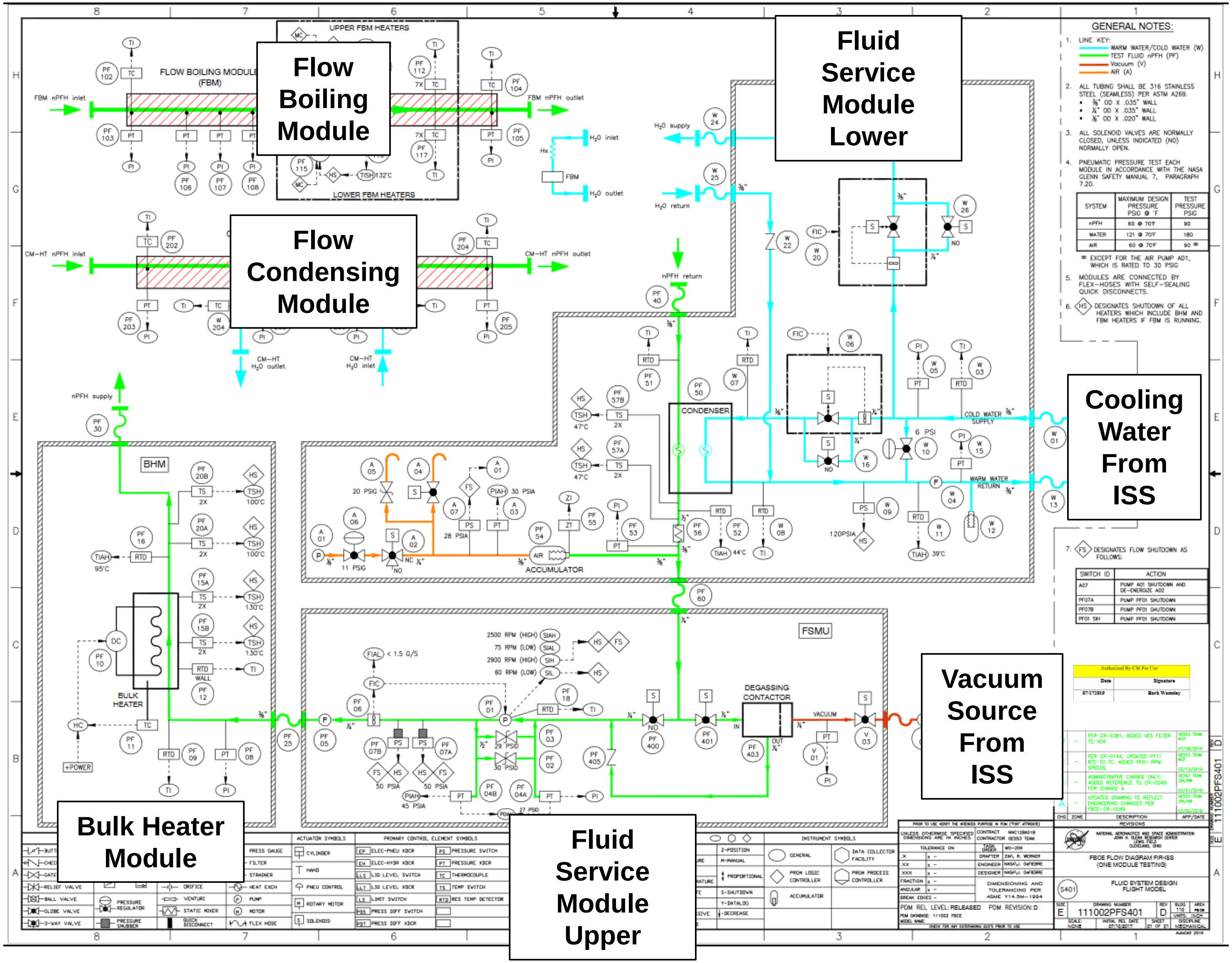
FBCE Modules:

- **BHM** – Bulk Heater Module
- **FSMU** – Fluids System Module - Upper
- **FSML** – Fluids System Module - Lower
- **RDAQM 1** – Remote Data Acquisition Module 1
- **RDAQM 2** – Remote Data Acquisition Module 2
- **TMA** – Test Module Assembly (1 of 2 installed):
  - **FBM** – Flow Boiling Module
  - **CM-HT** – Condensation Module - Heat Transfer

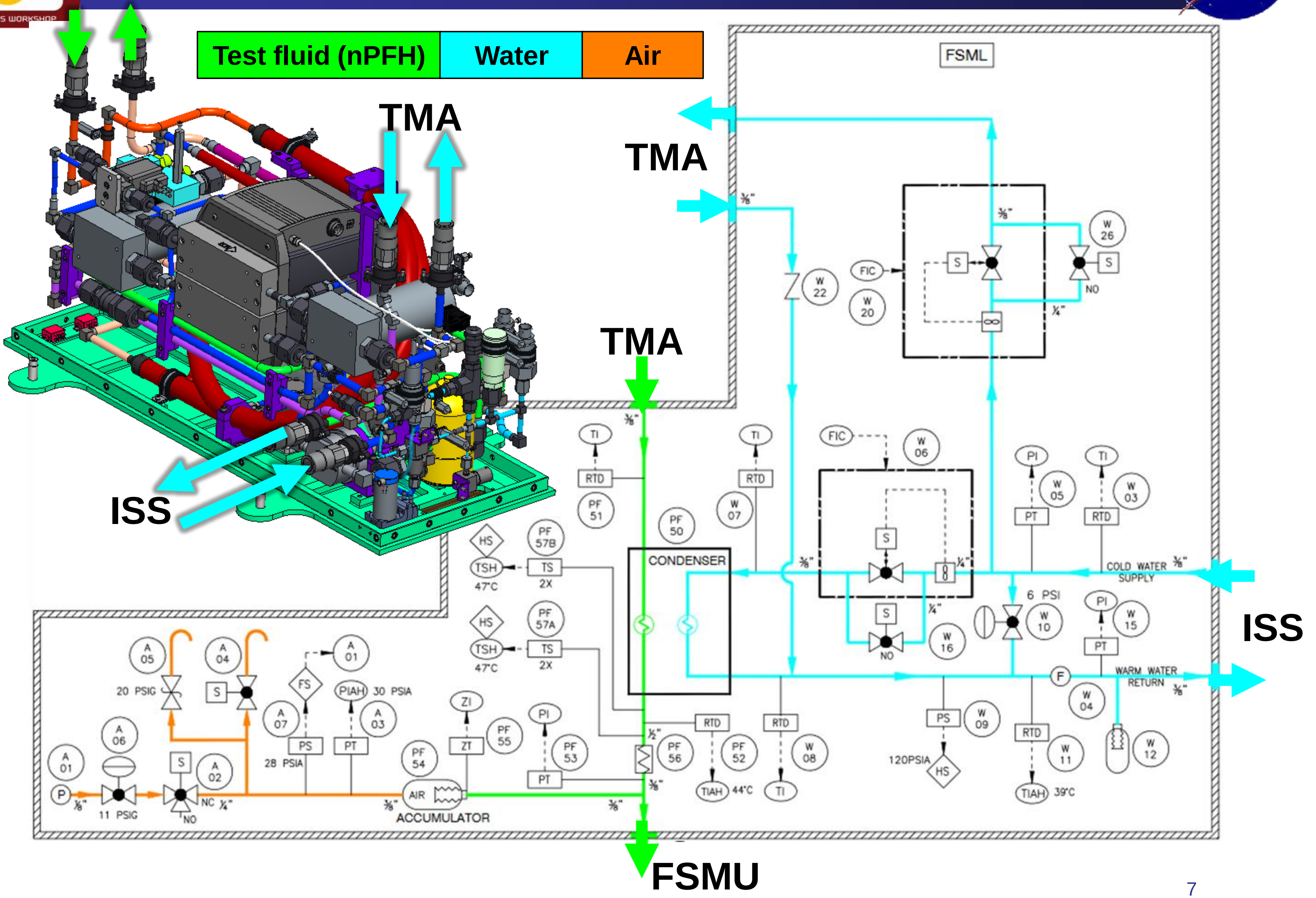
FIR Provided Hardware:

- **SAMS** – Space Acceleration Measurement System
- **CCU** – Confocal Control Unit (on back of rack)
- **IPSU-CL** – Imaging Processing Storage Unit – Camera Link (on back of rack)

Design – Fluid Schematic

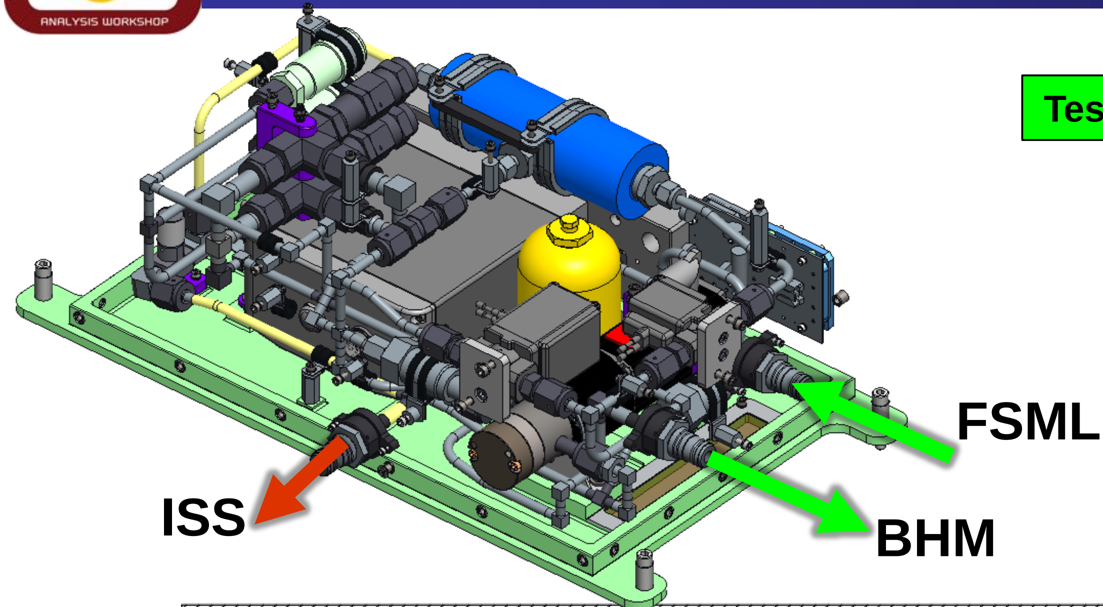


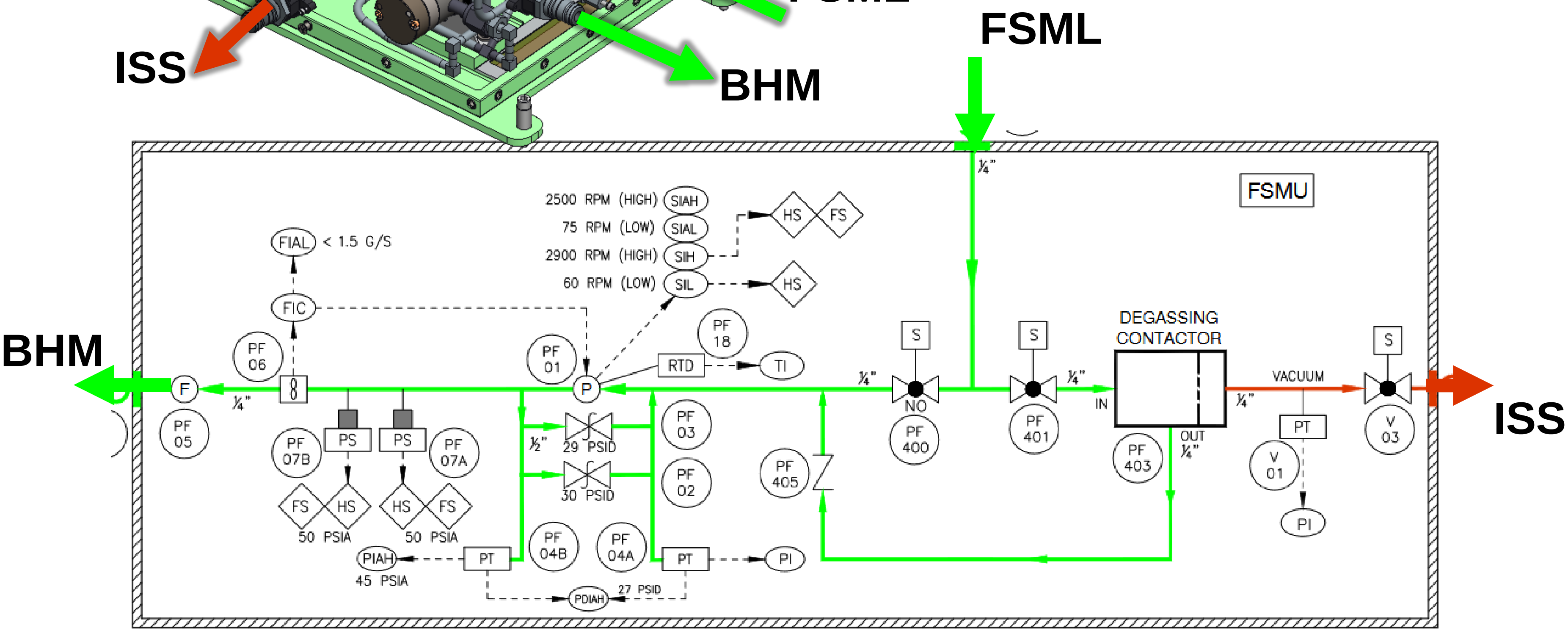
Fluid System Module – Lower (FSML)



