Heat Rejection System for Thermal Management in Space Using Non-planar Liquid Cooled Cold Plates

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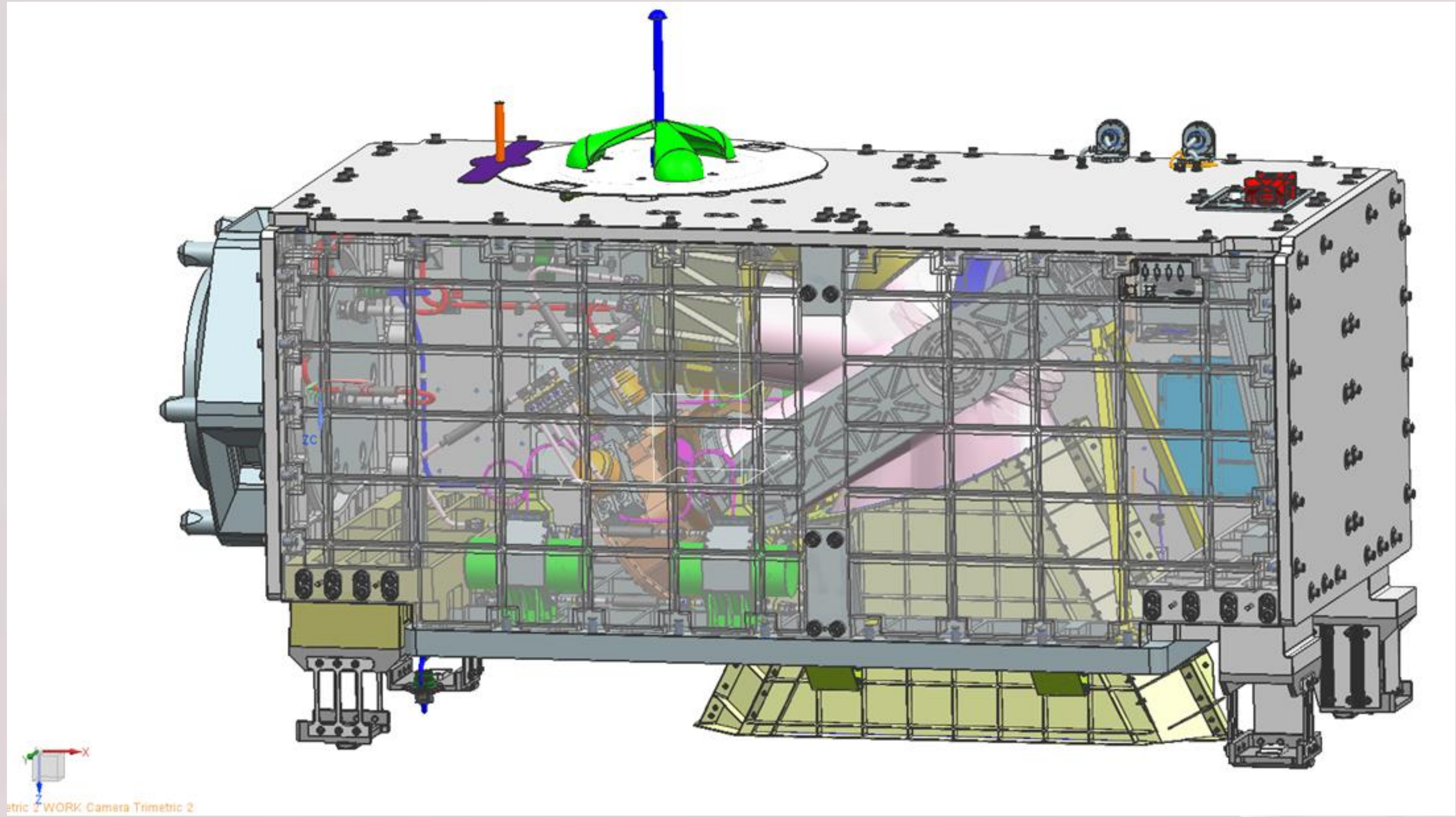
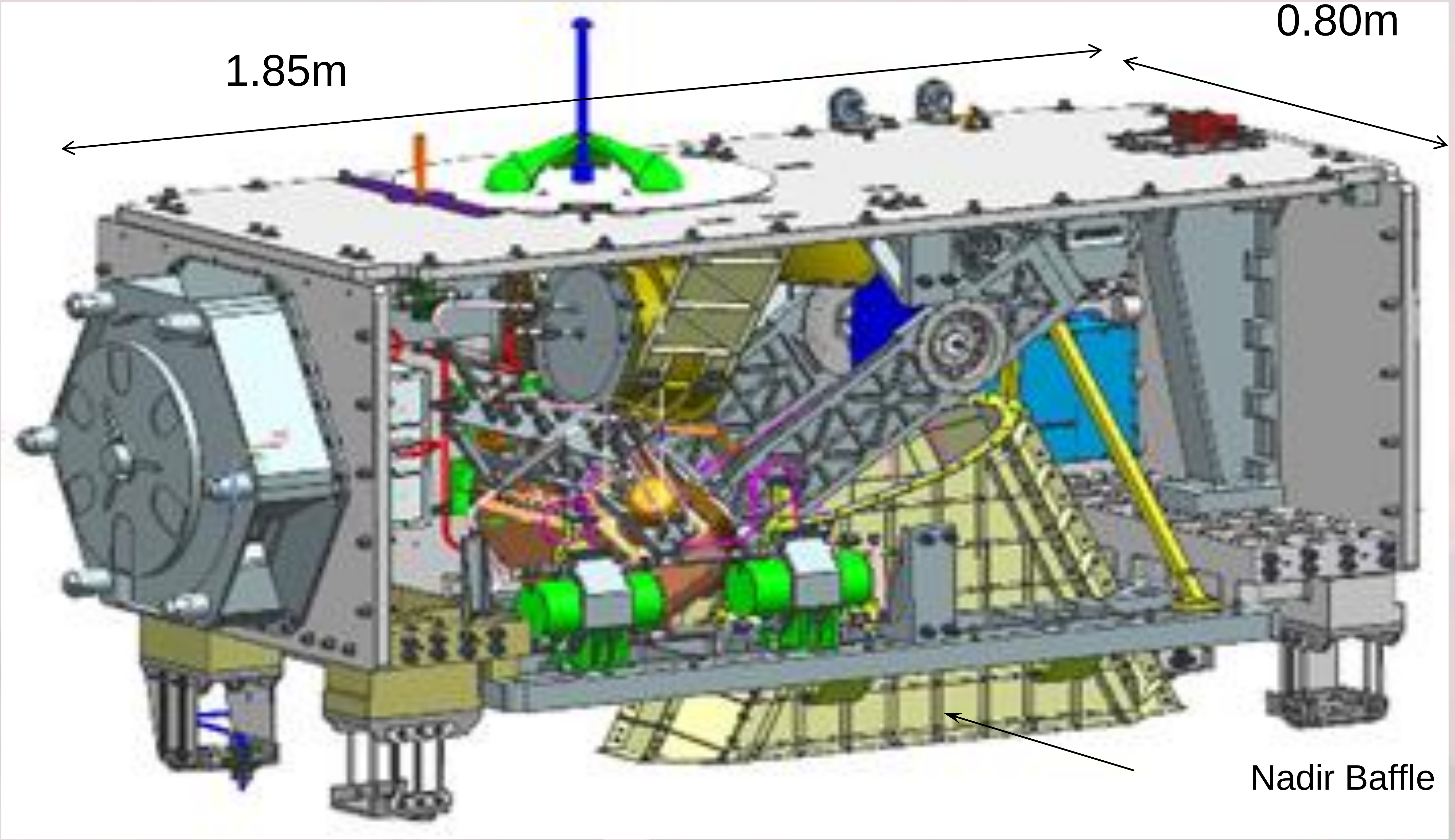
ECOSTRESS Instrument

