STP Presentation May 2021

The Active Thermal Architecture: Active Thermal Control for Small-Satellites

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Jet Propulsion Laboratory
California Institute of Technology

UtahStateUniversity

SSTP
Small Spacecraft Technology Program

Presentation Outline

Active Thermal Architectures (ATA)

- Overview of our team (Swenson)
- Brief Description of the technology (Swenson)
- Current results and status (Anderson)
- Potential next steps (Anderson)
- Audience Q&A

ATA Team

ATA Team

- **Charles Swenson,**
  - ECE Professor USU
- **Lucas Anderson**
  - ECE PhD USU
- **A.J. Mastropietro**
  - Jet Propulsions Laboratory
- **Jonathan Sauder**
  - Jet Propulsions Laboratory

ATA Facilities

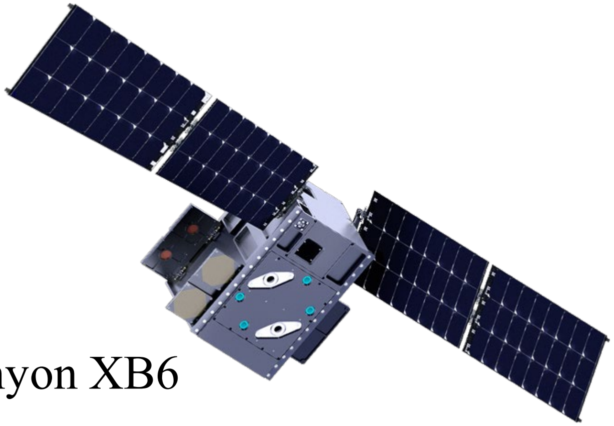
- Utah State University
  - Center for Space Engineering
- Jet Propulsions Laboratory TVAC Facilities
- ASTRA Space TVAC Equipment
- Rocky Mountain Testing
- Thermal Management Technologies

ATA Control Algorithm

Randy Christenson,
Associate Professor, Electrical Computer Engineering, USU
Bruno Henrique Mattos
PhD Student, Electrical Computer Engineering, USU

Technology Need

- **Thermal Control of CubeSats**
  - Low Power: Body mounted solar panels
  - High Power: Deployed solar panels
- **Need to dissipate the resulting thermal energy.**
  - Point sources of power
    - Cryocooler
      - Cryogenic Instrumentation
    - Intensive computing
      - Software defined radio
      - Onboard processing
    - Continuous RF transmitters
      - Radar