Fluid System Module – Upper (FSMU)

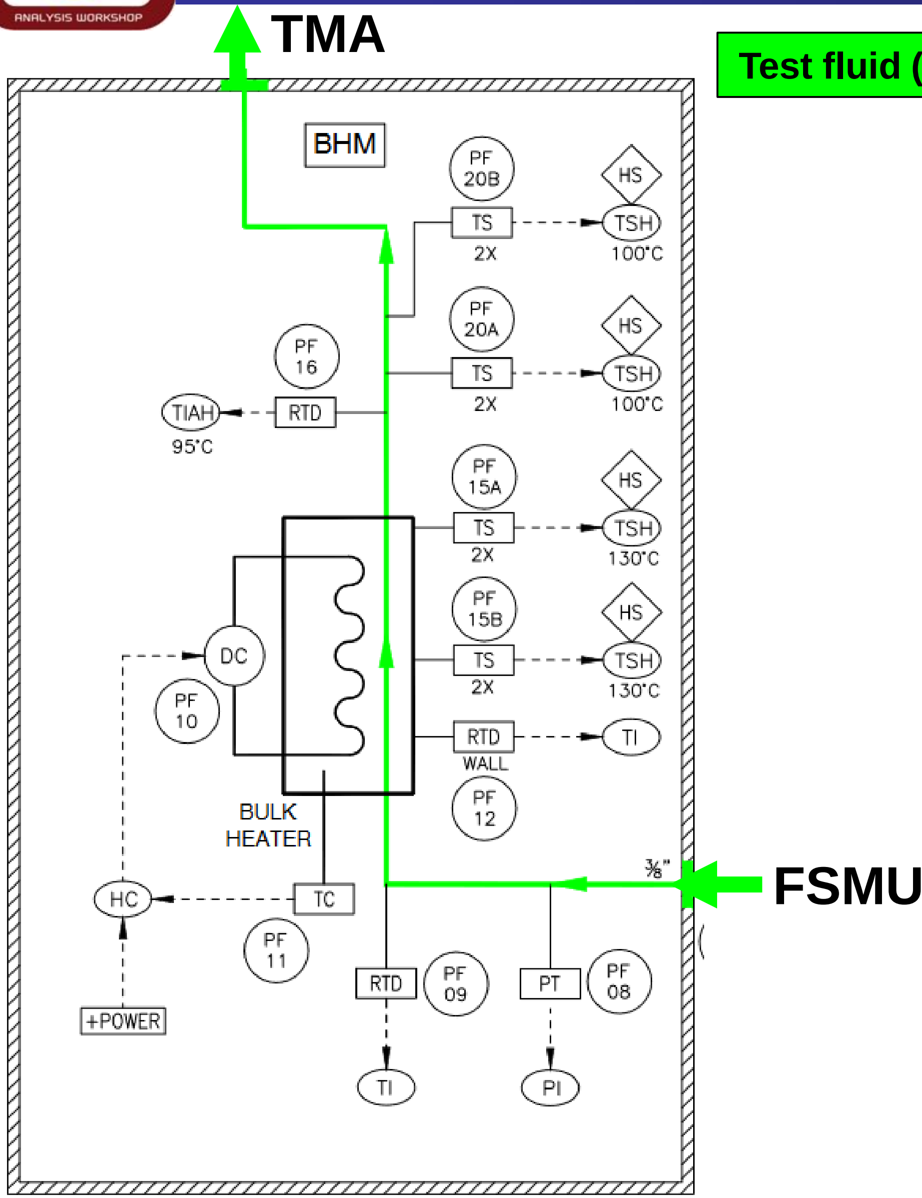
Test fluid (nPFH) | Vacuum

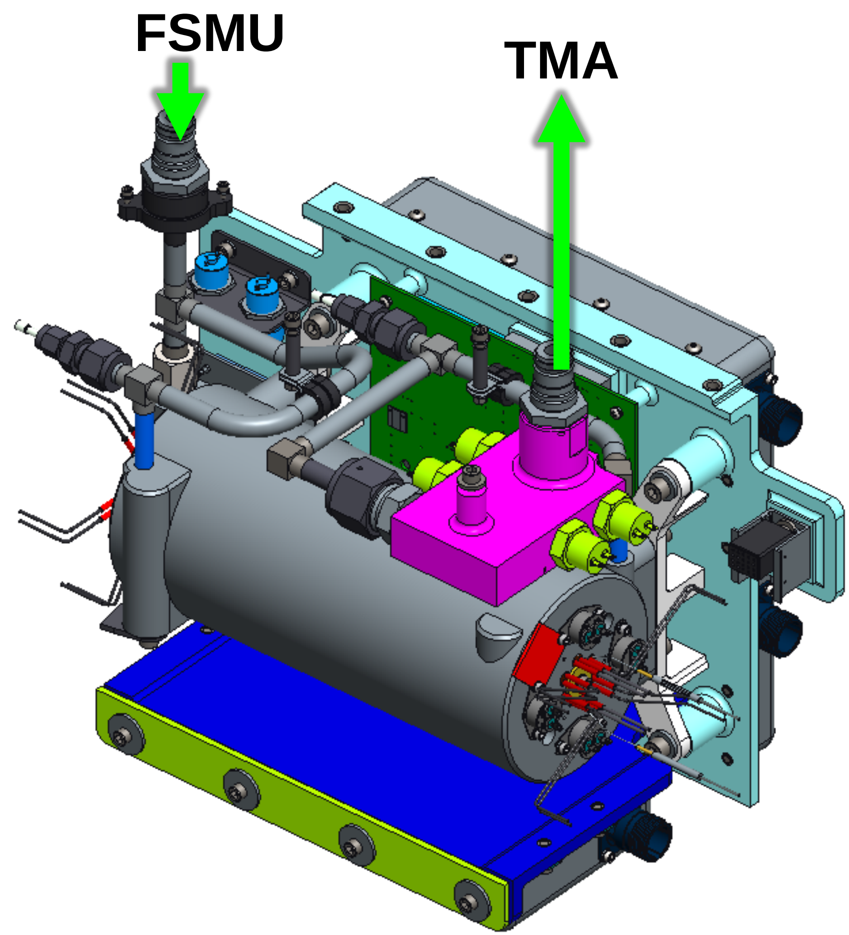




Bulk Heater Module (BHM)

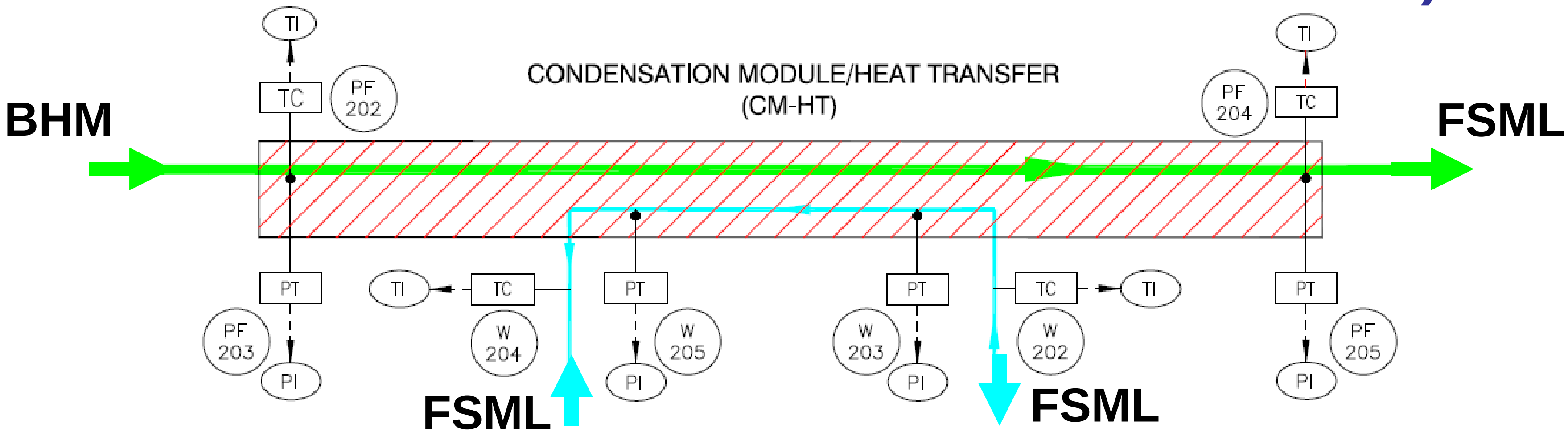
Test fluid (nPFH)



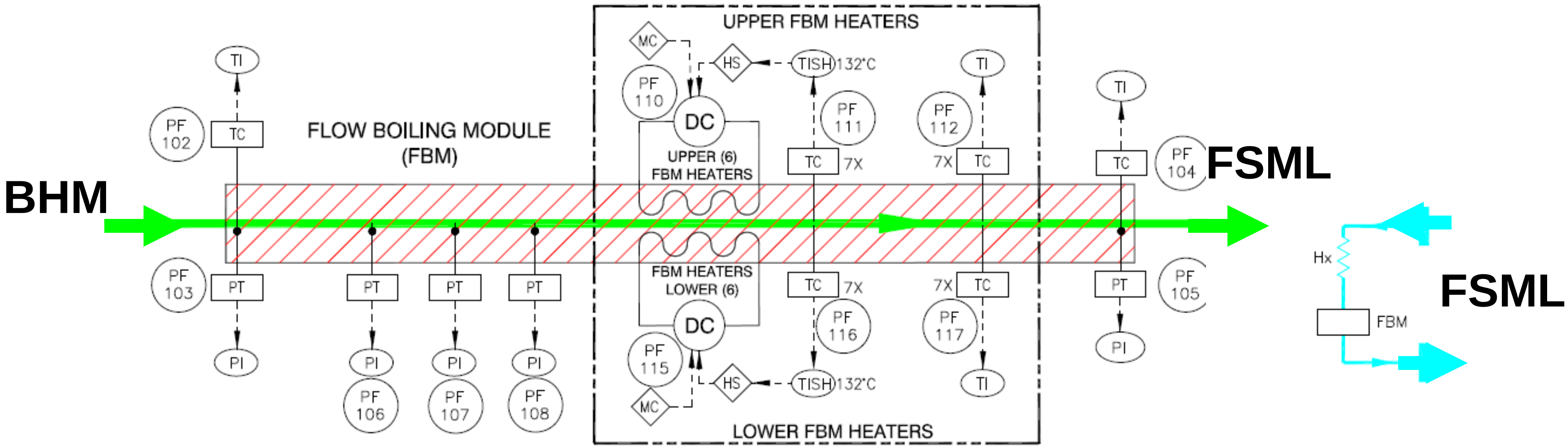


Test Module Assemblies (TMAs)

Condensation Module - Heat Transfer (CM-HT)



Flow Boiling Module (FBM)