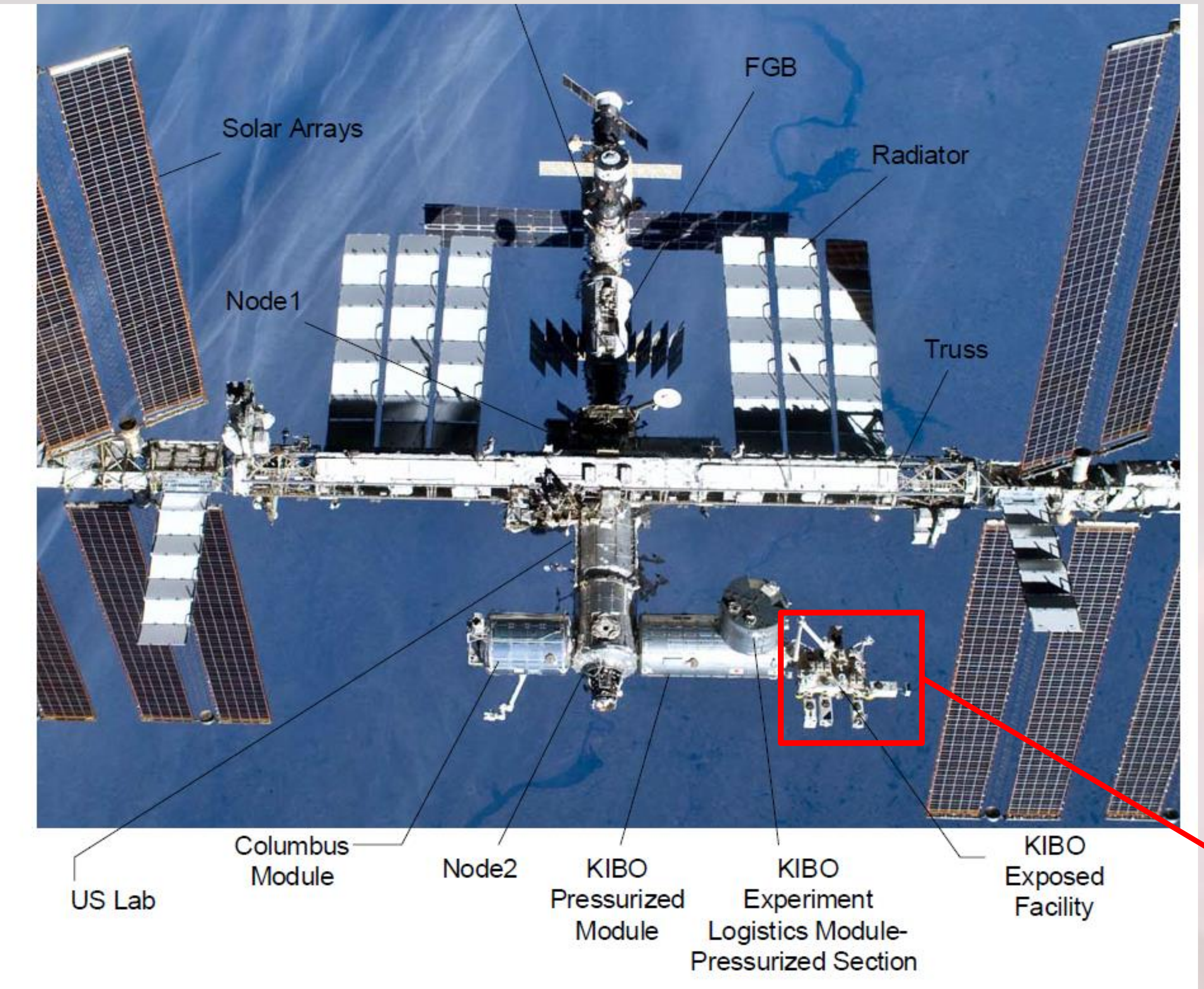




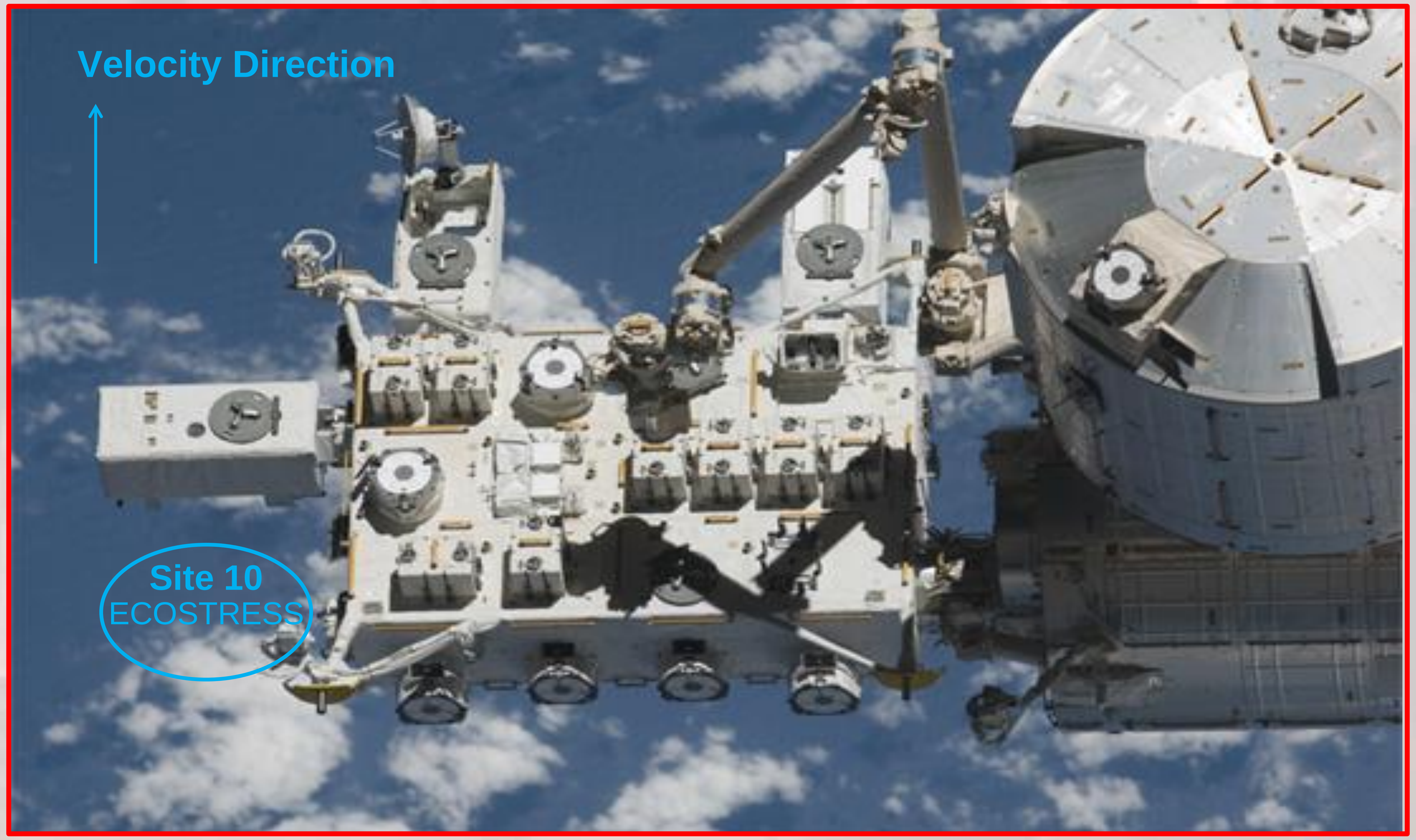
ECOSTRESS is an Earth Venture Instrument-2 on the ISS

- 8–12.5 μm Radiometer with a 400km swath, 60-m resolution
- Measure brightness temperatures of Earth at selected locations
- Launch April 2018 on SpaceX-15
- Deployed on the ISS on JEM-EFU 10
- Mission: 1 year

ECOSTRESS Thermal Environment



- ECOSTRESS will fly on the ISS and will be integrated with Japanese Experimental Module (JEM) Exposed Facility (EF) at site #10
- ISS orbital parameters
  - 278 km < altitude < 500km (150 nmi to 250 nmi)
  - 51.6° inclination orbit
  - $-75° < \beta < 75°$
- The payload is fully enclosed in an aluminum structure except
  - Grapple and H-Fixture
  - Payload Interface Unit (PIU)
  - Instrument Nadir baffle and WIFI Antennae (Nadir and Zenith)



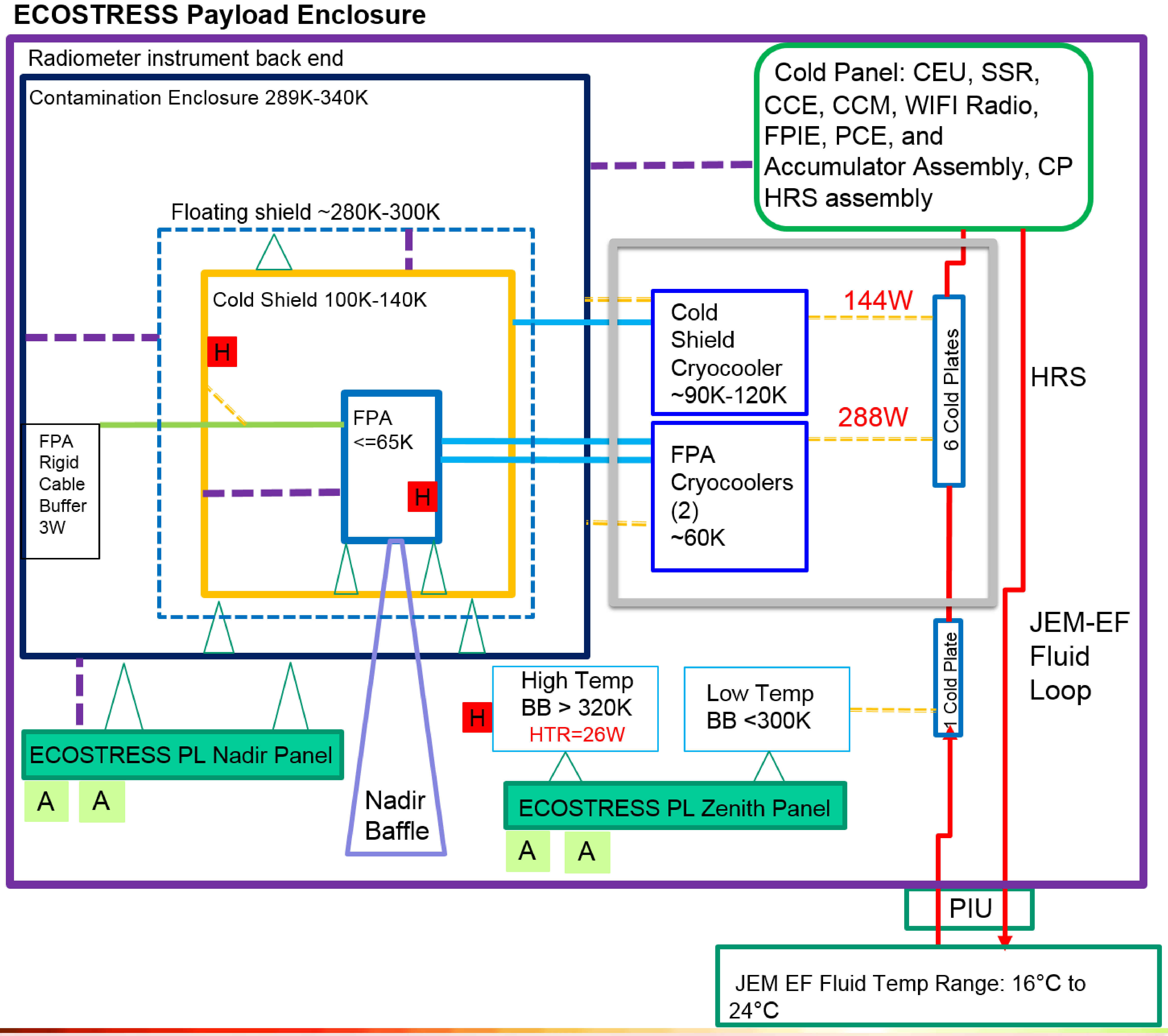
- The payload enclosure is covered in MLI

Required by JAXA
Beta cloth outer layer
$\varepsilon^* < 0.04$, $0.31 < \alpha < 0.6$, $0.85 < \varepsilon < .96$

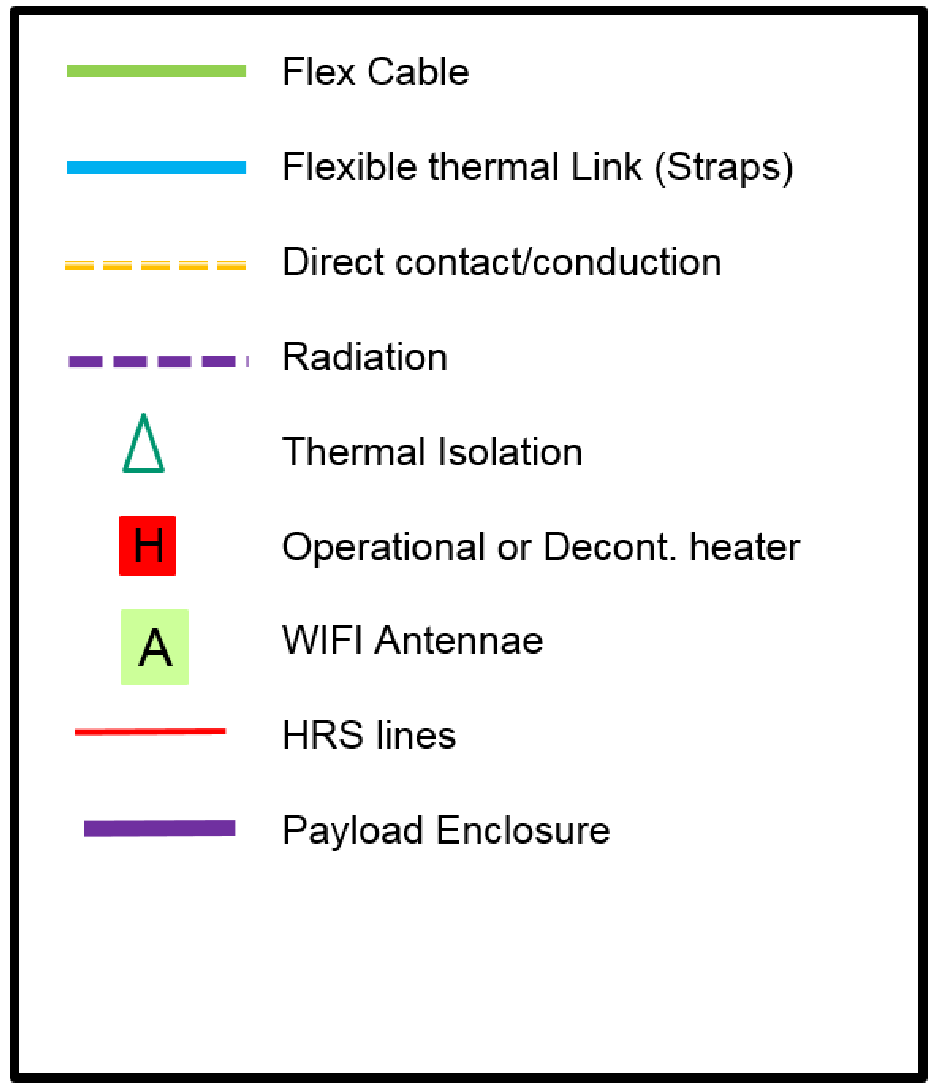
- JEM-EF provides a pumped fluid for heat rejection

Fluorinert liquid FC-72
Flow rate: 155kg/hr +18%/-0%
Supply fluid temp range: 16°C to 24°C
Return fluid temp range:16°C to 50°C

ECOSTRESS Thermal Control System Architecture



- Active Thermal Control: Three split-stirling Pulse Tube coolers are used to cool the FPA to <=65K and instrument cold shield to 100K-140K.
- Cryogenic staging: Cold shield and floating shield are used to minimize the radiation and conduction parasitic loads onto the FPA assembly