Blue Canyon XB6

CubeRRT (CubeSat Radiometer Radio Frequency Interface Technology) Concept

UtahStateUniversity Jet Propulsion Laboratory California Institute of Technology

Potential Solutions

- **1) Conduction**
  - Passive

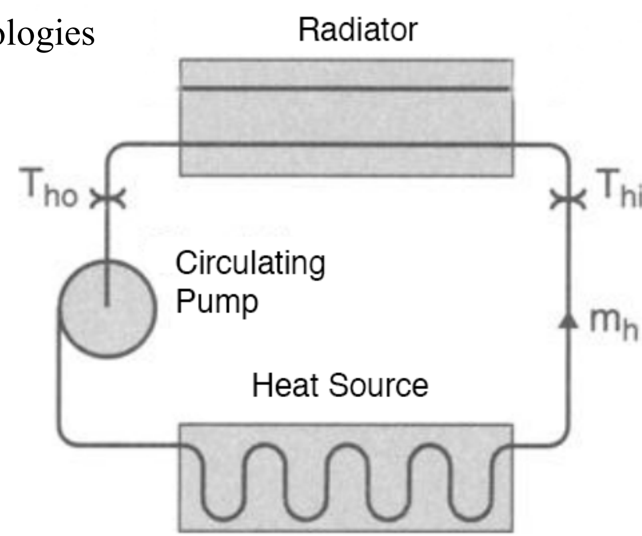
Thermal Management Technologies

- **2) Heat Pipe**
  - Passive
  - Limited range

Advanced Cooling Technologies

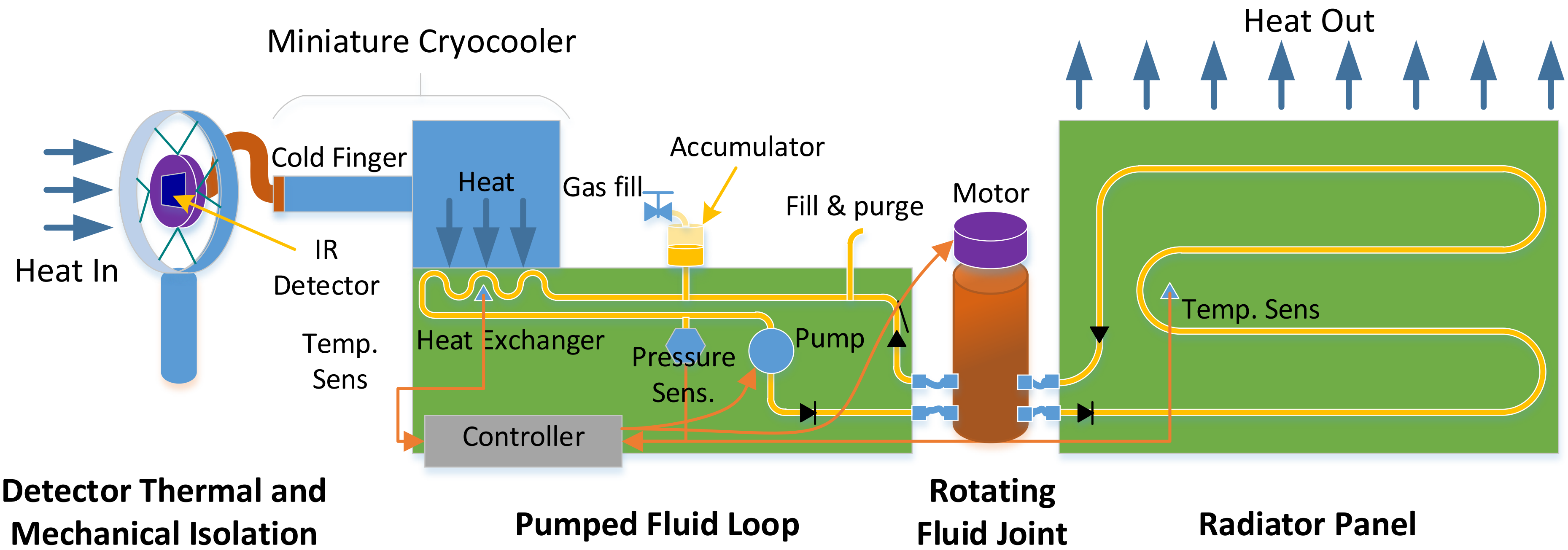
- **3) Pumped Fluid**
  - 0.25 to 1.25 W input
  - 10 to 80 W thermal
  - 0.3 U volume