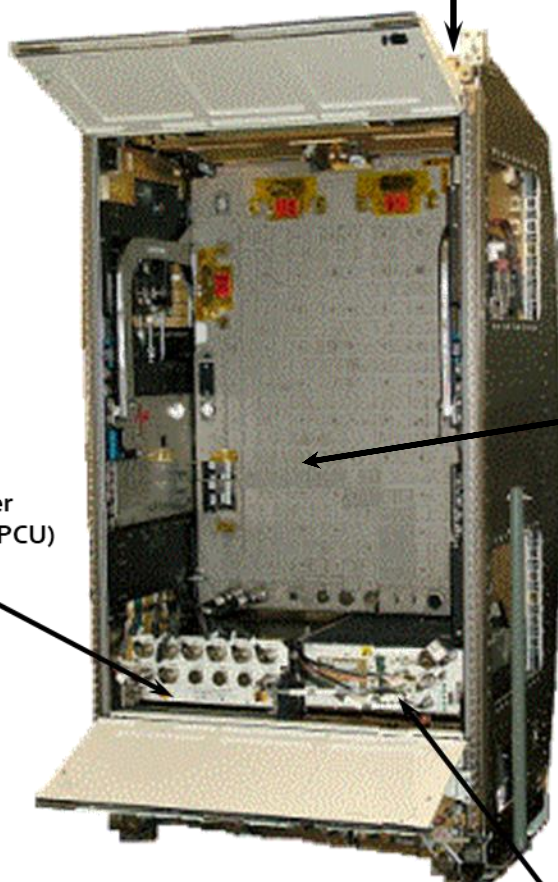


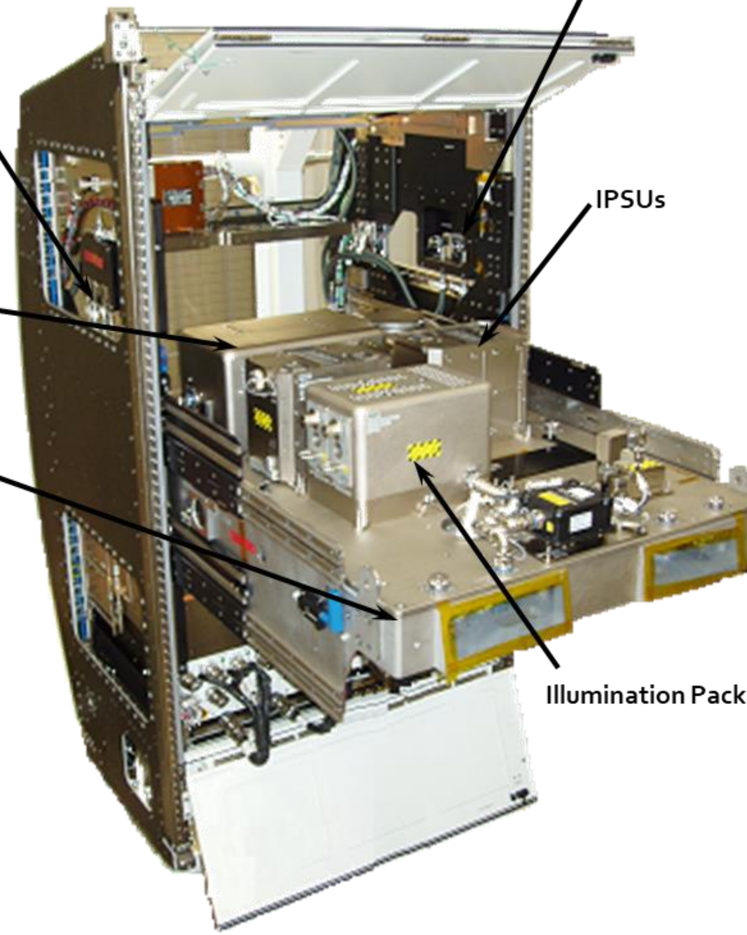
Test fluid (nPFH)	Water

Fluid Integration Rack (FIR)

Environmental Control (ECS)

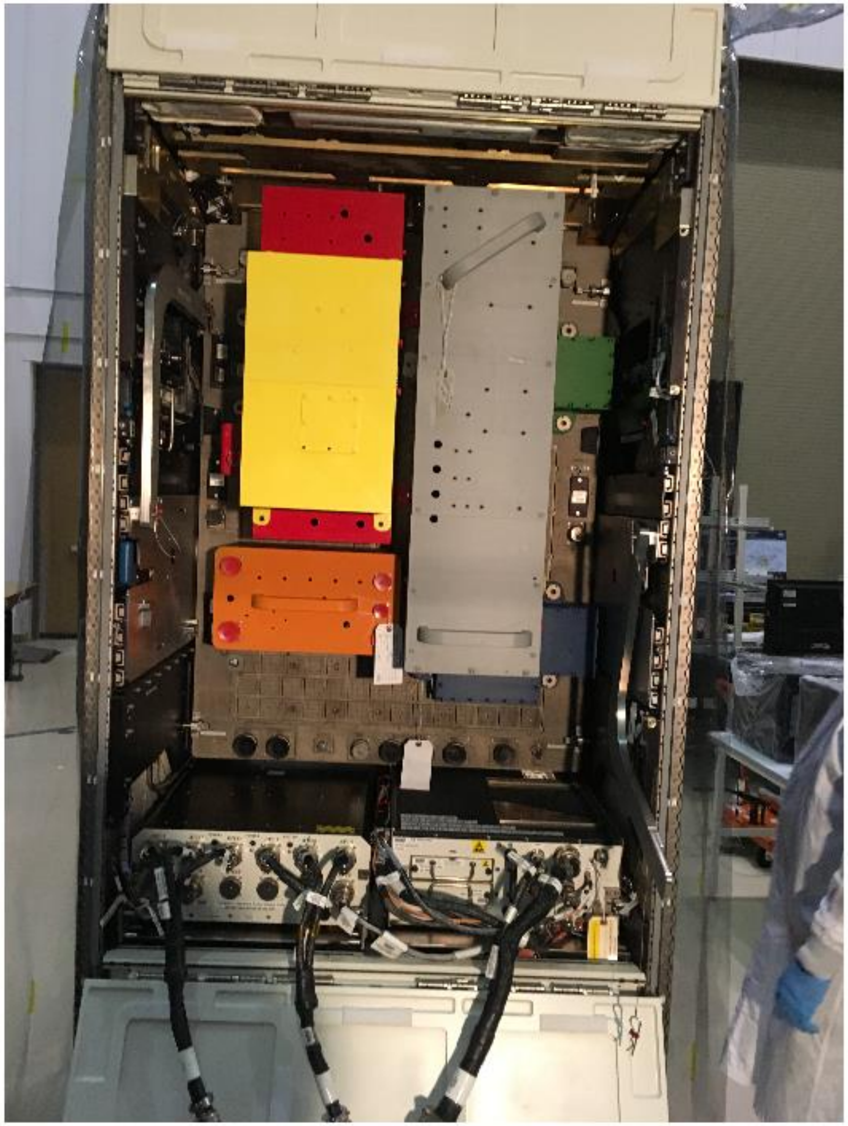
- Air Thermal Control
- Fire Detection & Suppression
- Water Thermal Control
- Gas Interfaces (GN_2, VES, VRS)

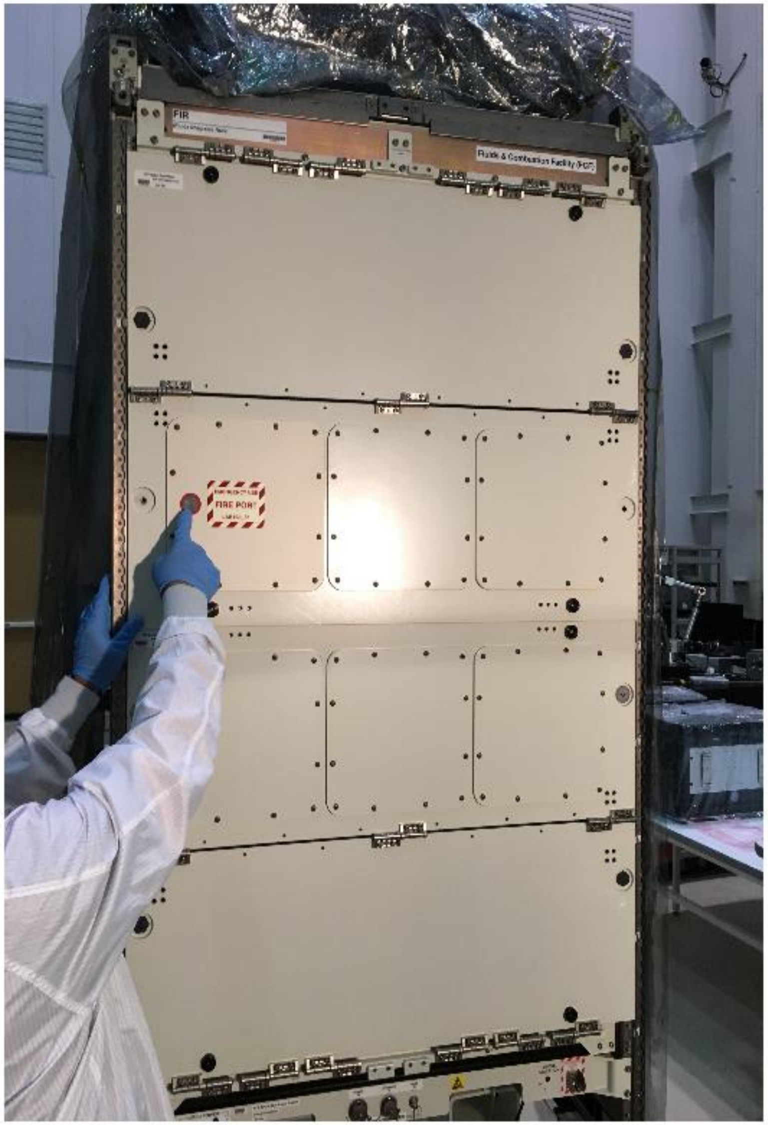




ZIN Technologies

FBCE Integration Fit Check in the FIR





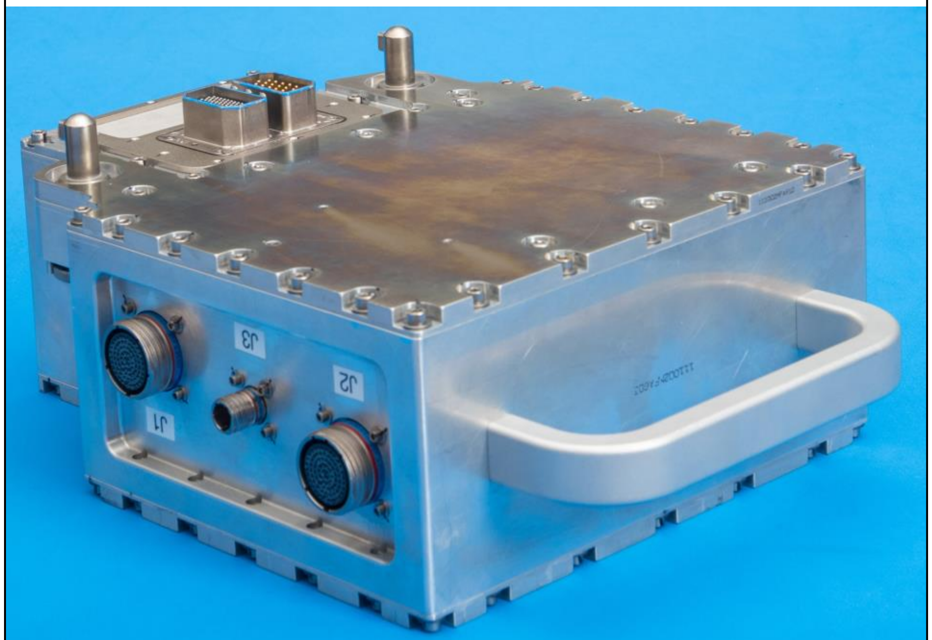
FBCE Payload Operations

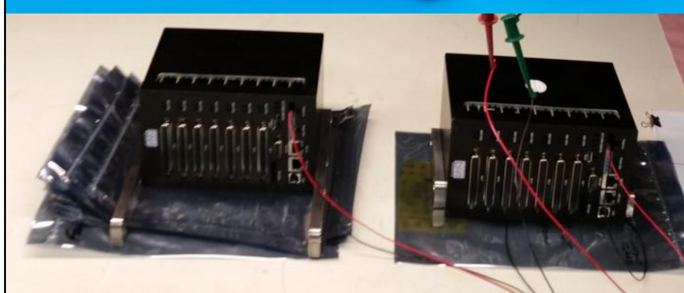
- All payload operations will be remotely controlled from the Telescience Support Center at NASA GRC
- Astronaut interactions with FBCE hardware are limited to installation and removal of hardware into and out of FIR

FBCE Hardware Assembly

FBCE hardware assembly was completed in July 2019

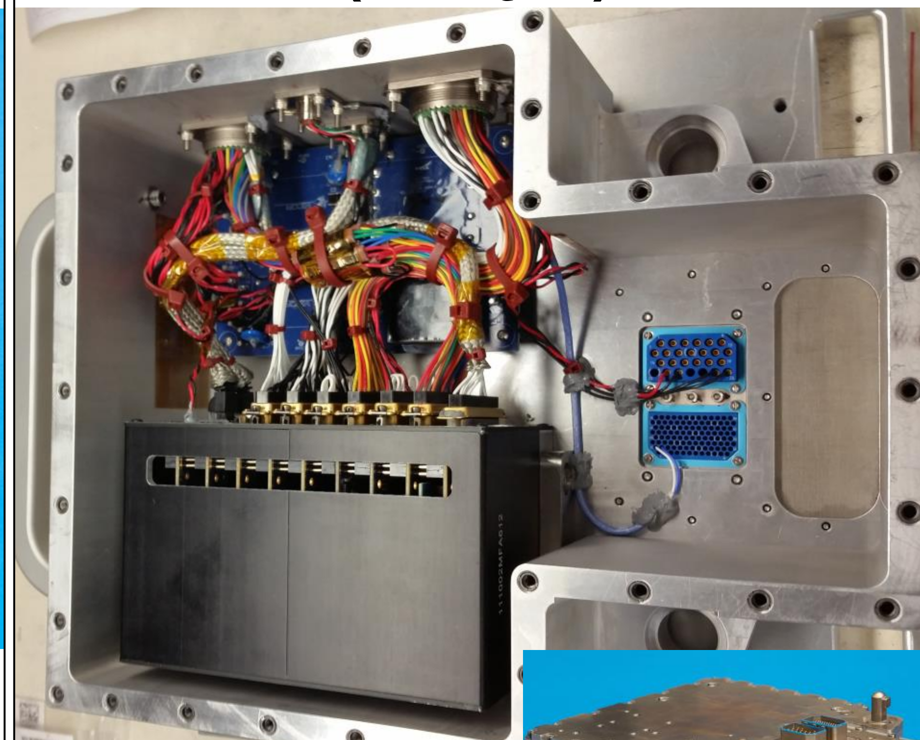
Remote Data Acquisition Module 1 (RDAQM1)