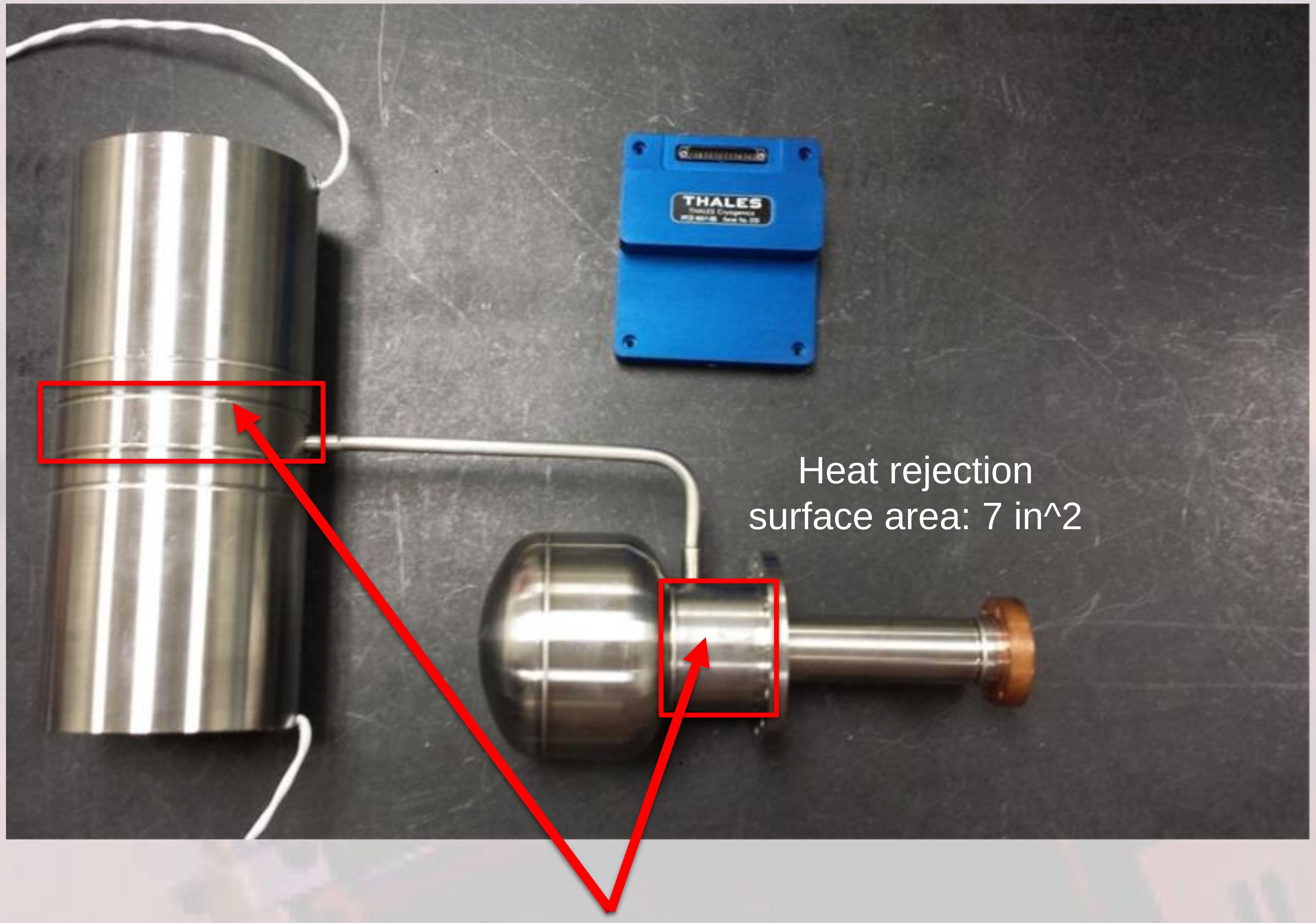


- The TCS is based on a pumped fluid loop with the fluid circulation provided by JEM-EF
- Radiometer FPA is cooled and temperature controlled by means of pulse tube cryocoolers
- Dedicated cold plate heat exchangers (HX) remove waste heat from cryocooler compressors (3), expanders (3), and low temp black body target (1)
- A "Cold Panel" is used to remove waste heat from ECOSTRESS payload bus components/units
- The fluid loop heritage of MSL and experience of CATS and OCO-3 is used in this TCS

Thermal Challenges

Challenges:

1. Cryocoolers generate waste heat up to 432W (144W per cooler). Maintaining cooler heat rejection surface temperature below **40°C** with **24°C** fluid sink temperature is a challenge.
2. Cooler performance is a strong function of heat rejection temperature. Performance degrades with higher reject temperature.
3. Non-planar geometry/surface at cryocooler heat rejection interface.
4. JEM-EF ATCS usage requirements and ISS fracture control requirements. (pressure drop, fluid compatibility, cleanliness, etc)



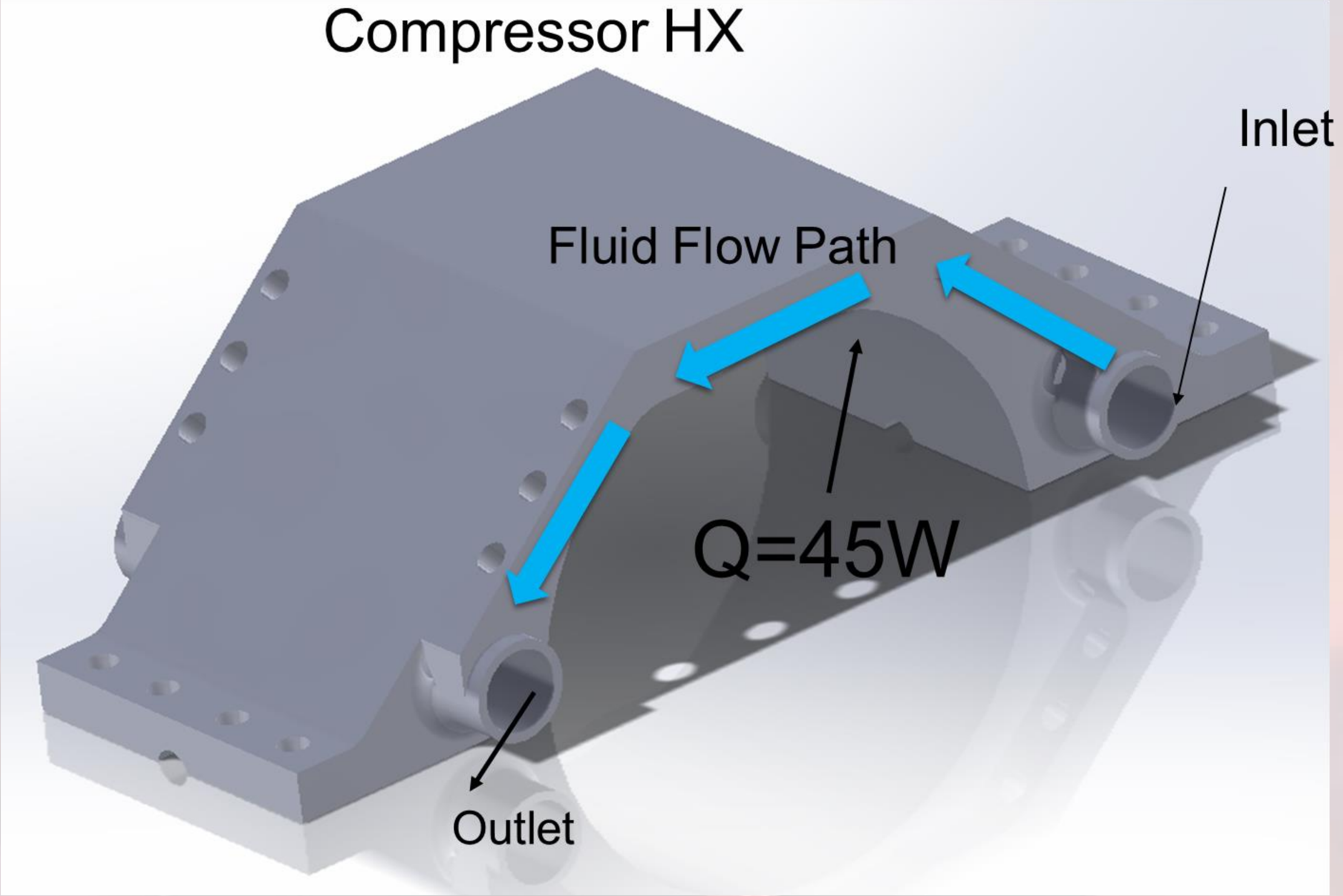
Non-planar (round) heat rejection interface

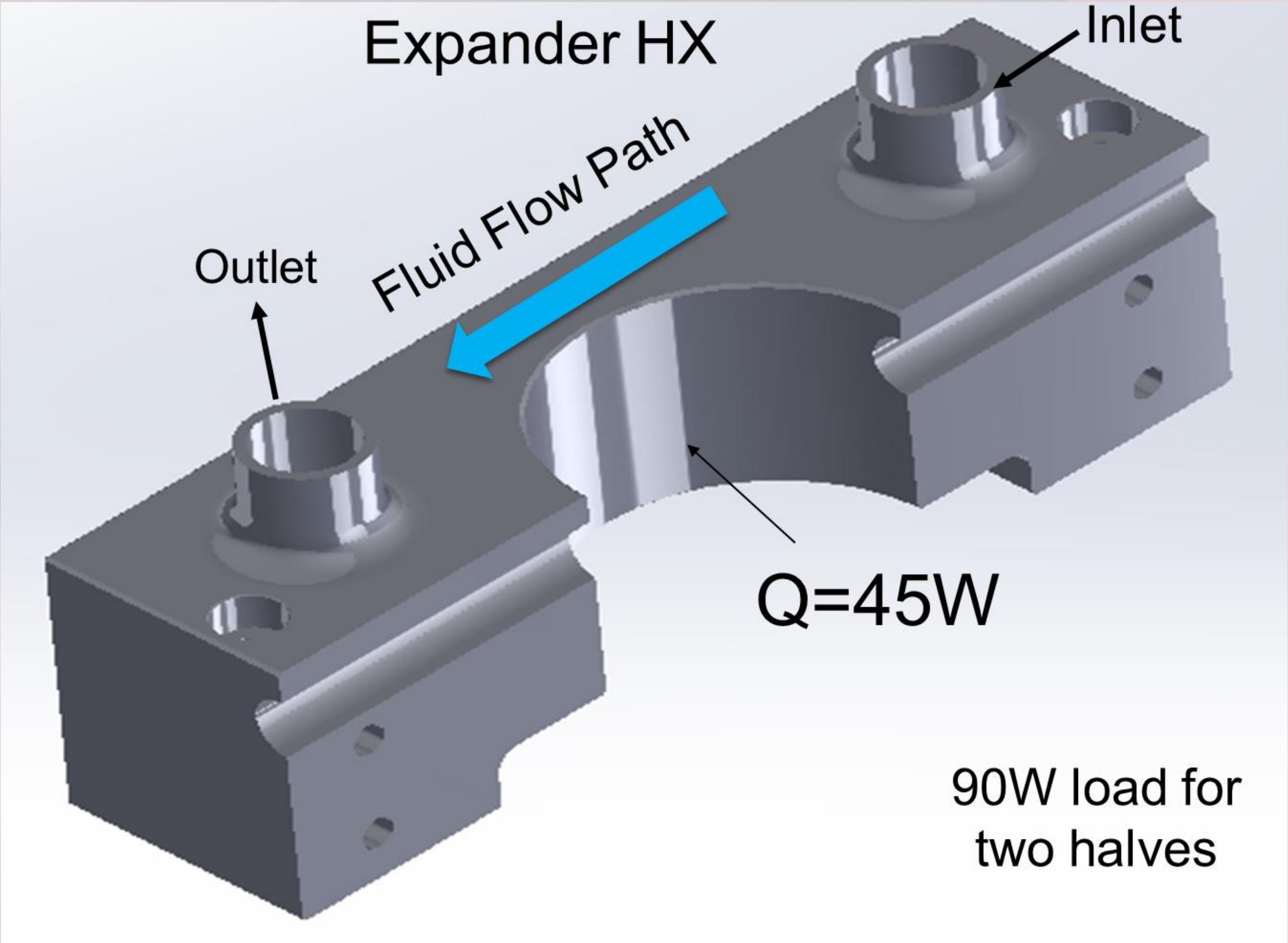
Finding the right thermal management solution was key to closing the ECOSTRESS thermal design

Liquid Cooled Cold Plate(LCCP) Requirements and Designs

Performance Requirements and Design Drivers	
Cold Plate Interface Type	Non-Planar
Pressure Drop	<0.2 PSI at 155 kg/hr
Mass Flow Rate	155 kg/hr
Coolant Temperature Range	10°C to 55°C
Heat Rejection Capability	90W per HX
Maximum Design Pressure (MDP)	227 PSI
Fluid Compatibility	Flouinert-72
Proof Pressure	1.5x MDP
Burst Pressure	2x MDP
Non Destructive Evaluation	Radiography and Dye Penetrant
Thermal Resistance	<0.09 C/W
Cold Plate Dry Mass	< 3 kg
Design life	3 years