UEI Data Cube Checkout Testing

Remote Data Acquisition Module 2 (RDAQM2)

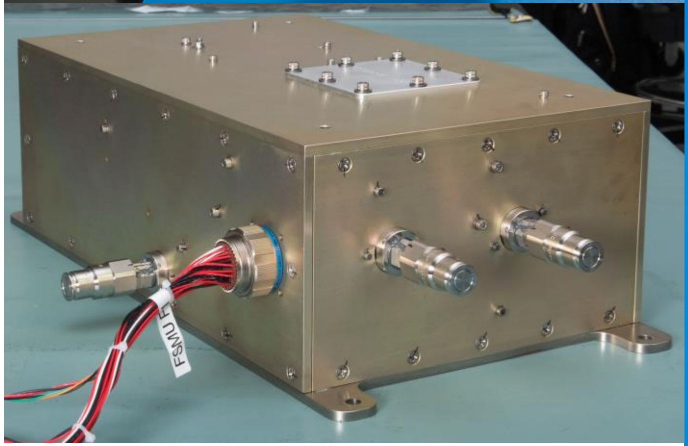


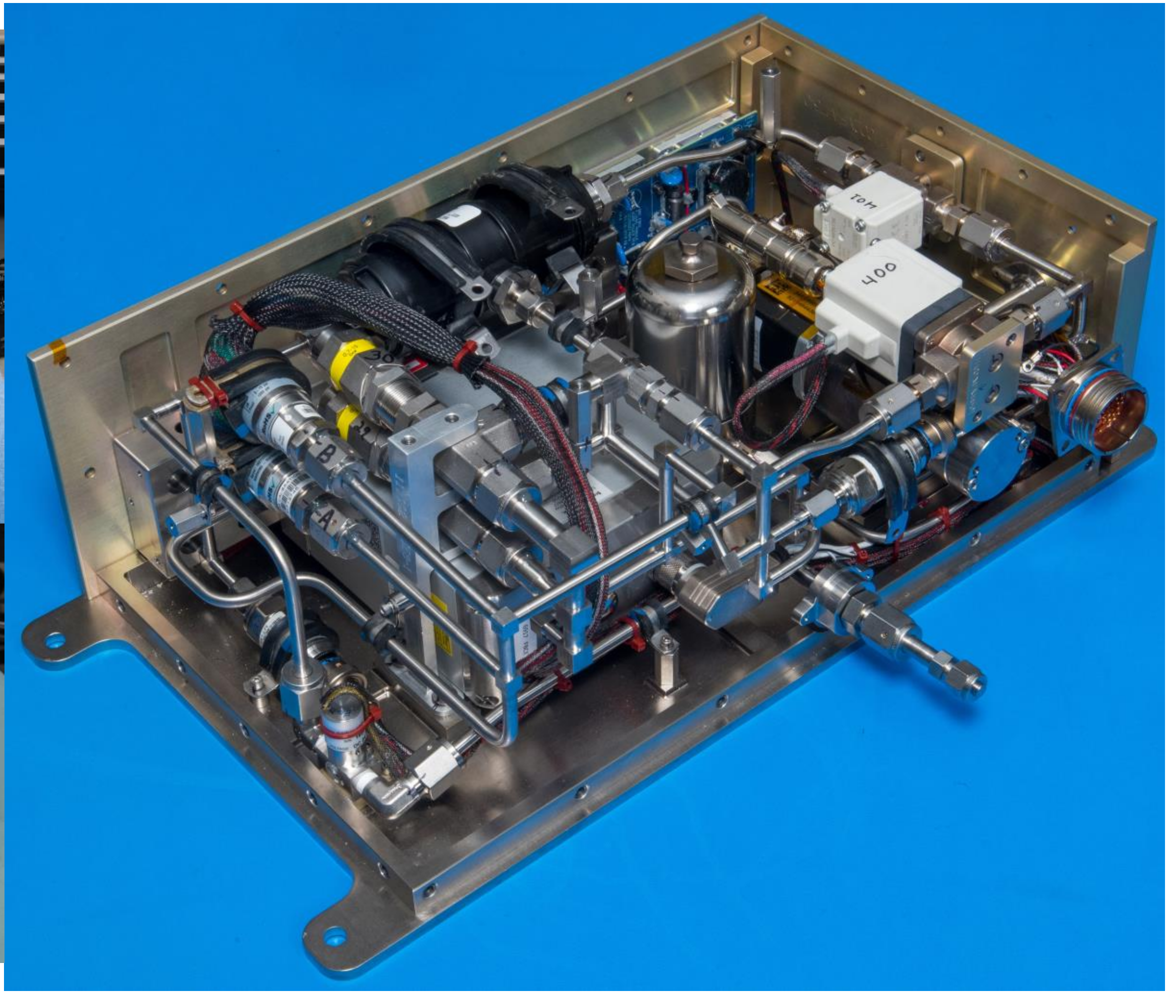
UEI Data Cube plus Custom Sensor Supply Printed Circuit Board

FBCE Hardware Assembly

FBCE hardware assembly was completed in July 2019

Fluid System Module-Upper (FSMU)

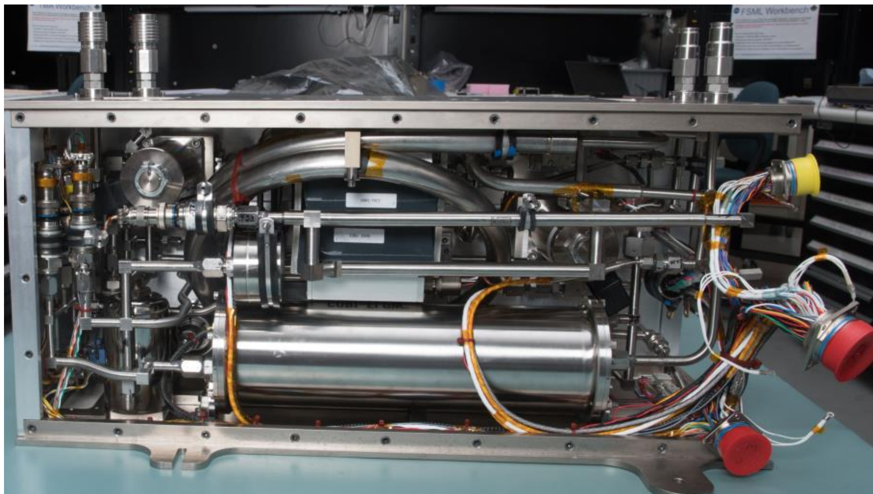


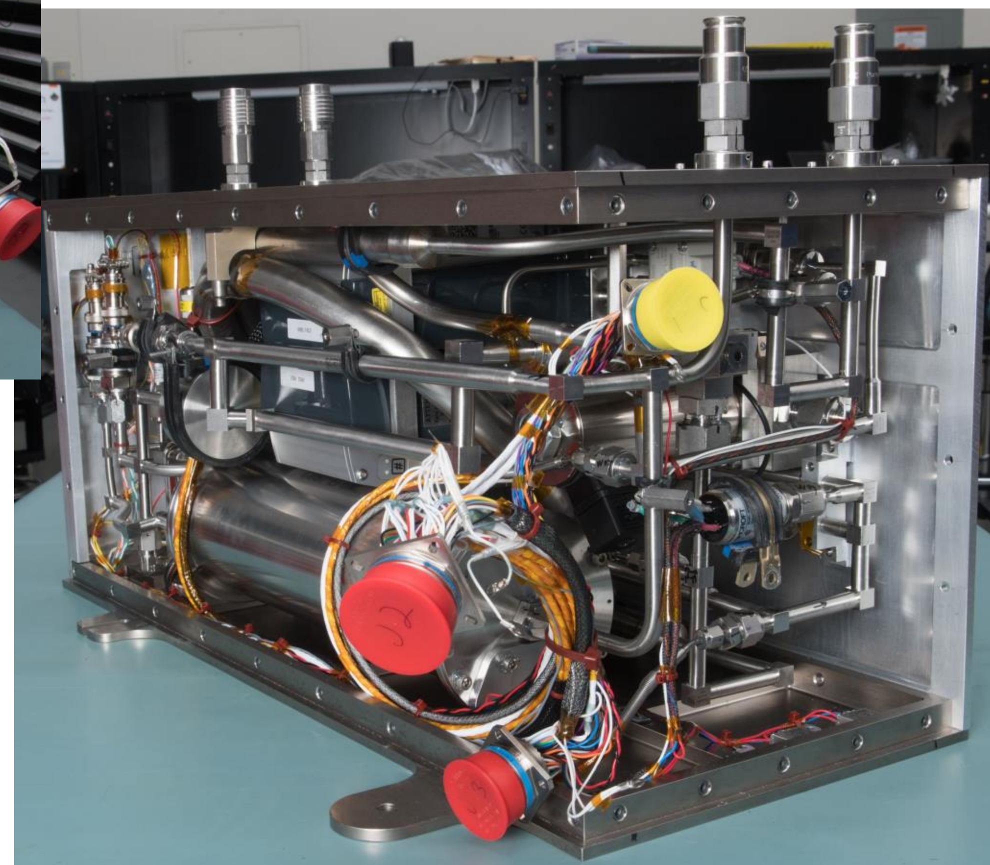


FBCE Hardware Assembly

FBCE hardware assembly was completed in July 2019

Fluid System Module-Lower (FSML)

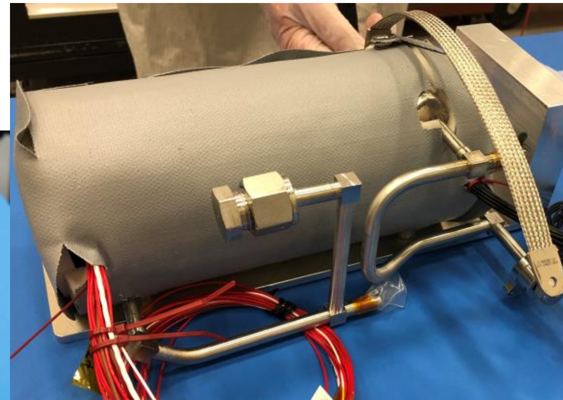


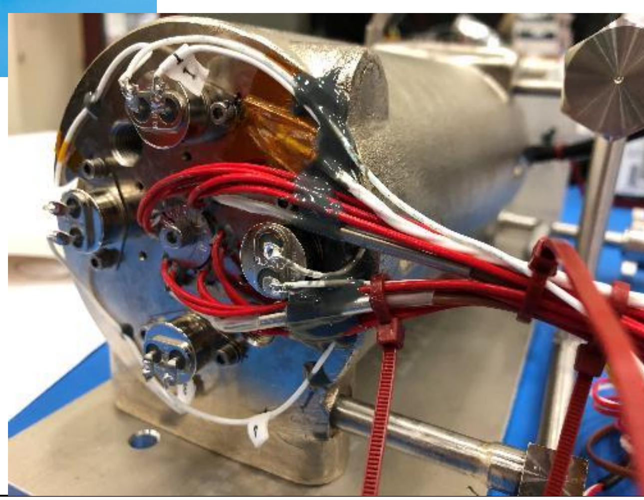


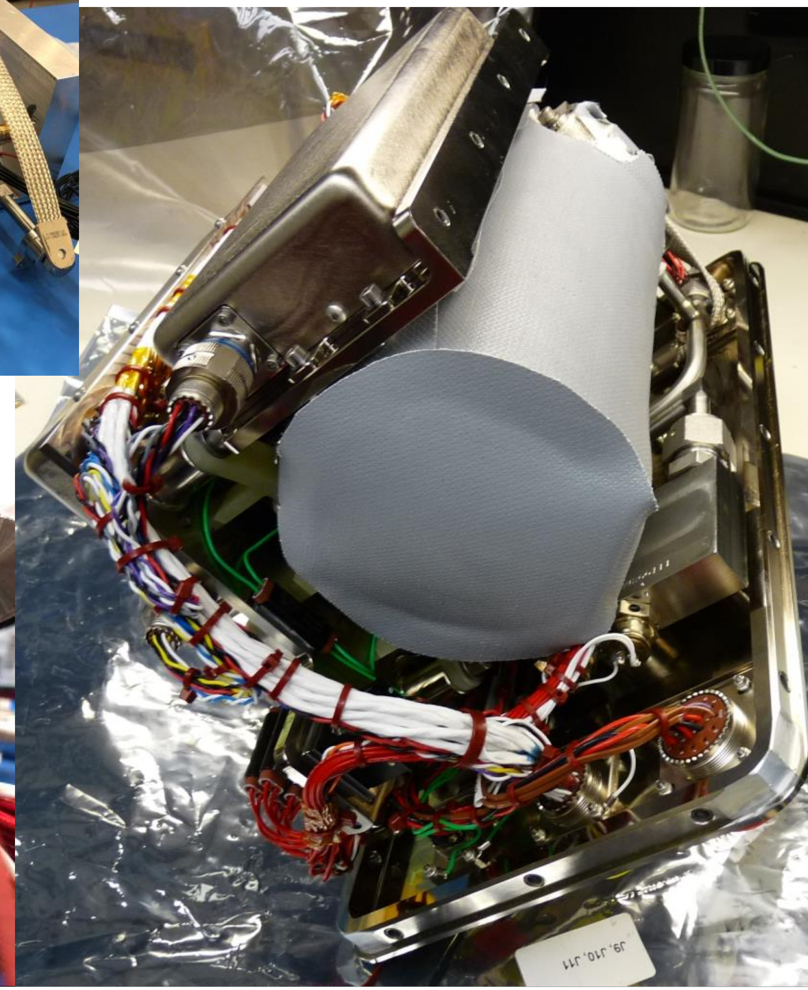
FBCE Hardware Assembly

FBCE hardware assembly was completed in July 2019

Bulk Heater Module (BHM)



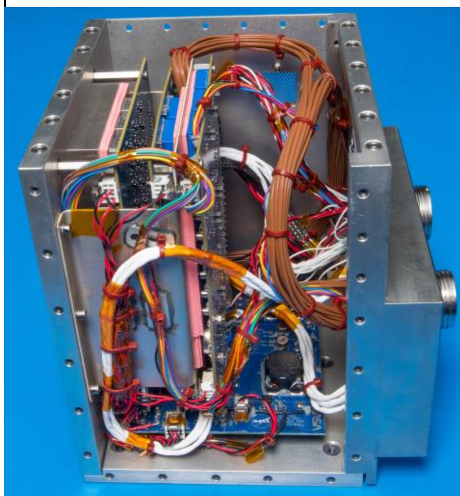


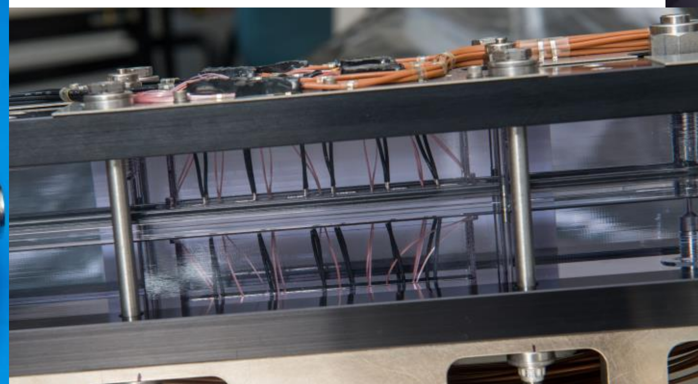


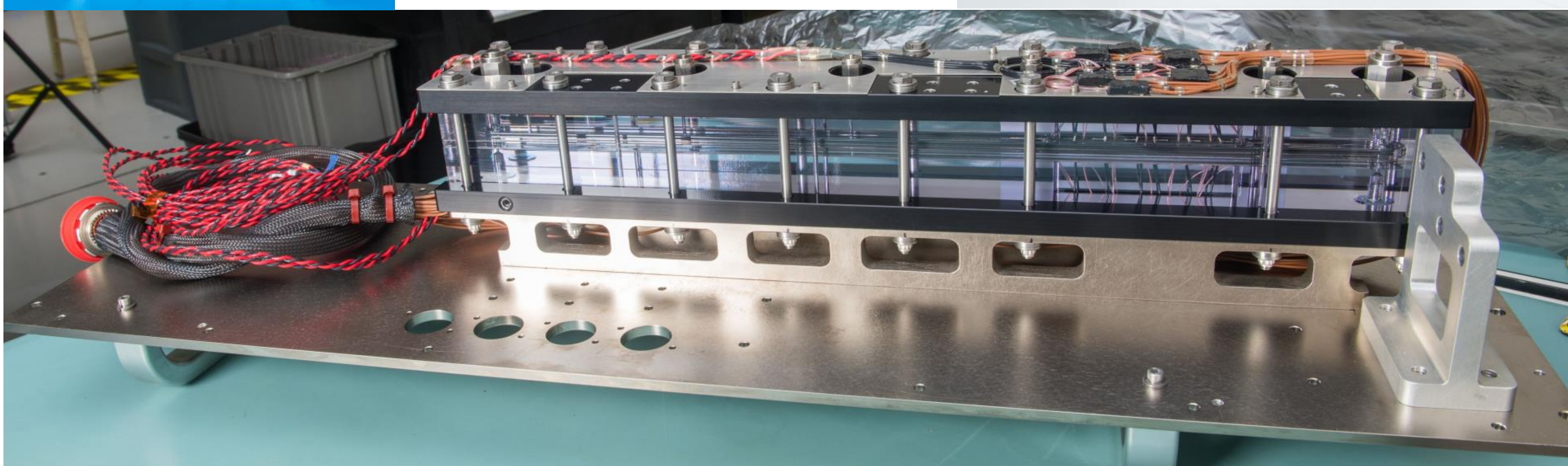
FBCE Hardware Assembly

FBCE hardware assembly was completed in July 2019

Flow Boiling Module (FBM)

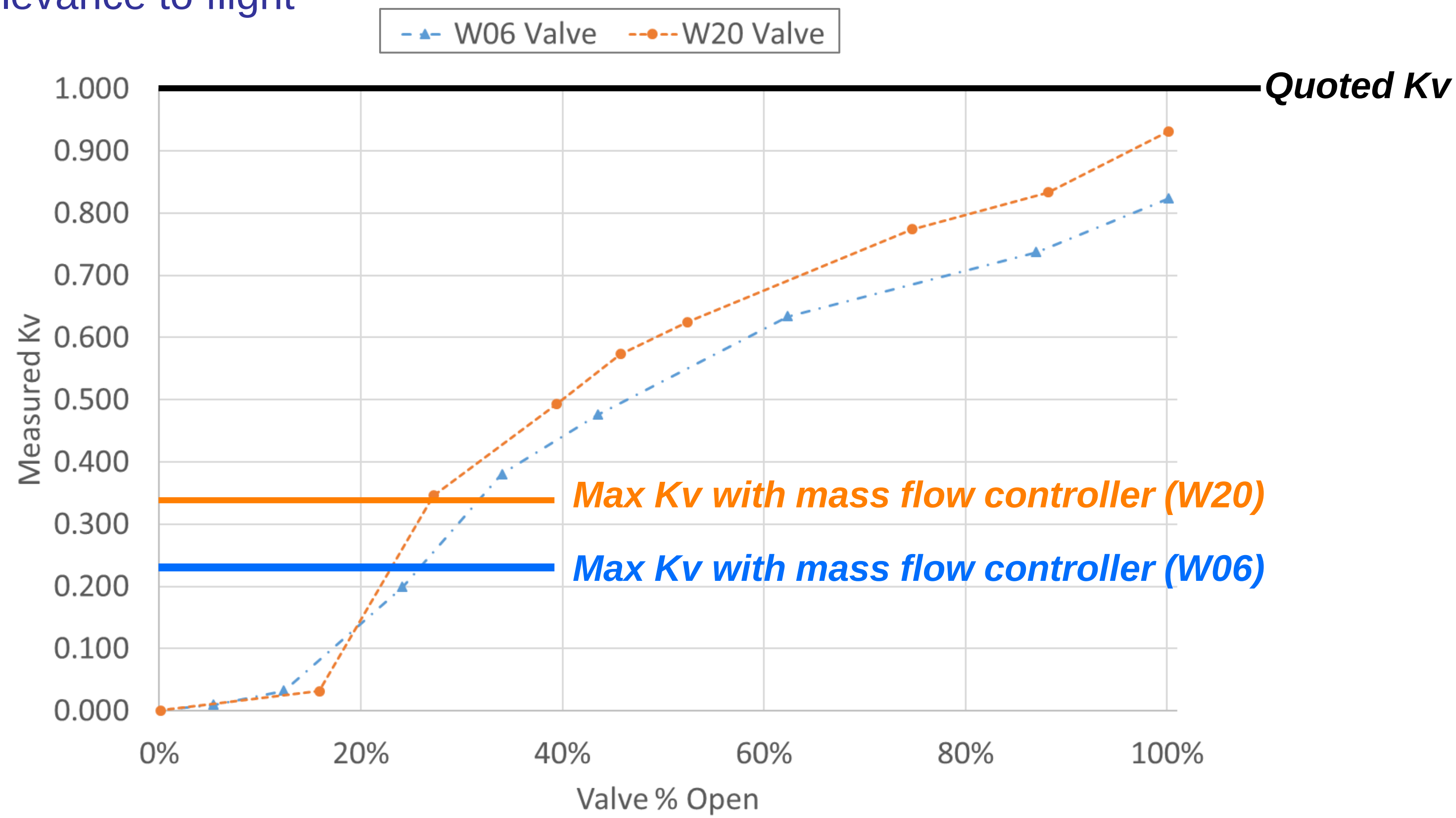






FBCE Brassboard Testing: Control Valves

- During brassboard testing, the water control valves showed an unexpectedly high pressure drop that would prevent the system from operating as required on ISS
- Testing showed that the valves were operating below their quoted Kv when the mass flow controller should be commanding the valve to fully open
- Currently working with the valve manufacturer to diagnose the issue and determine relevance to flight



FBCE Flight Water System Checkout

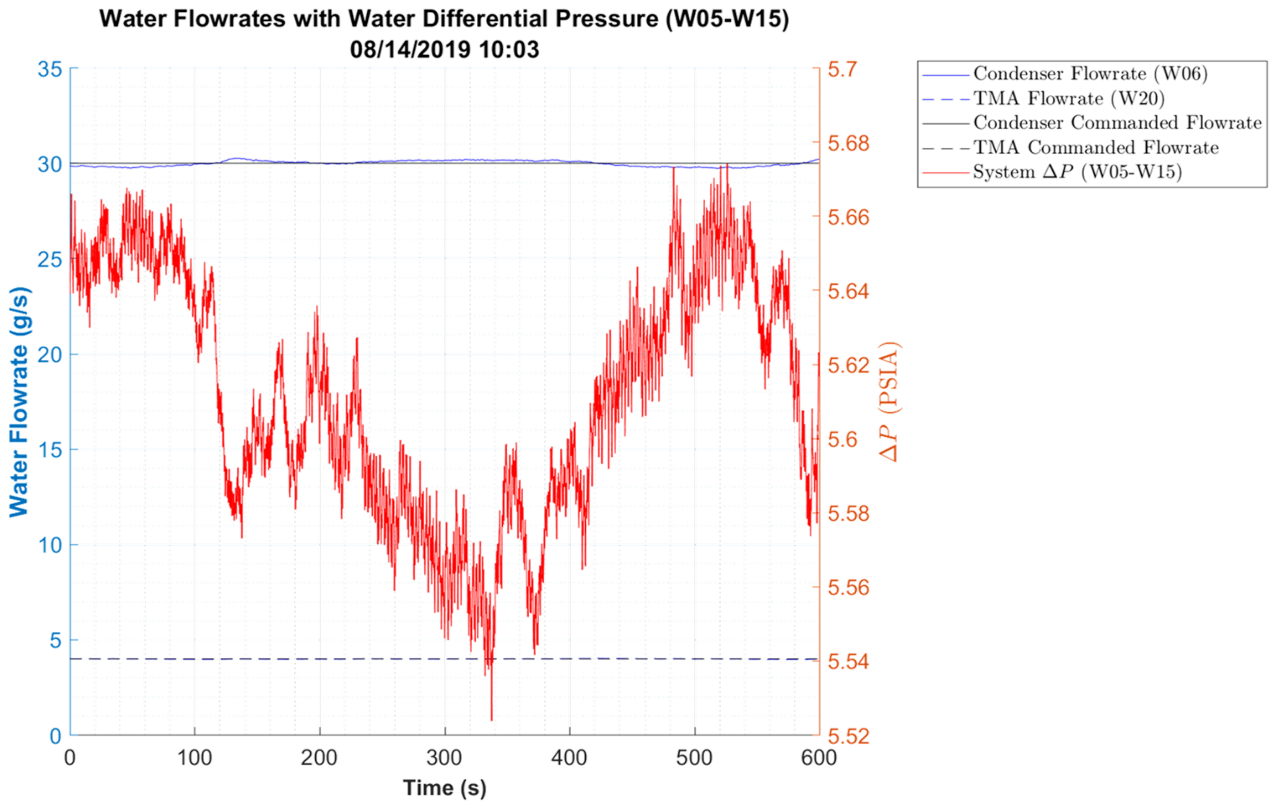
- Dedicated pressure drop testing of the flight FSML showed that the system pressure drop was higher than expected, particularly in the TMA cooling lines
- All FBM test cases can be met, but not all CM-HT test cases can be achieved

TMA (%Test Points)	Required Condenser Flow	Achieved Condenser Flow	Required TMA Flow	Achieved TMA Flow	System Pressure Drop
FBM (100%)	30 g/s	30.24 g/s	4 g/s	4.01 g/s	5.26 psid
CM-HT (58%)	10 g/s	9.97 g/s	30 g/s	22.75 g/s	5.86 psid
CM-HT (21%)	20 g/s	19.93 g/s	20 g/s	18.48 g/s	5.86 psid
CM-HT (21%)	30 g/s	28.86 g/s	10 g/s	10.03 g/s	5.86 psid