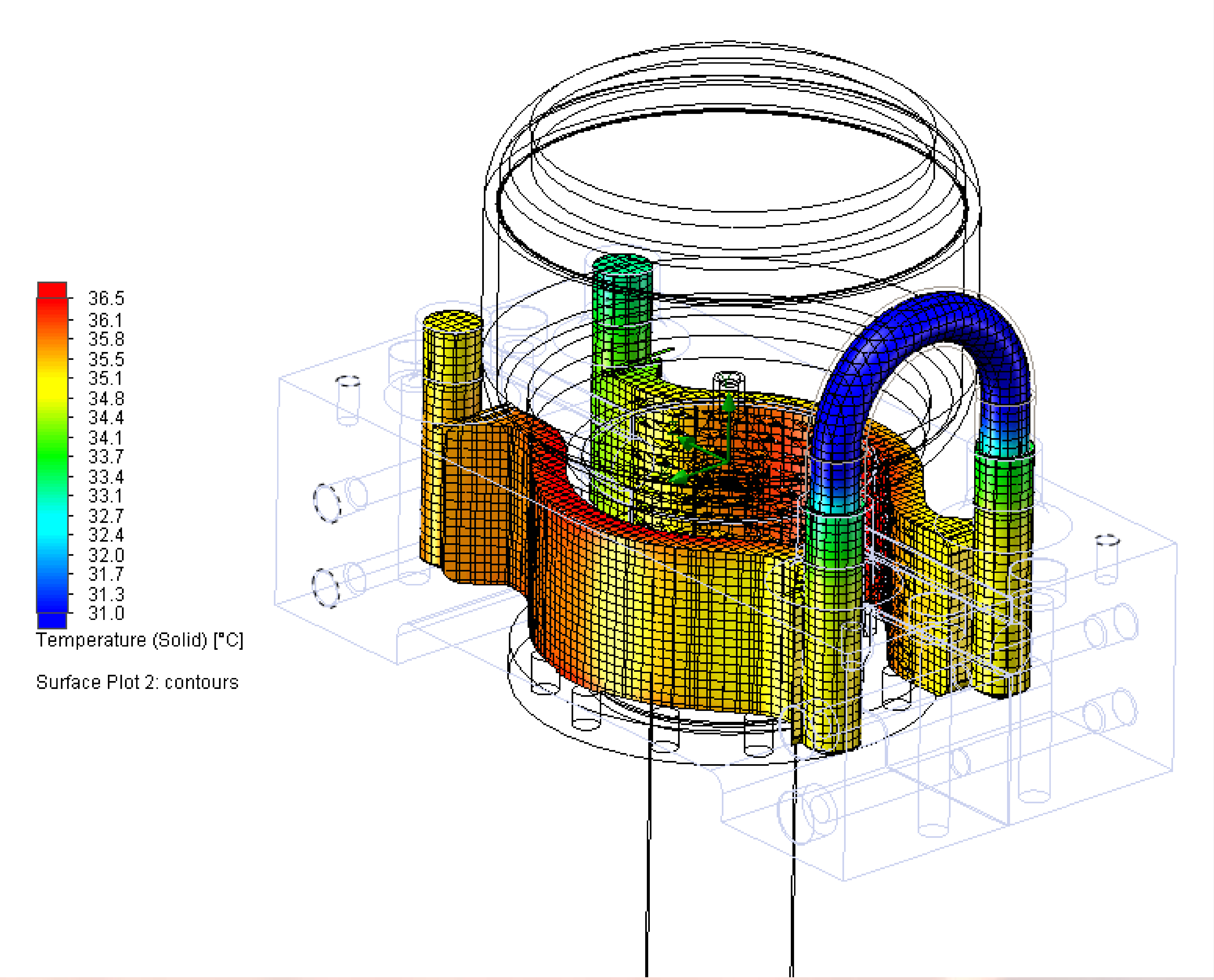
MaxQ Technologies selected as LCCP heat exchanger vendor and designed, built, and delivered qualification and flight units for ECOSTRESS project.





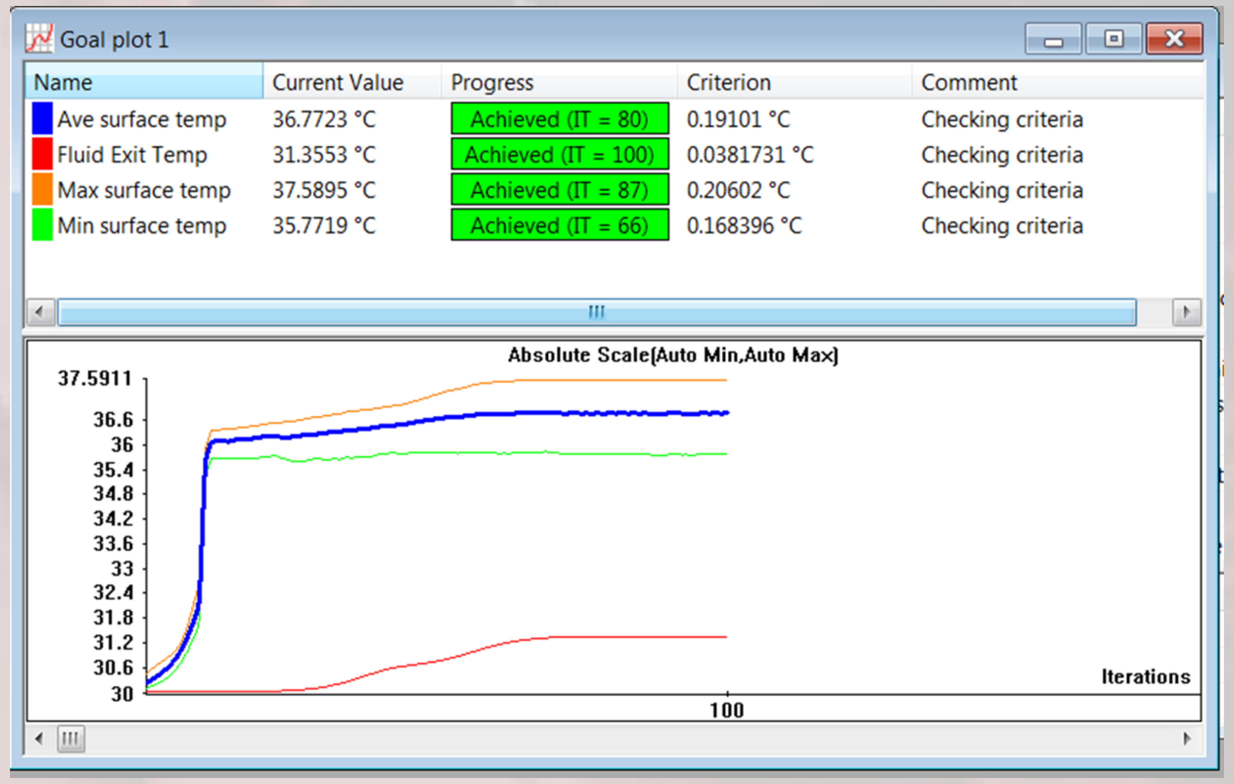
Thermal Fluid Modeling Simulation Tool: SolidWorks Flow

Number of total nodes: ~59,000



Modeling Capability

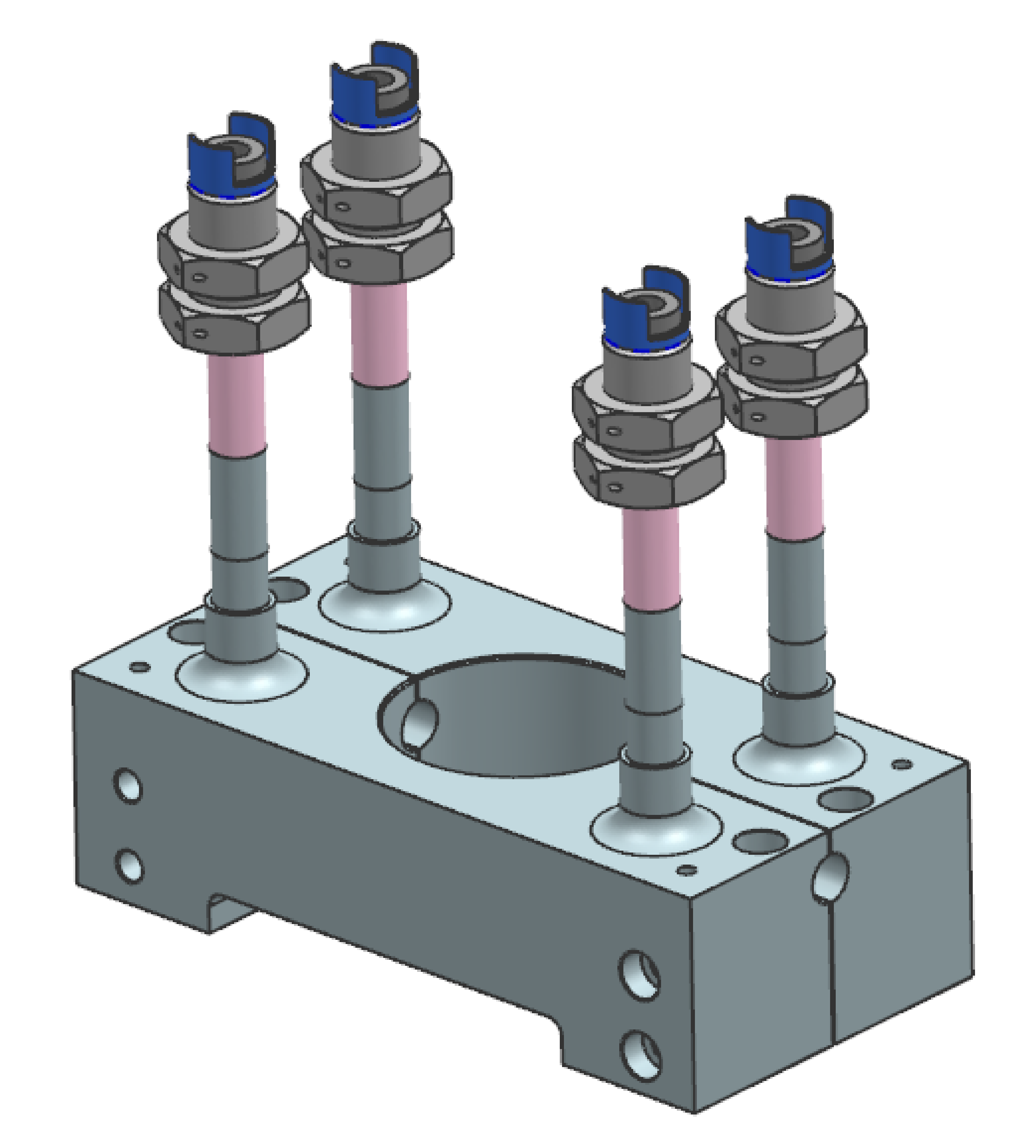
- Uses 3D CAD and CFD to solve thermal fluid problems
- Liquid and gas flow with heat transfer, laminar and turbulent flow
- Pressure drop and temperature estimates

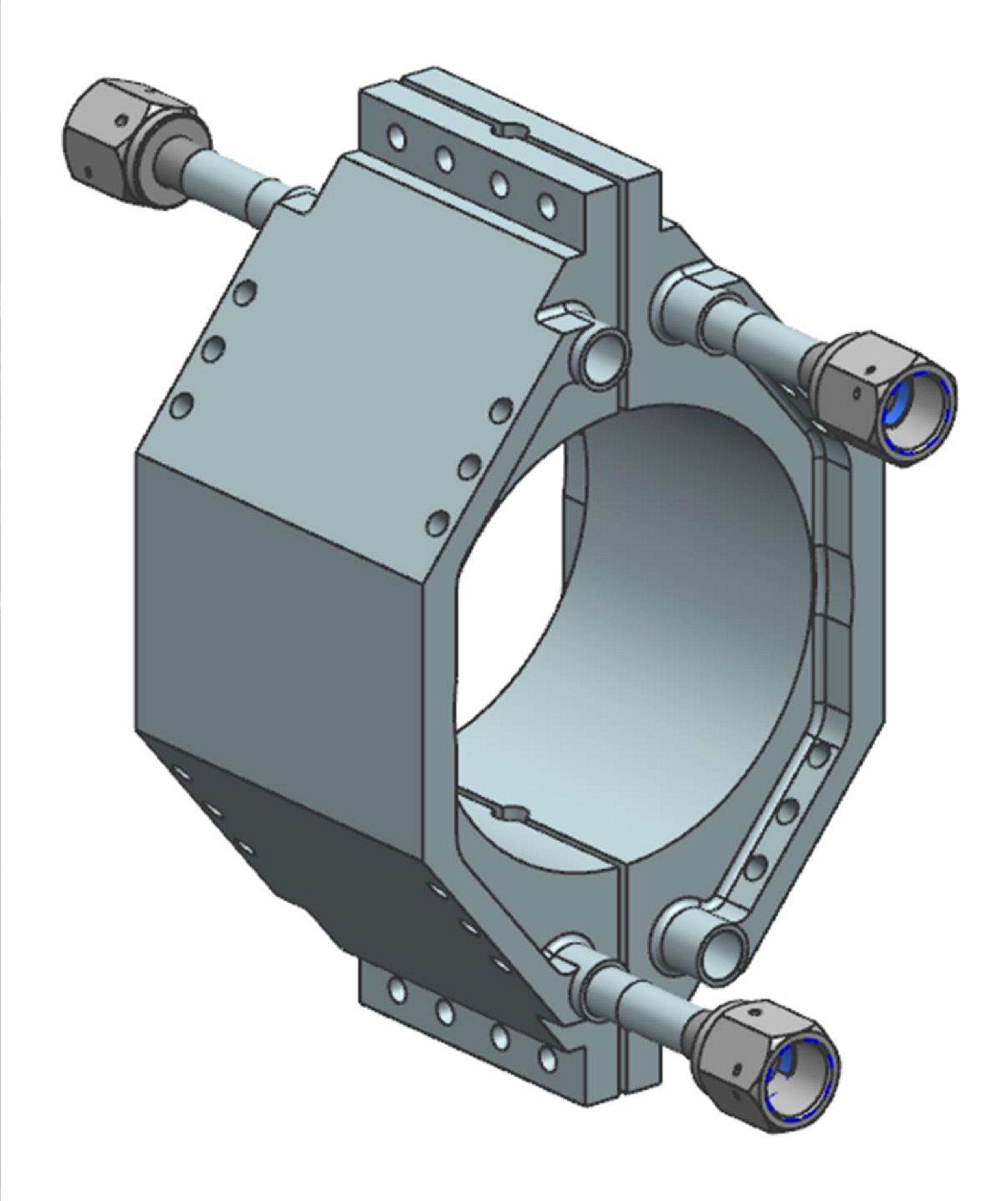


LCCP Heat Exchangers

- Heat exchanger design is
  - All aluminum 6061-T6 construction
  - Friction stir welded (FSW) assembly
- Fluid interface
  - Hand weld Al 6061 – SS 316 transition fitting
  - Orbital weld ¼” VCR fitting
- Maximum dissipation requirement: 90W per HX
- Fracture Control Plan
  - Weld qualification according to ASTM E8
  - Burst qualifying unit
  - Stress analysis at 1.5 and 2.0 x MDP
  - Leak-Before-Burst analysis
  - Proof to 1.5 x MDP
  - X-Ray and dye penetrant inspection of all welds