- Per the FIR Interface Control Document, payloads are limited to 5.8 psid at a cumulative 40 g/s flow through the system when utilizing ICTS water coolant
- To achieve all CM-HT test cases in current matrix, the system pressure drop would be 8.4 psid for a cumulative 40 g/s flow (30 g/s through the TMA)
- Project is evaluating potential forward path in parallel with FBM EMI testing

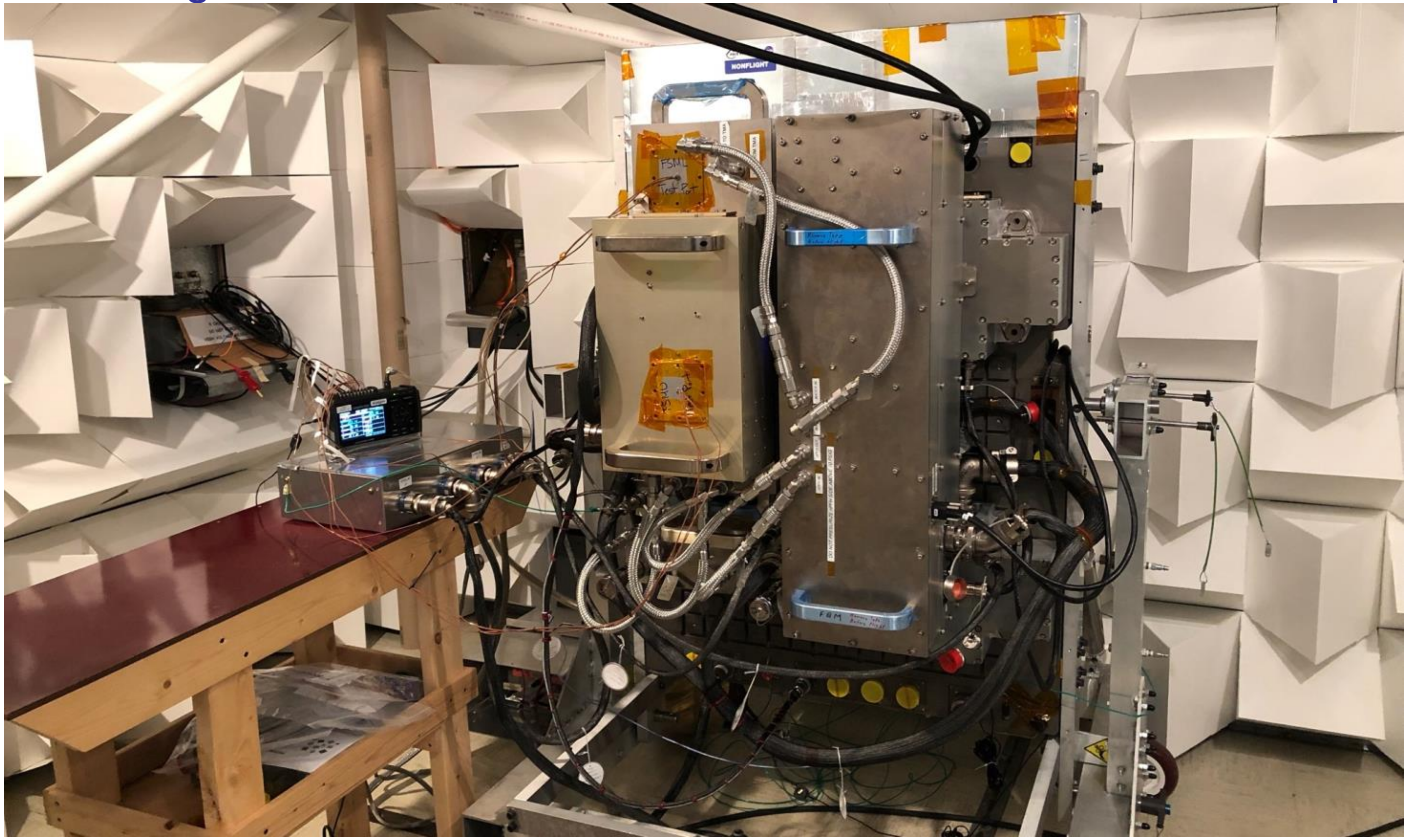
FBCE System Checkout Testing for FBM

- Checkout testing of the FBCE flight hardware for FBM operations was completed on August 14, 2019
  - All hardware and software systems performed as expected
  - Successfully ran four of the most aggressive test points in the FBM test matrix prior to relocating to the EMI test facility
  - EMI test points were achieved within the pressure drop requirements



Future Plans and Forward Work

- FBCE hardware is currently undergoing EMI testing at NASA Glenn Research Center through September 20, 2019
- Following completion of EMI testing, action will be taken (as required) to address control valve concerns prior to proceeding to thermal testing
- On track for flight hardware available in December 2019, launch in Spring 2020



Future Plans and Forward Work

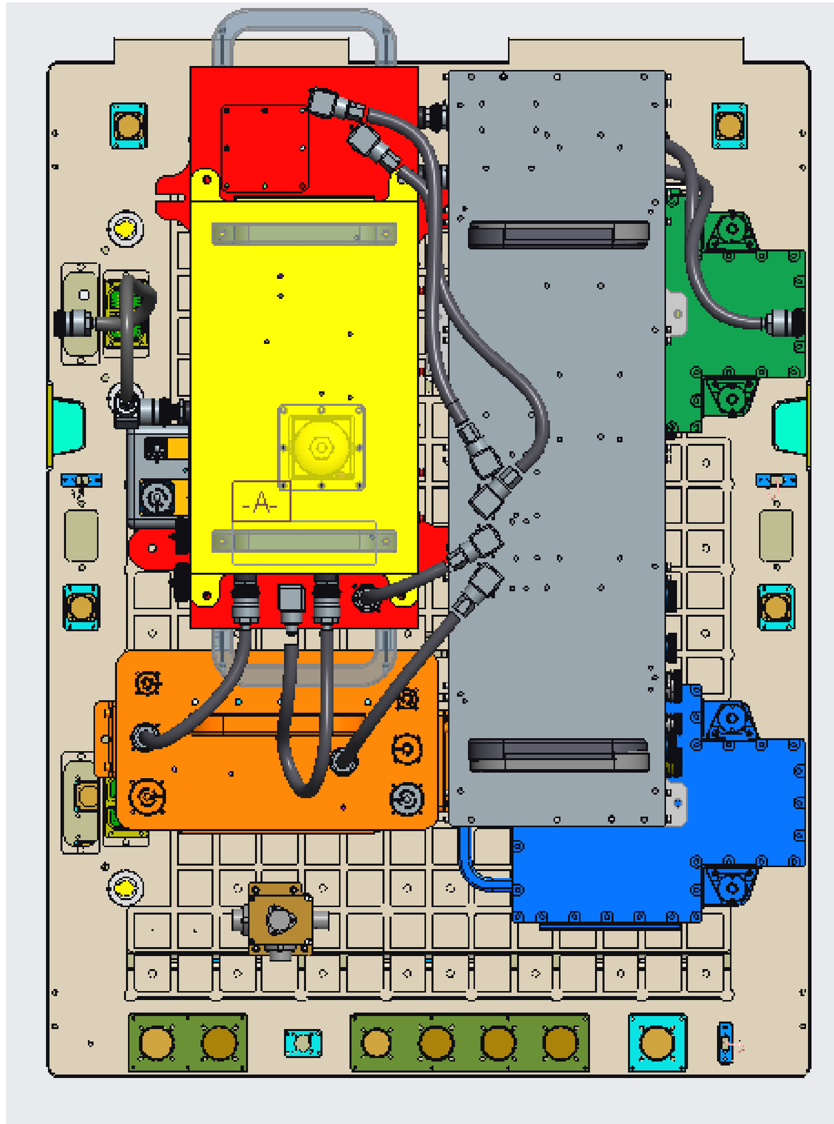
- Flow Boiling and Condensation (FBCE) test bed
  - FBCE flight testing with FBM and CM-HT on ISS will complete operations in 2021
  - FBCE facility modules (FSML, FSMU, BHM, RDAQM1, RDAQM2) will remain installed in the FIR as an FBC test bed to provide thermally conditioned flows (single or two phase) to future test modules
  - Currently planning one follow-on test module to utilize the FBC test bed: Condensation Module – Flow Visualization
  - A call for proposal for additional test modules to interface with the FBC test bed will be issued in the near future
  - Potential areas for investigation are still under consideration

Moving towards Flight Verifications!

Questions


µg
FBCE
NASA Glenn Research Center
Purdue University
FLOW BOILING AND CONDENSATION EXPERIMENT

Backup



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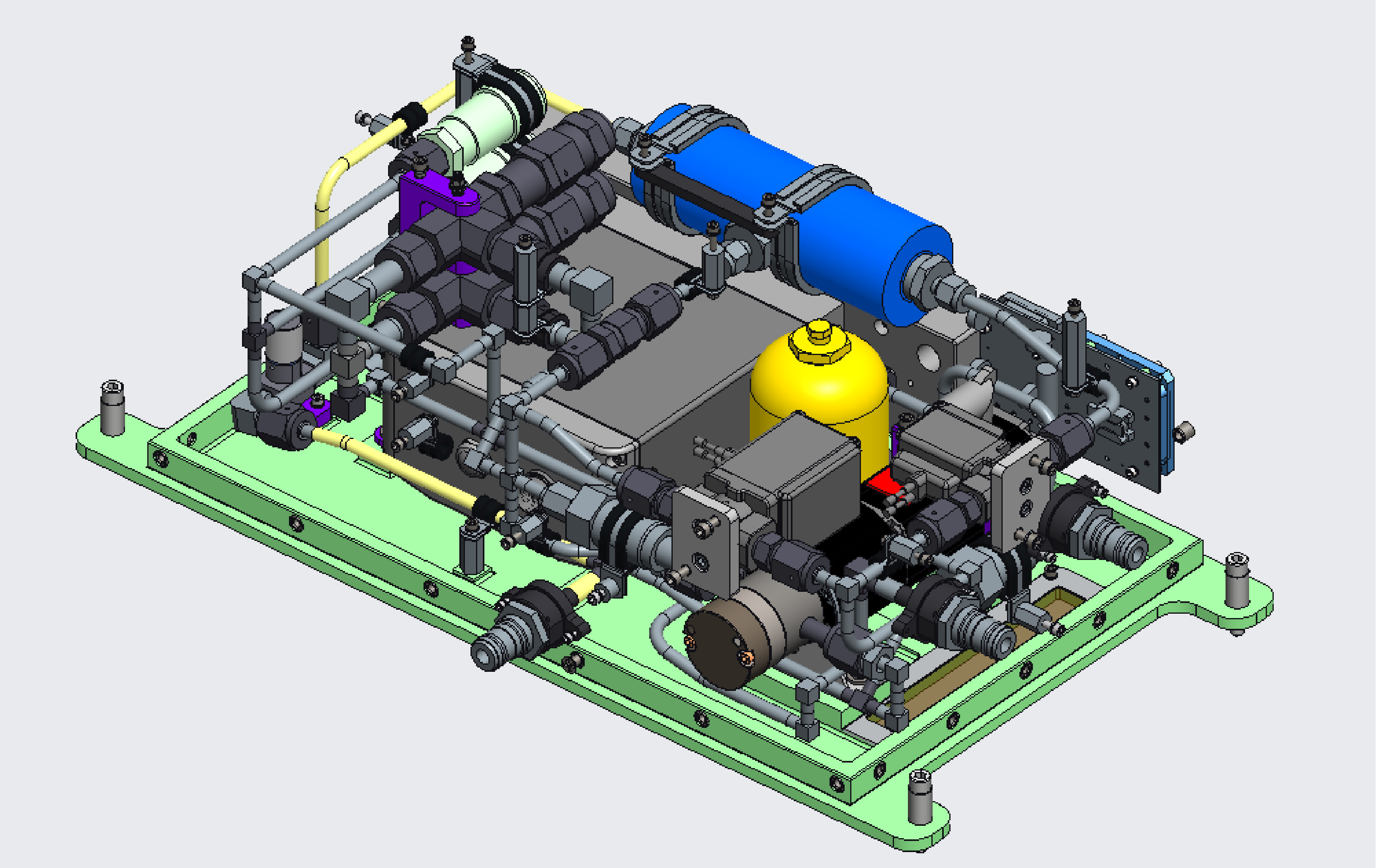

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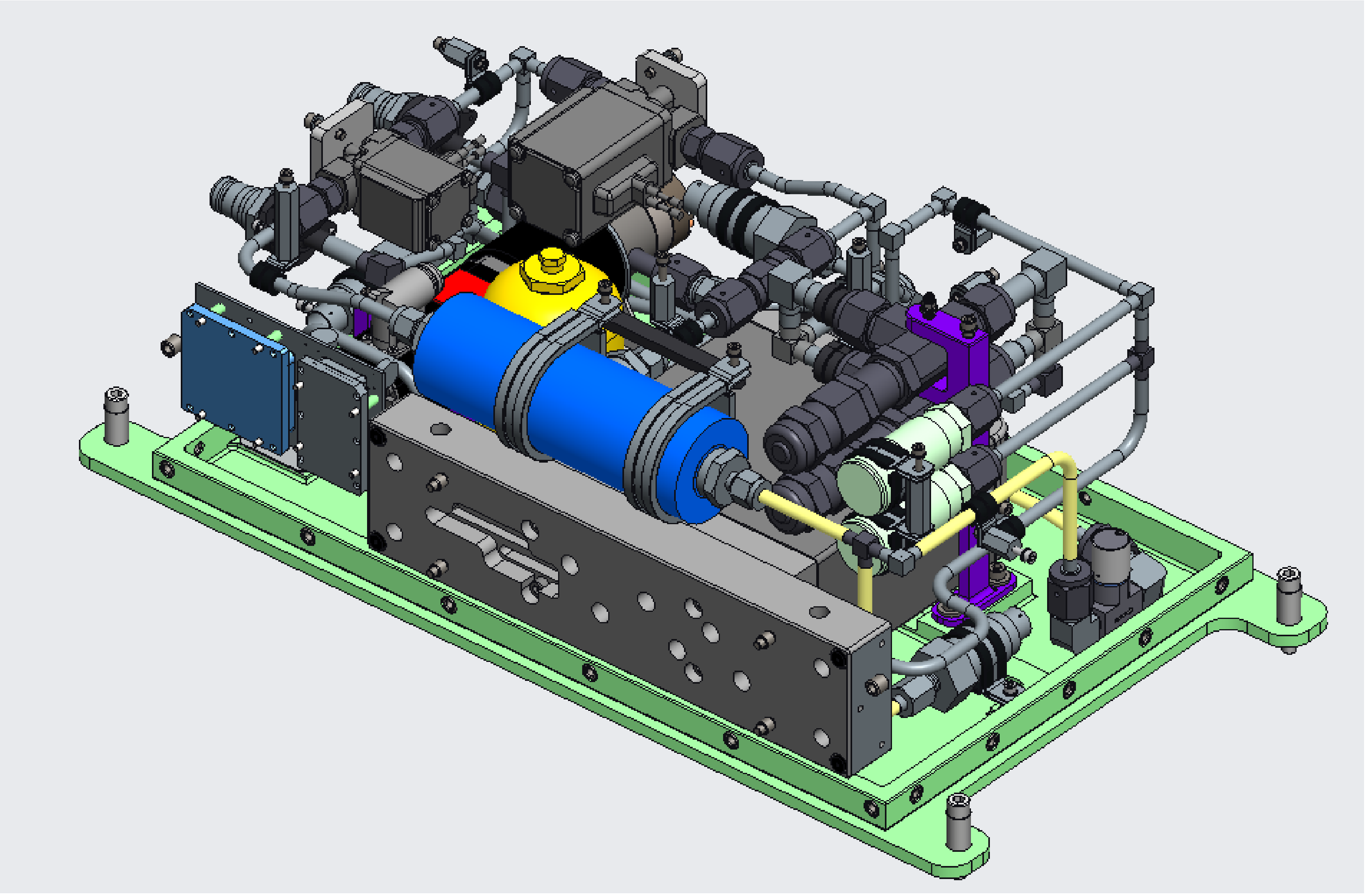

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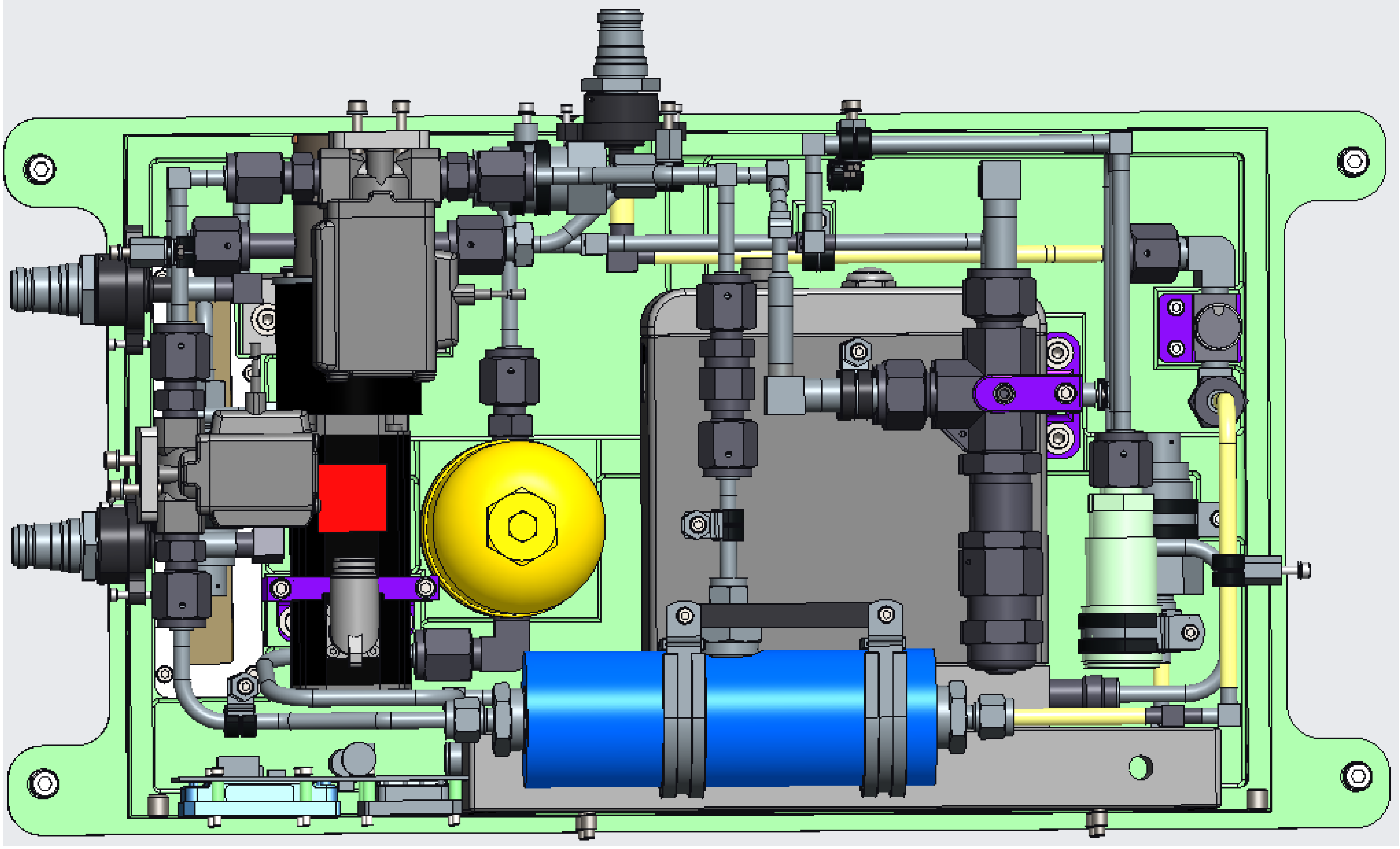

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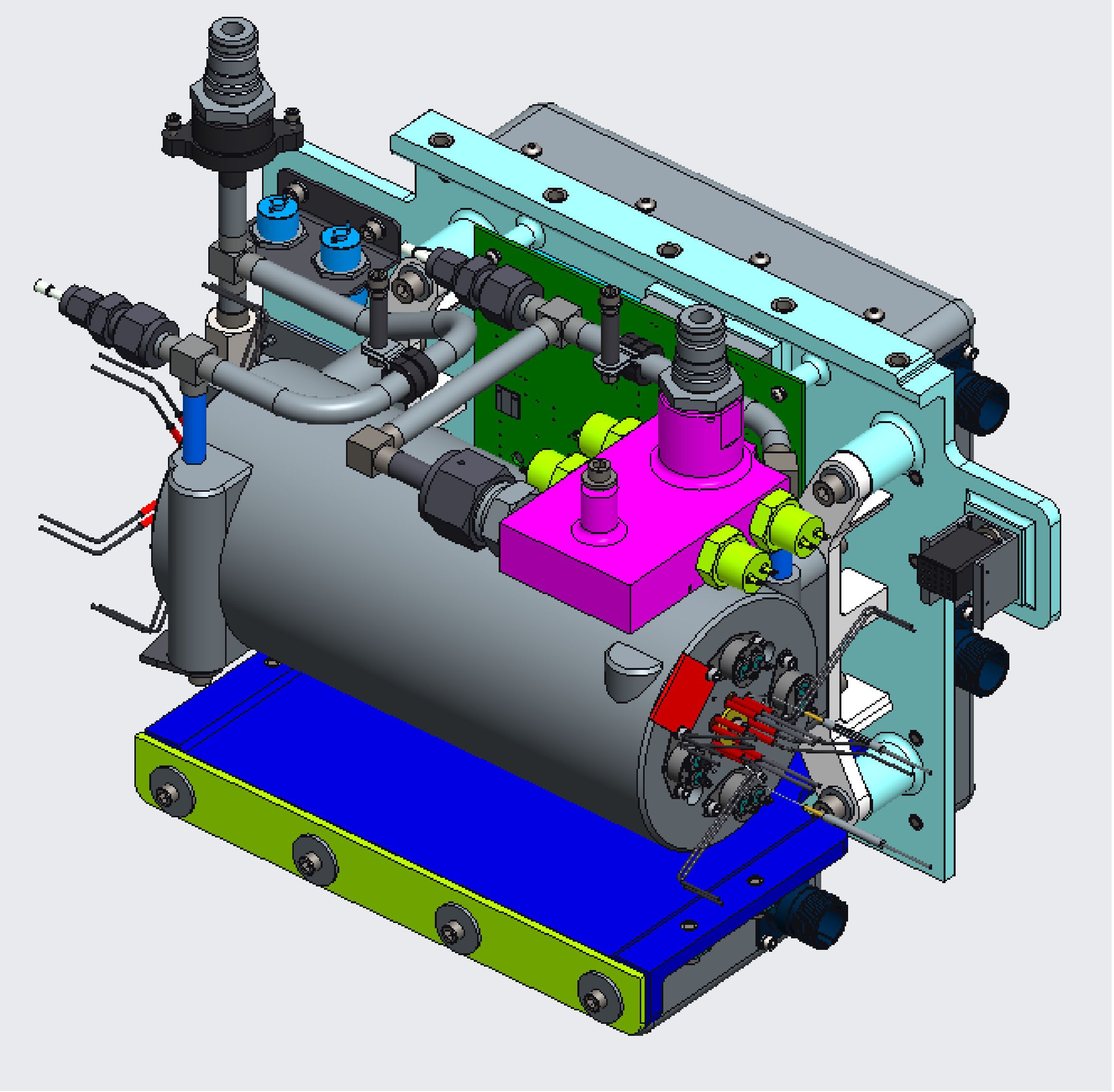

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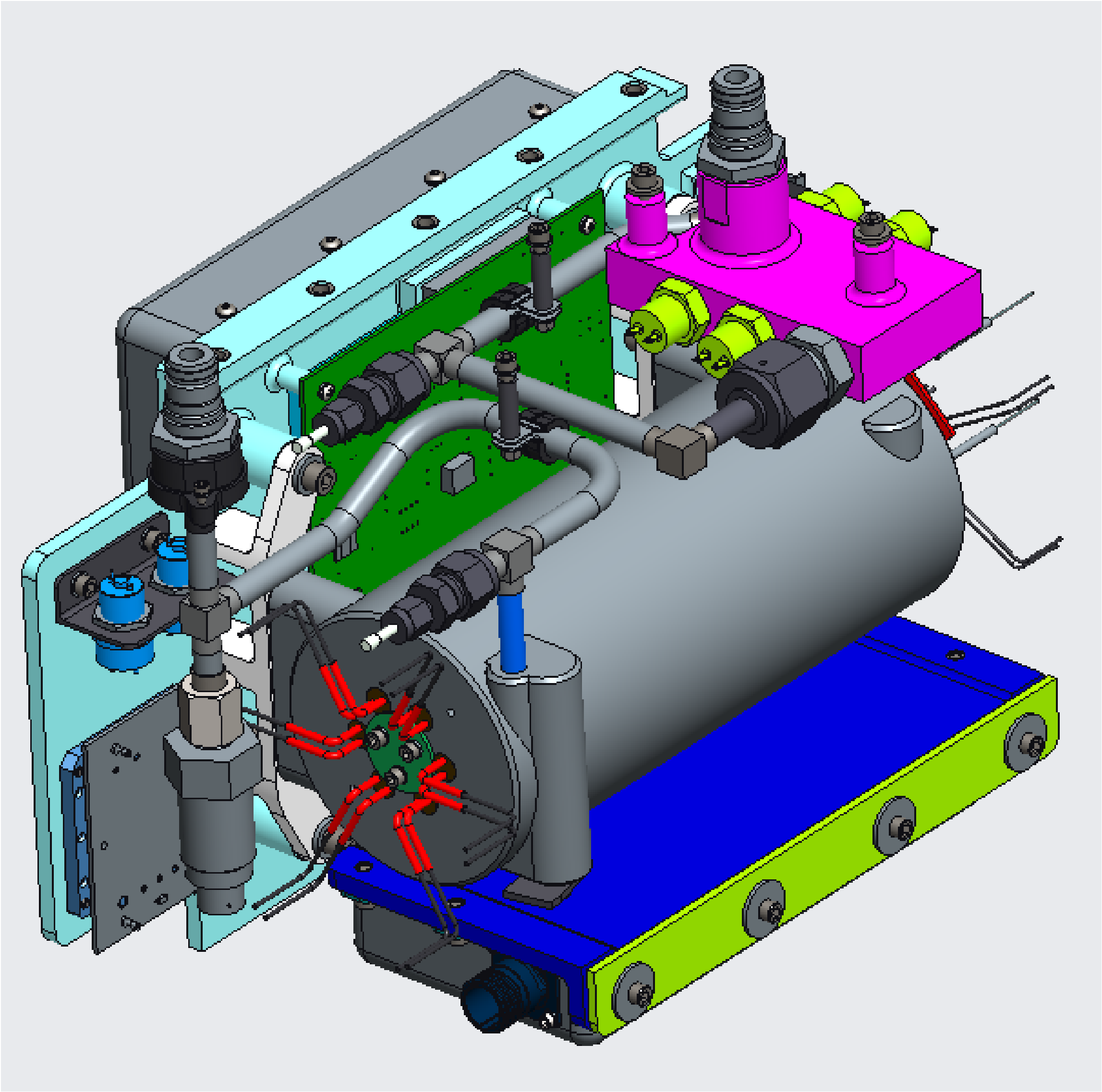