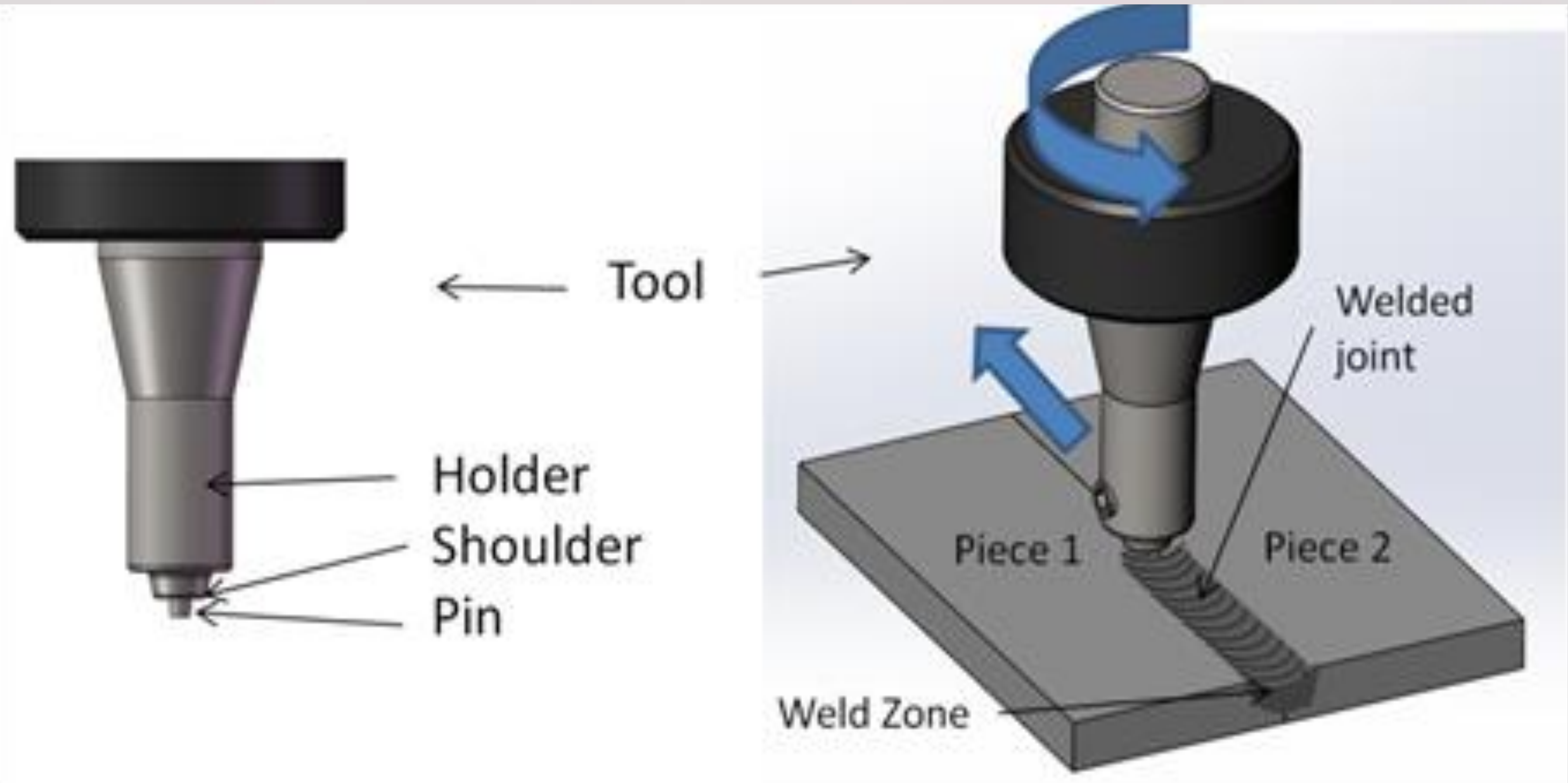
CAD Model





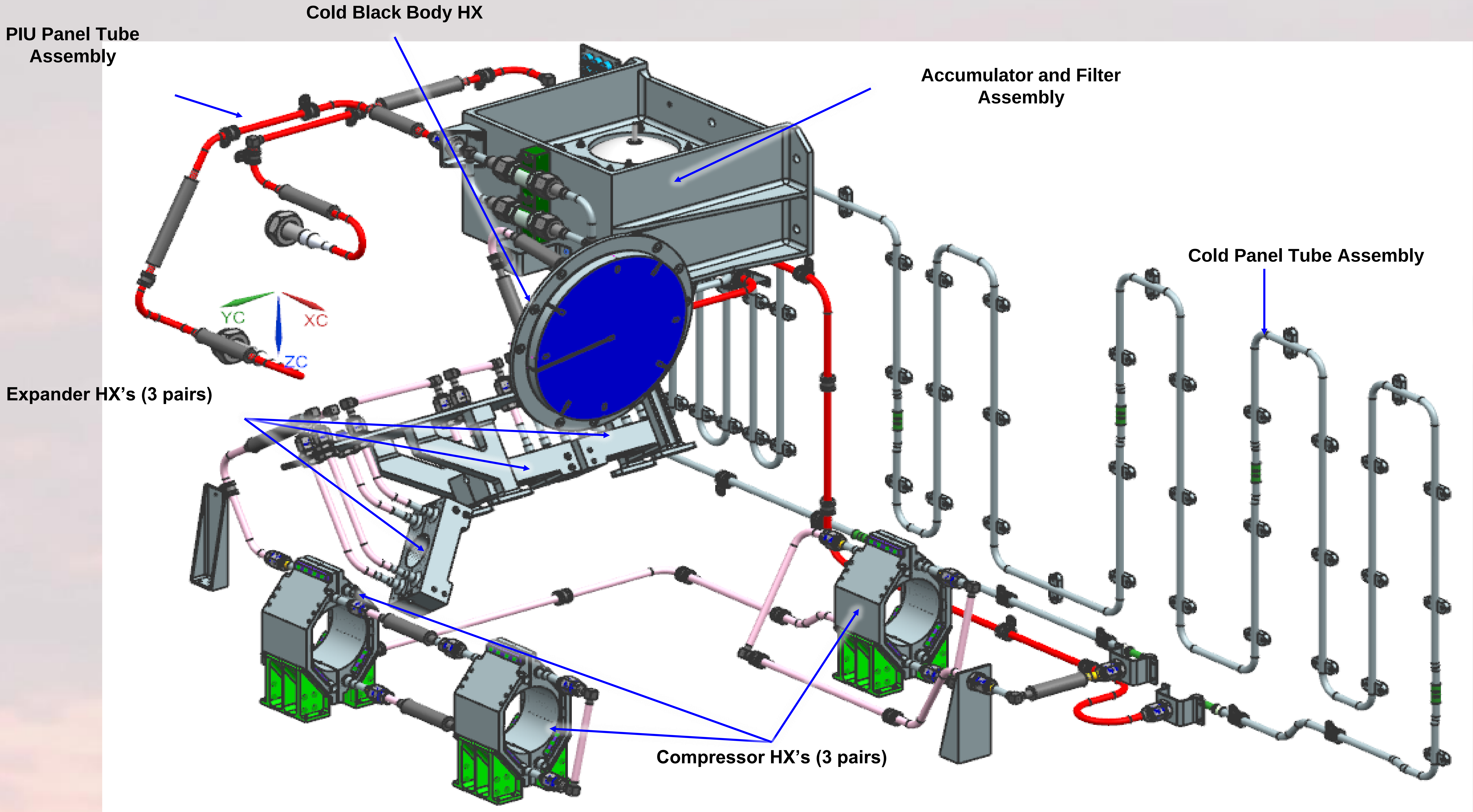
ECOSTRESS LCCPs

Friction Stir Welding Manufacturing Process

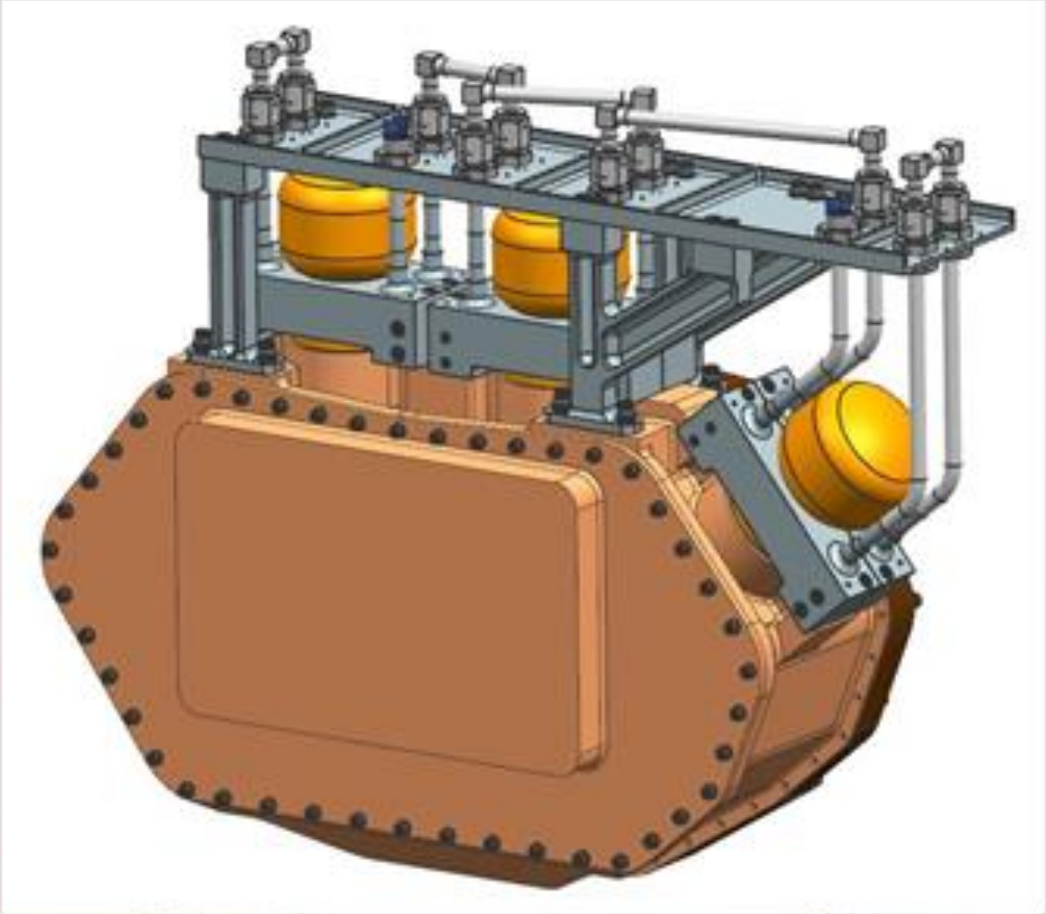


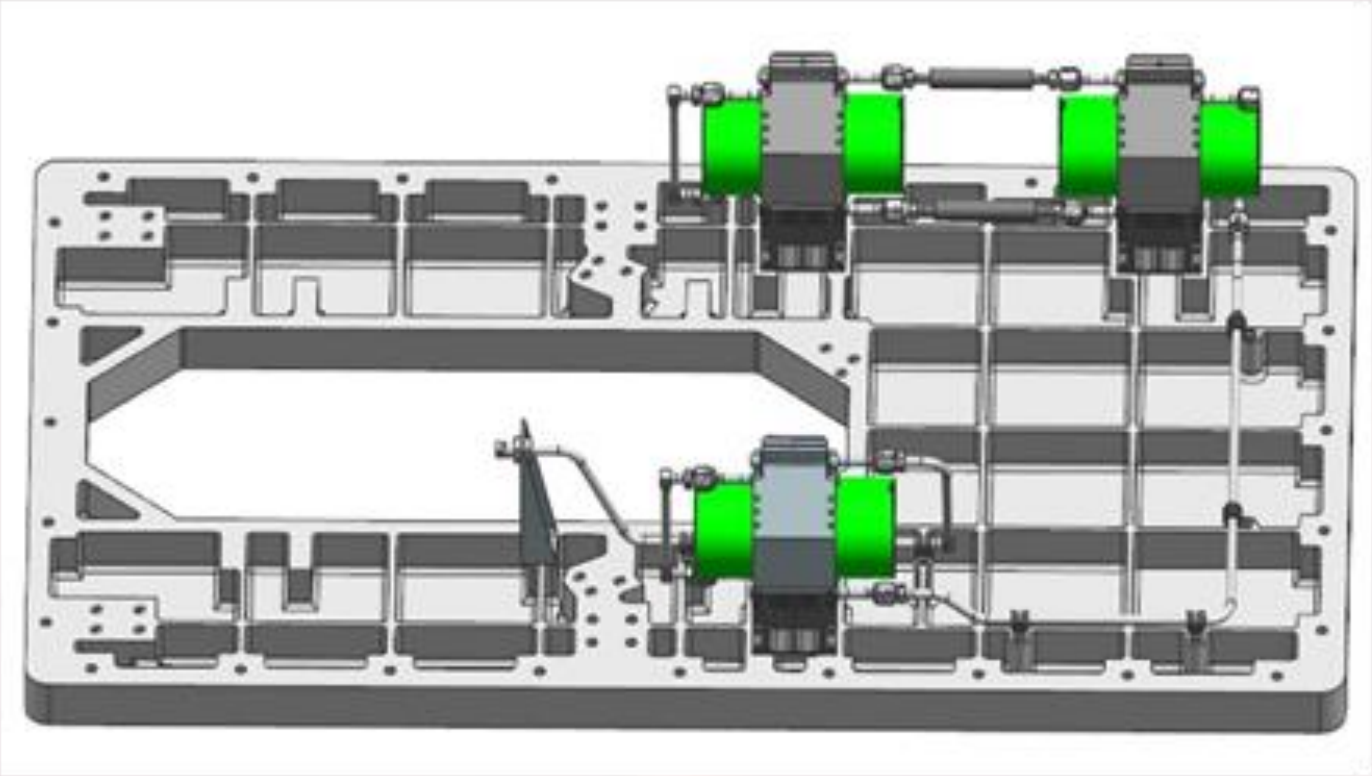
- Incorporates an advance Friction Stir Welding (FSW) manufacturing process to produce high-performance robust LCCP structures
- Process involves local heating, plasticizing and mixing of two adjacent metals to form a monolithic structure with mechanical and thermal properties very close to the parent material, often a 6061-T6 alloy.
- The major advantage of FSW compared to conventional aluminum welding and brazing operations is that it does not require the use of any filler material.