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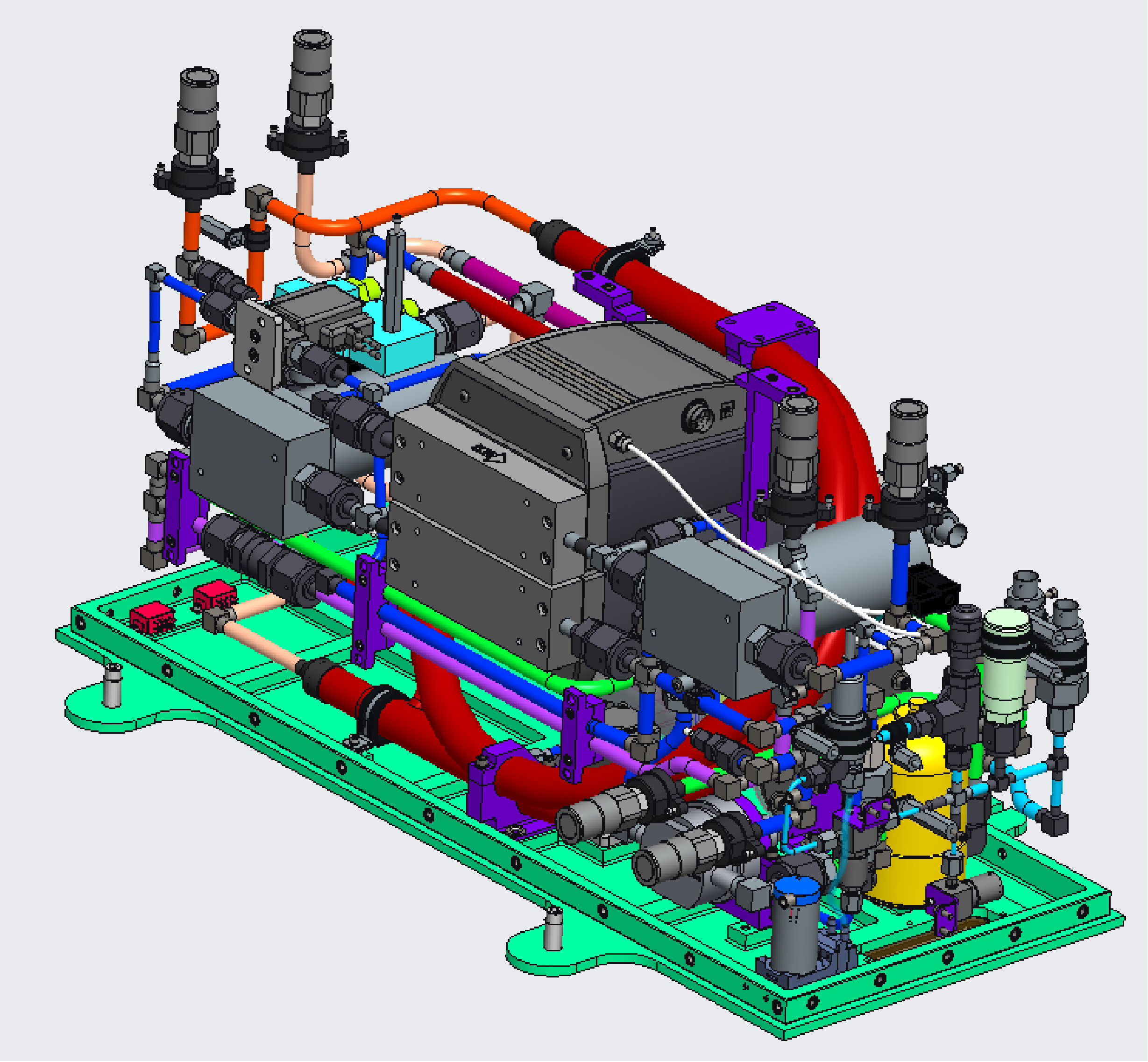

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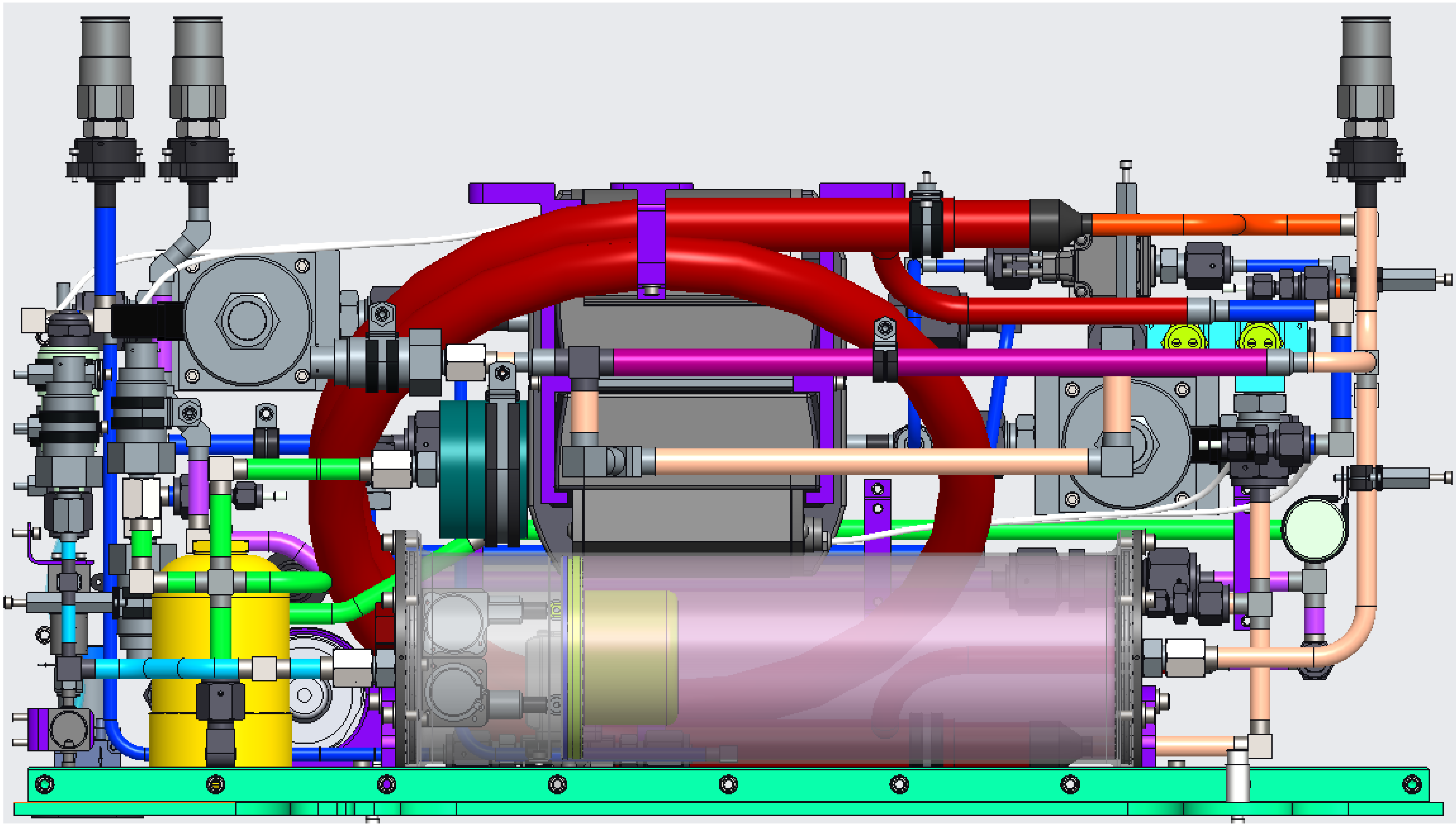

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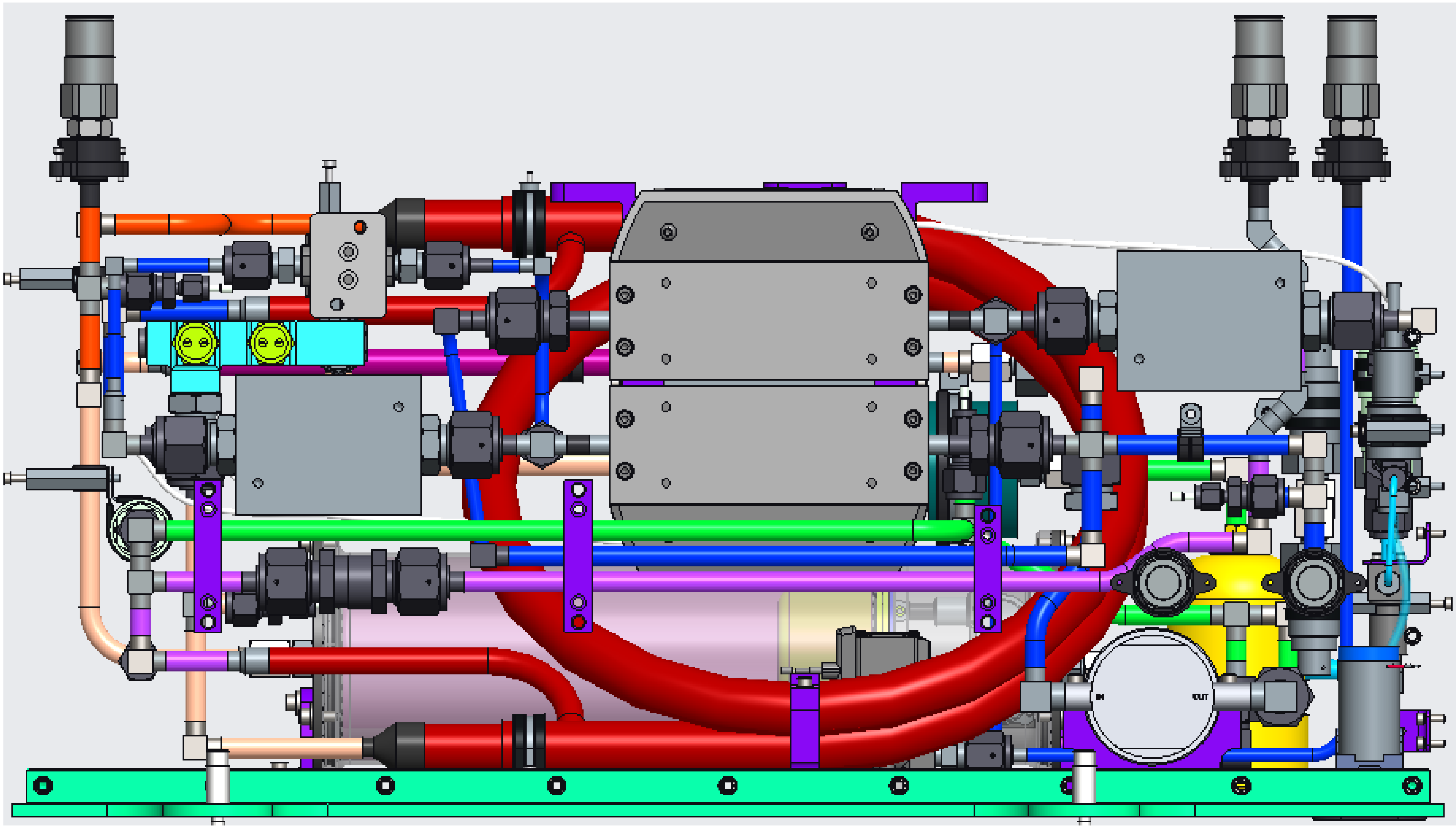

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