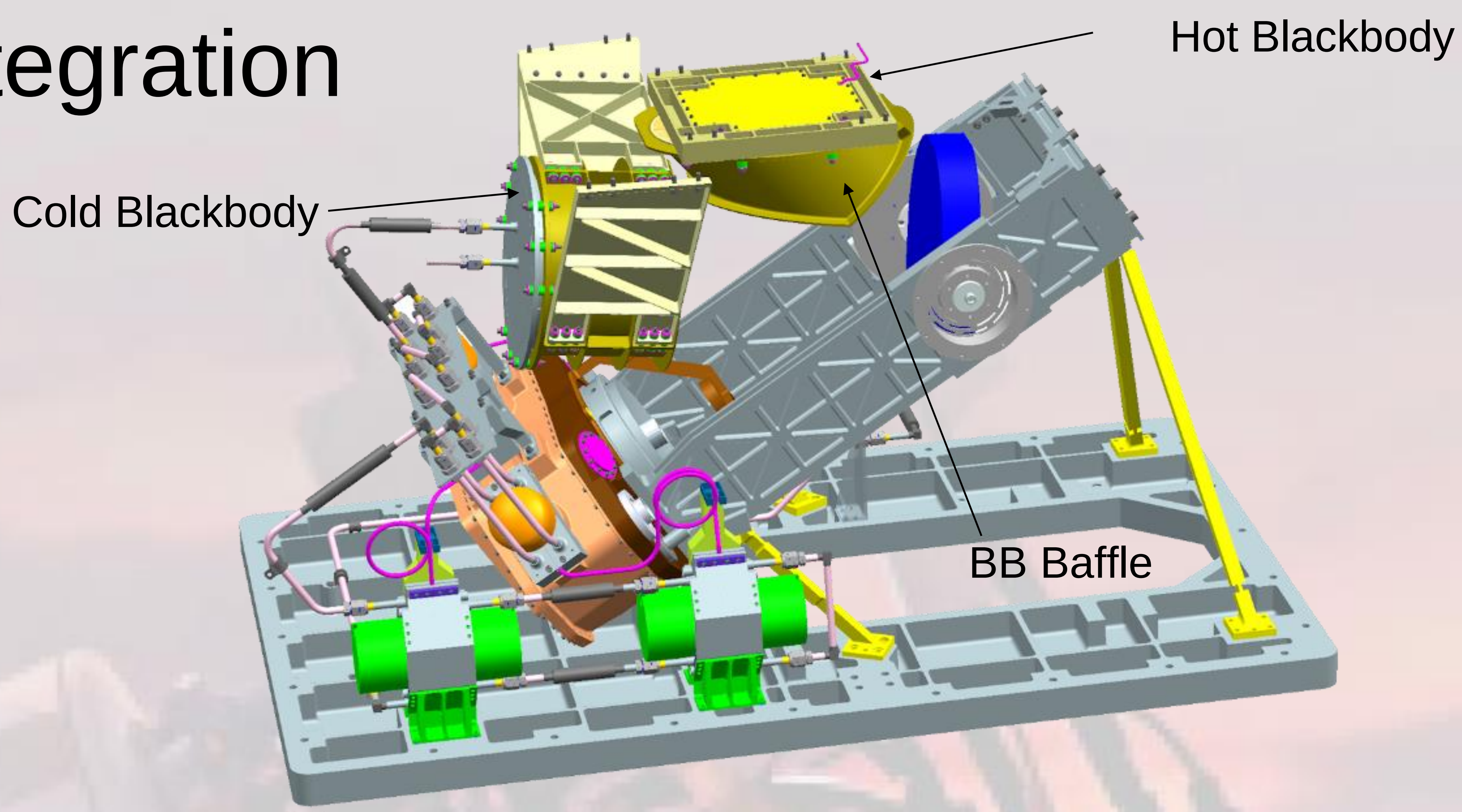
Heat Rejection System

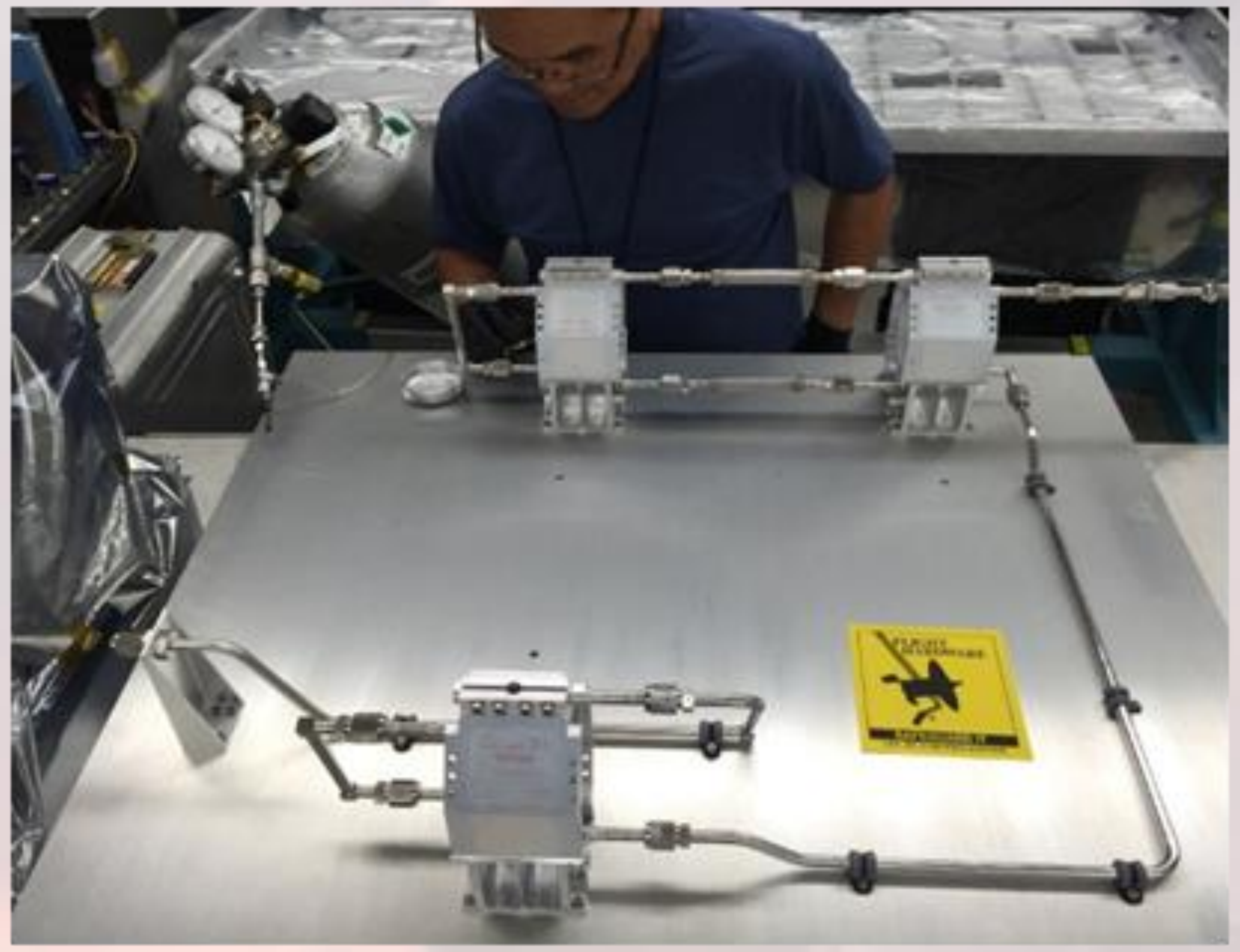


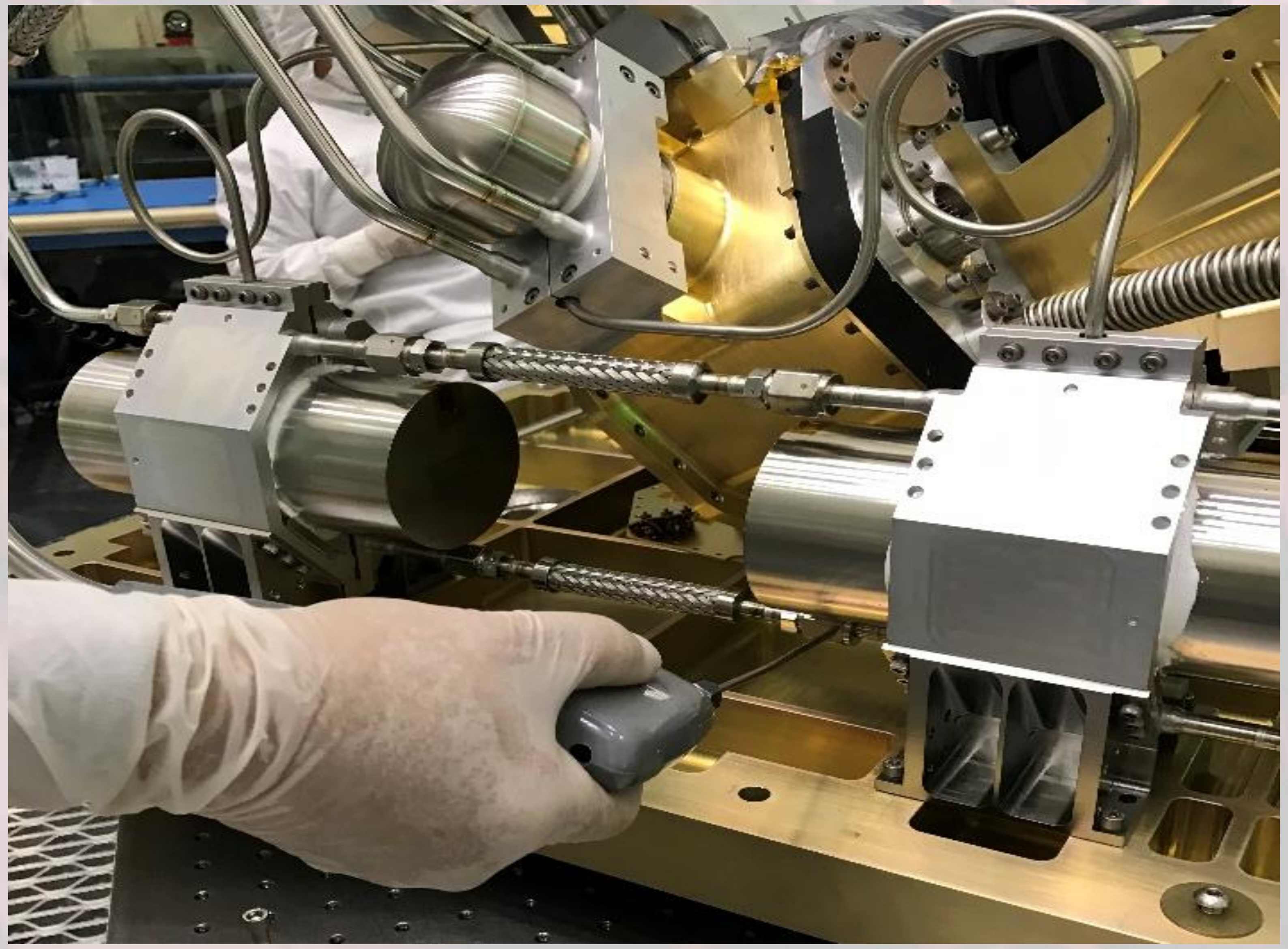
Flight Hardware Integration





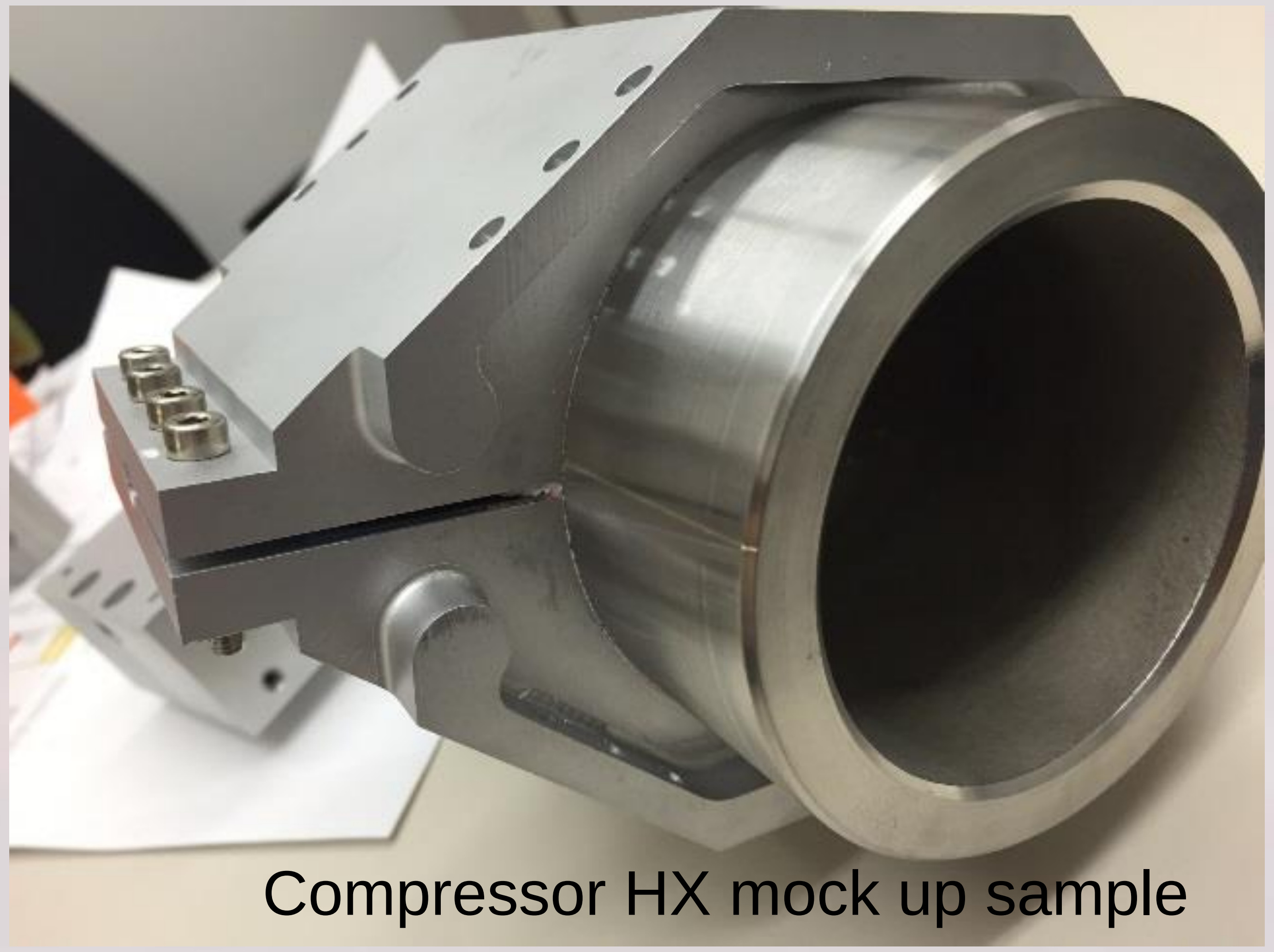


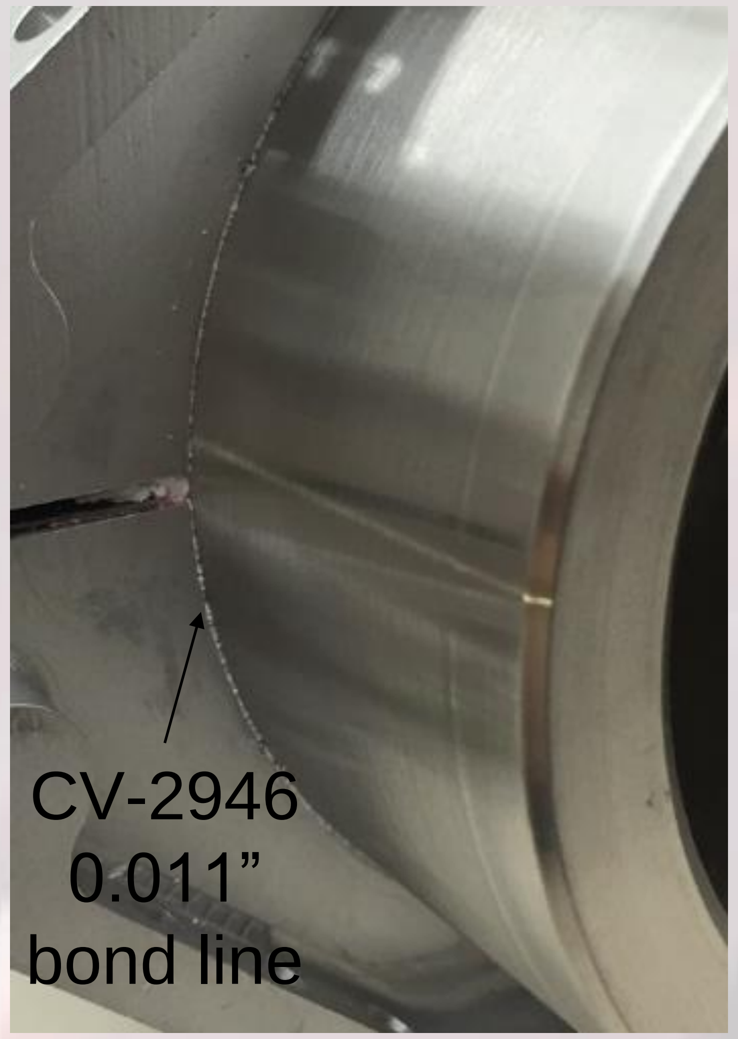


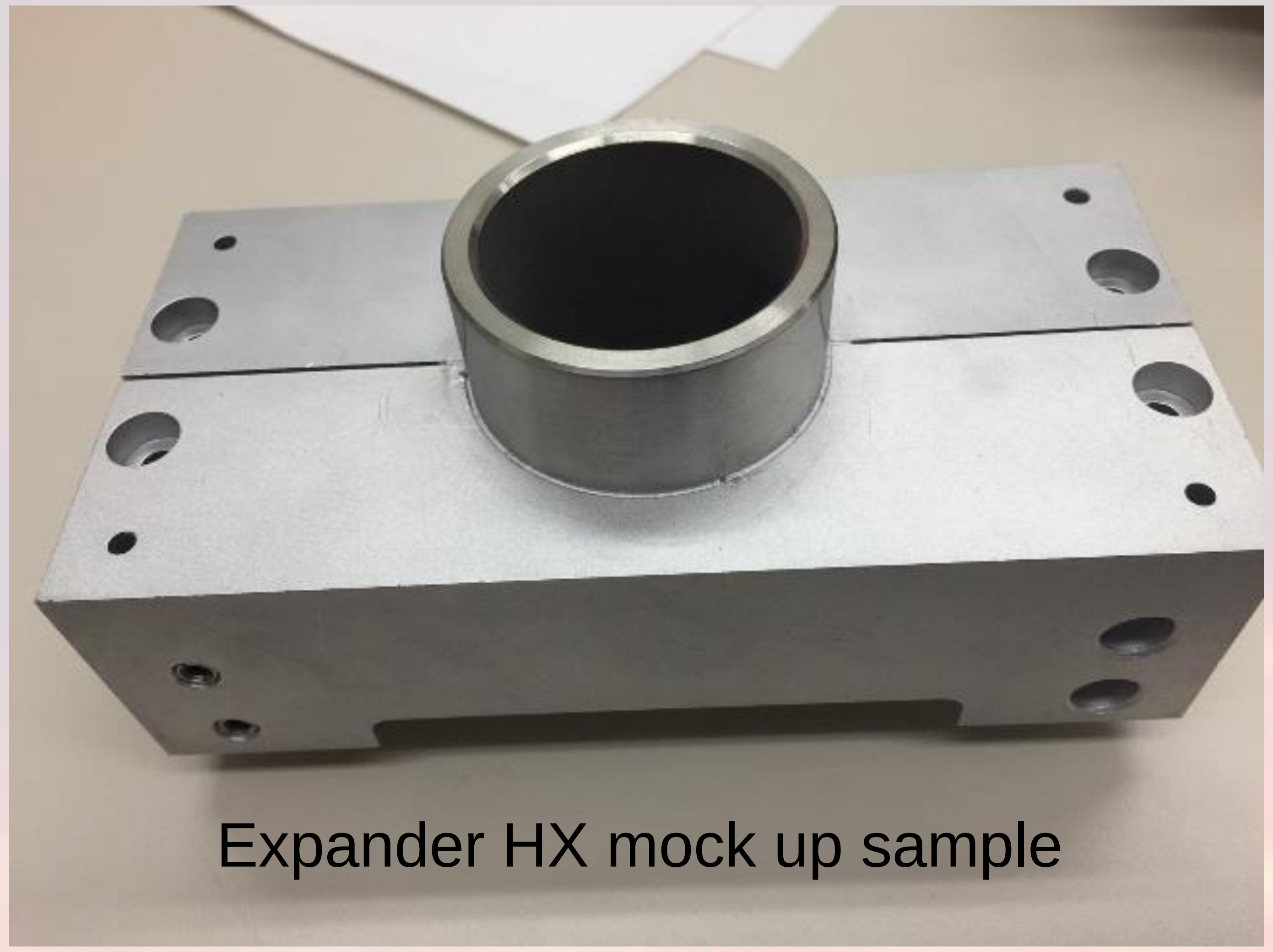


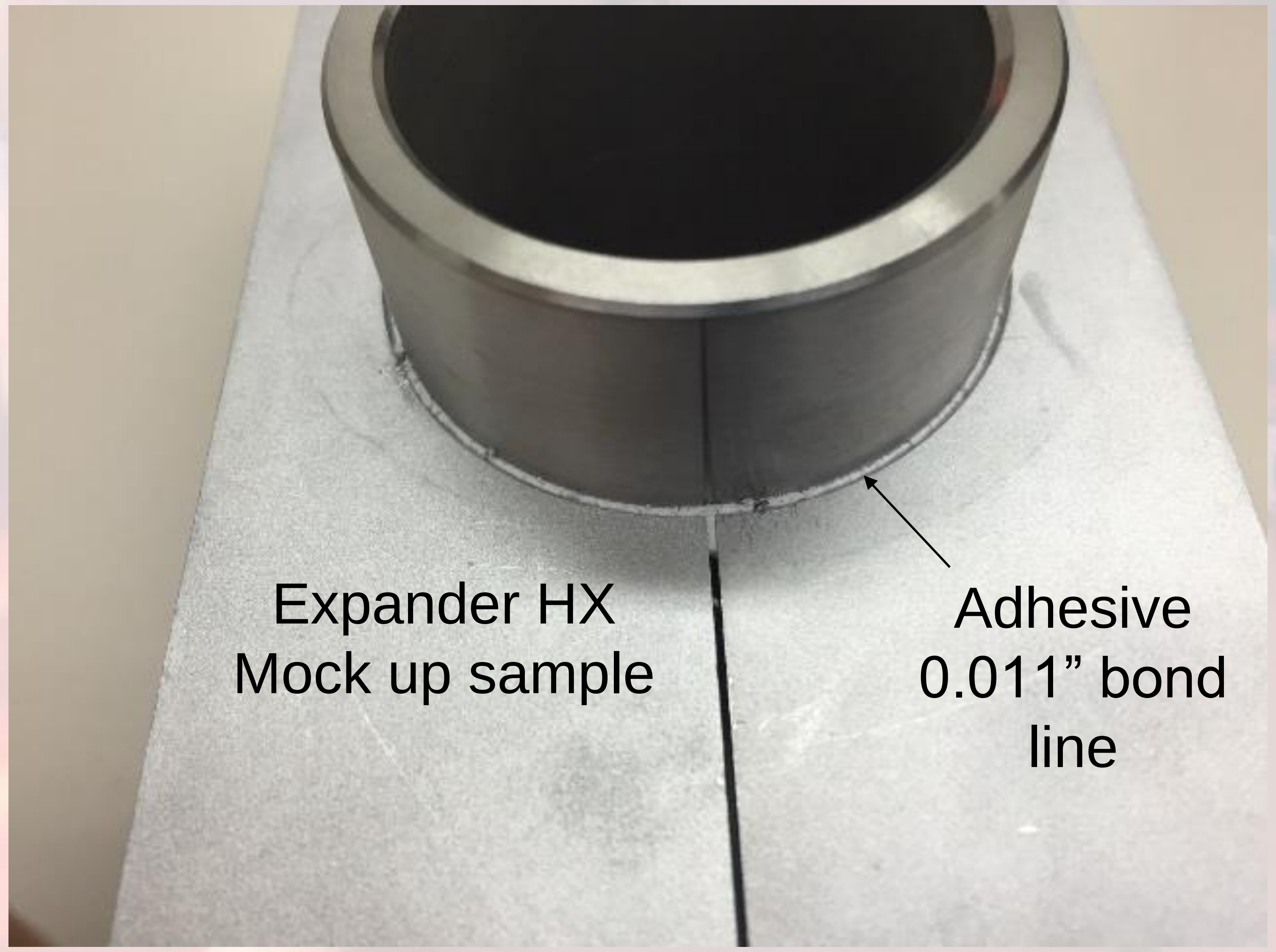
Tooling and assembly fixtures used to fabricate the cryocooler expander LCCP assemblies. CAD model and expander LCCP assembly fixture (left) and compressor LCCP assembly (middle).

Thermal Interface Material Installation Verification Test



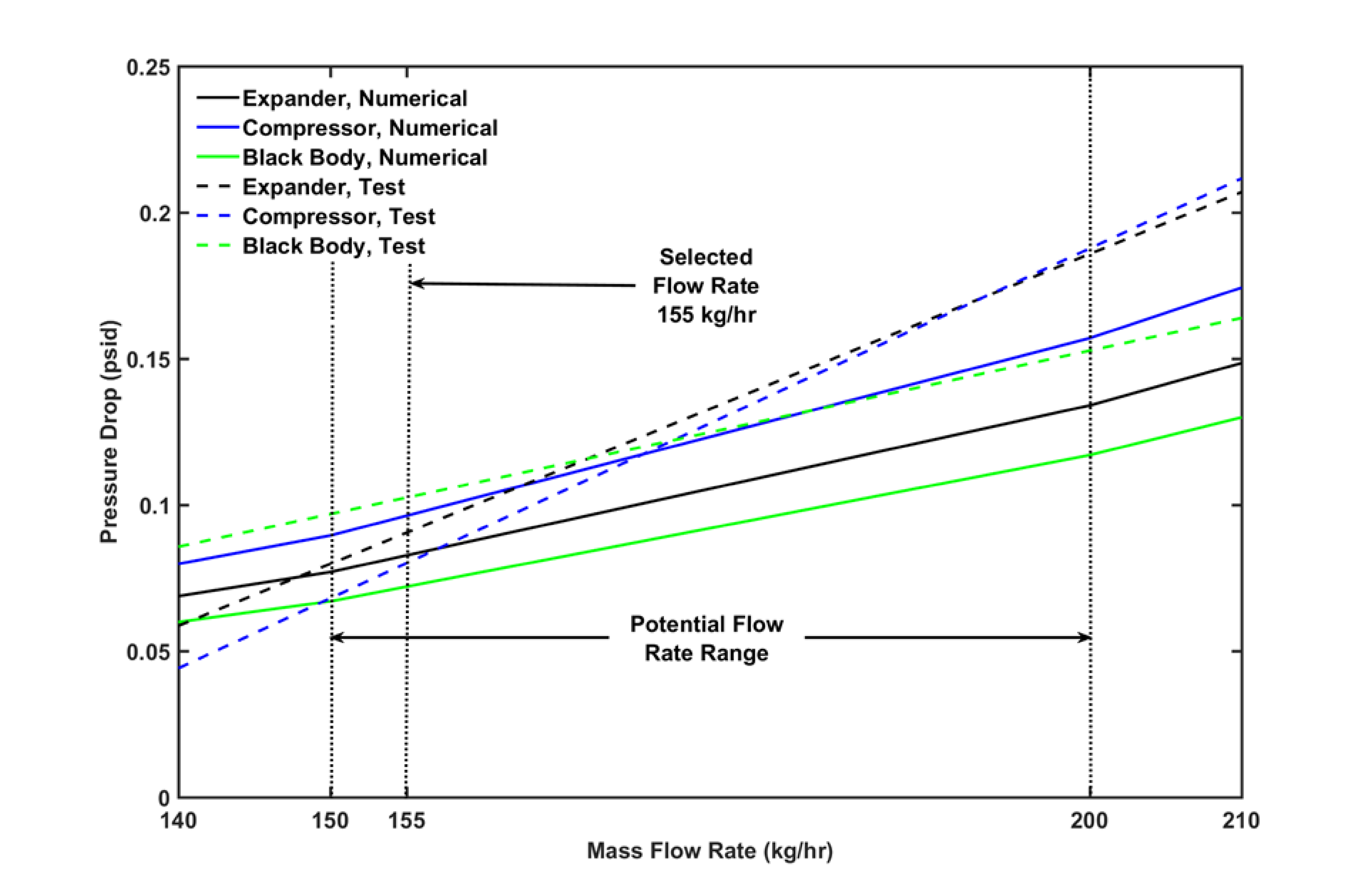






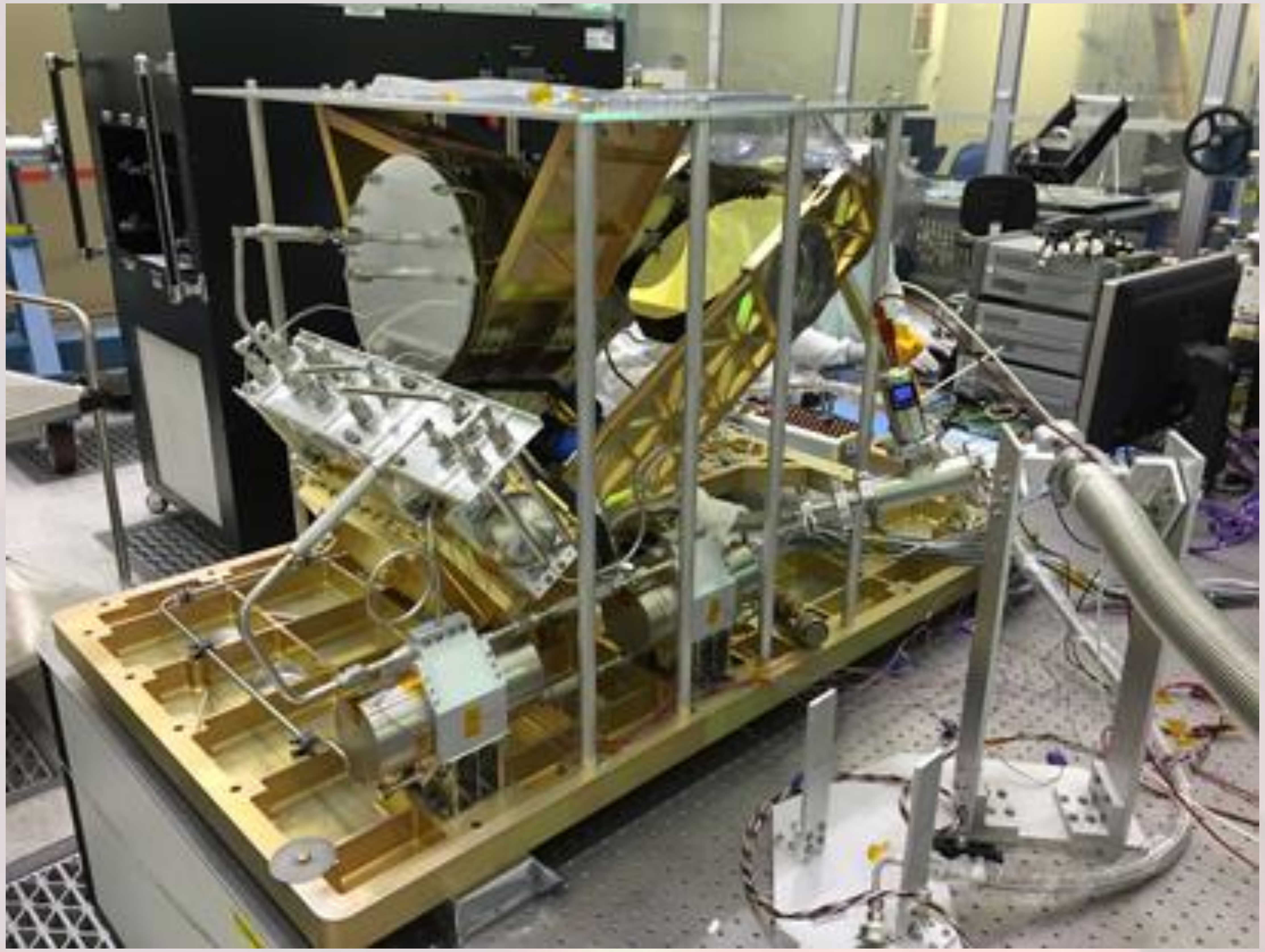
- TIM installation verification performed with mock up unit
- Adhesive material: Nusil CV-2946
- Bond line thickness: controlled via 11 mils wire
- Successfully installed TIM
- Cure time: 7 days in ambient condition or 2 hrs in oven at 65C or **5 to 6 hrs at 50C**.

Hydraulic Performance Test and Results



Pressure drop test bed used for measuring heat exchanger pressure drop across a range of fluid mass flow rates.

Radiometer Thermal Test



Radiometer Telescope Assembly Thermal Test Configuration.

Thermal Parameters	Expander Cold Plate	Compressor Cold Plate
Cold Plate Inlet Fluid Temperature, K	289.15	292.37*
Cold Plate HX Skin Temperature, K	292.20	294.87
Waste Heat Dissipation, W	52	48
Thermal Resistance between fluid and HX Skin temperature, C/W	0.057	0.052
FPA Cooler 1 Expander Skin Temperatures, K	296.77	N/A
FPA Cooler 1 Compressor Skin Temperatures, K	N/A	298.2

*calculated using measured cooler power and mass flow rate, and fluid intrinsic properties.

All requirements met

ISS Fracture Control

Performance Requirements and Design Drivers		maxQ LCCPs
Cold Plate Interface Type	Non-Planar	Non-Planar
Pressure Drop	<0.2 PSI at 155 kg/hr	<0.1 PSI at 155 kg/hr
Mass Flow Rate	155 kg/hr	155 kg/hr
Coolant Temperature Range	10°C to 55°C	10°C to 55°C
Heat Rejection Capability	90W per HX	90W per HX
Maximum Design Pressure (MDP)	227 PSI	227 PSI
Fluid Compatibility	Flouinert-72	
Proof Pressure	1.5x MDP	Pass: 1.5xMDP
Burst Pressure	2x MDP	Pass: 2xMDP
Non Destructive Evaluation	Radiography and Dye Penetrant	Pass
Thermal Resistance	<0.09 C/W	<0.09 C/W
Cold Plate Dry Mass	< 3 kg	0.64 kg (exp) and 0.96 kg (comp)
Design life	3 years	6 years

Conclusions

- Non-planar liquid cooled cold plates have been successfully designed, developed, and tested for use in ECOSTRESS Instrument thermal fluid system.
- An advance friction stir welding manufacturing technique enabled compact packing with a non-planar interface.
- The hydraulic and thermal performance test results were excellent and repeated performance was demonstrated over a range of FC-72 fluid temperatures (16°C to 24°C).
- The cold plates performed better than anticipated and met all performance and JEM-EF and ISS requirements.
- The cold plates developed and provided by MaxQ Technology has been demonstrated to be robust, having high thermal performance, and appear to be suitable for space applications.
- Cryocoolers has positive technical margin
- The system level thermal control system design will be verified in Payload TVAC testing which is planned for summer 2017.

Acknowledgements

- ECOSTRESS Project team members and JPL.

Backup

Blackbody Calibration Target Thermal Design