Active Thermal Architectures



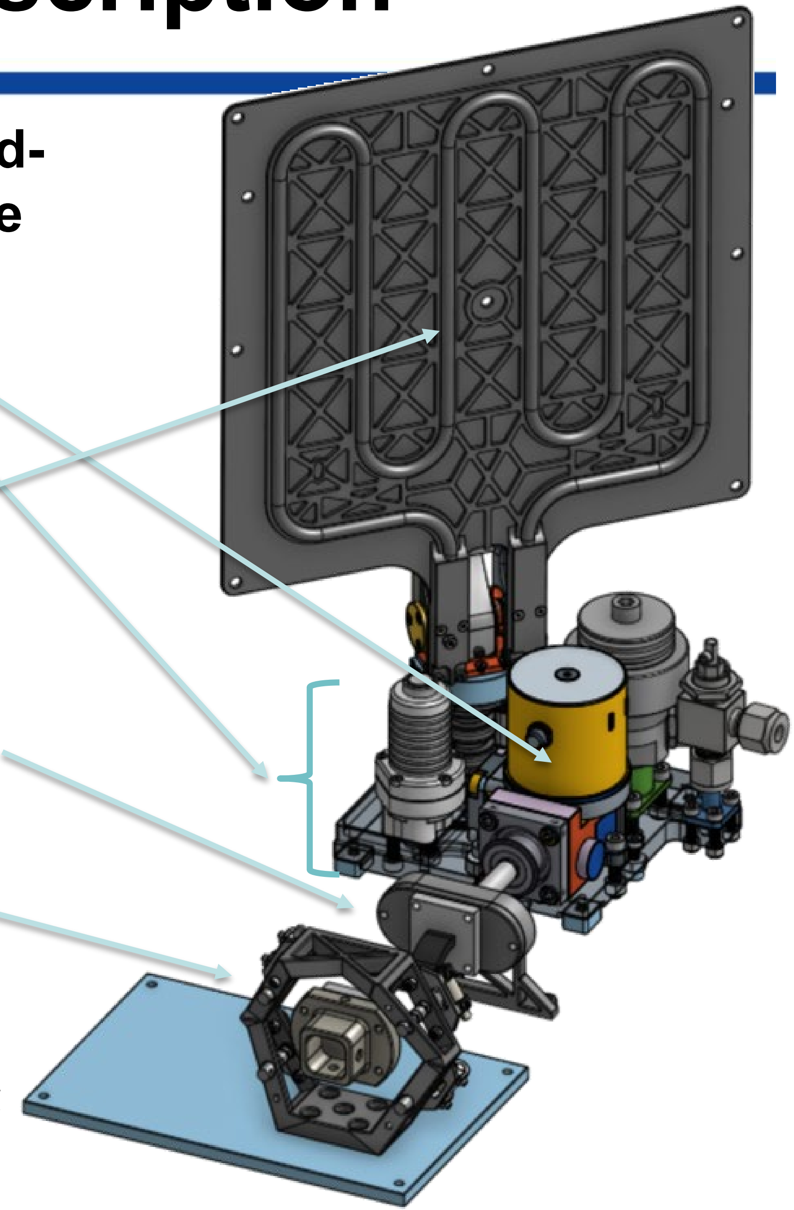
Principle of Operation

The ATA project has demonstrated a pumped fluid loop to support a cryocooler as the thermal load which cool an IR payload on a 6U CubeSat



Technology Description

- **The ATA project has developed a ground-based prototype with a cryocooler as the thermal load:**
  - A Ricor tactical cryocooler
  - Heat exchanger and pump assembly
  - A 4U deployable tracking radiator
  - A prototype miniature piston fluid accumulator
  - Integrated passive vibration isolation & damping
  - A prototype electro-optical isolation mount



The ATA project utilizes advanced 3D rapid fabrication techniques such as UAM, DMLS, PEEK, and PLA along with traditional fabrication techniques.

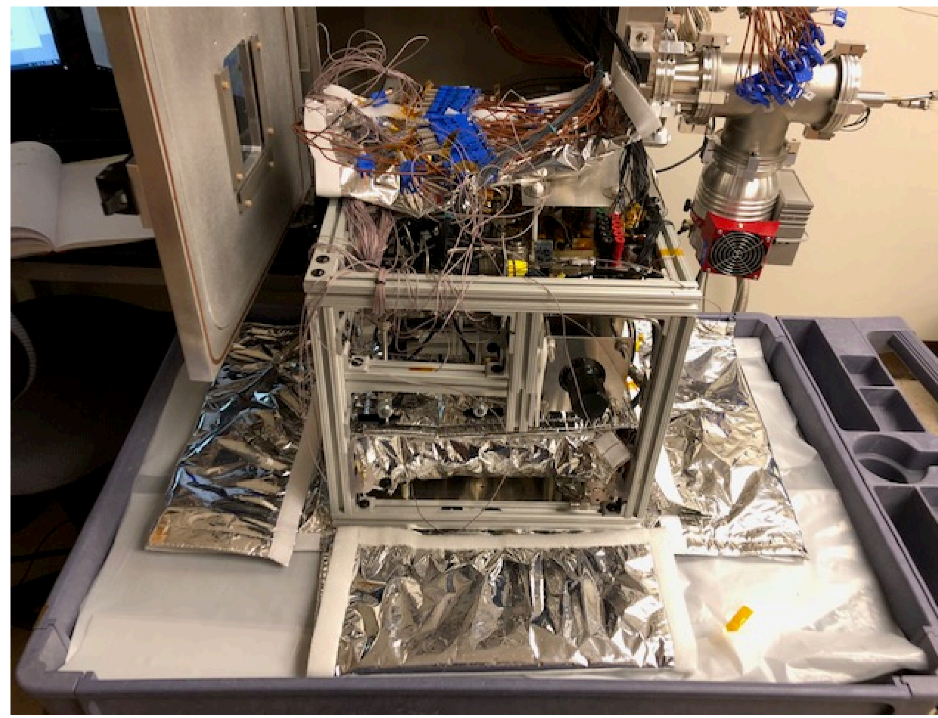
Current results and status

Luke Anderson

Active CryoCubeSat: ACCS

The ACCS project was the forerunner to the ATA project. An SSTP grant from 2015 to 2018. The accomplished the fundamental development, modeling, and characterization of the ATA system.

1	Developed a miniature mechanically pumped fluid loop thermal control subsystem for a CubeSat and demonstrated it in a relevant TVAC environment
2	Developed multifunctional structural-thermal components for a CubeSat via UAM additive manufacturing
3	Demonstrated thermal accommodation of a cryocooler suitable for cryogenic instrumentation on a CubeSat
4	Developed Analytical and Numerical design tools
5	Developed Systems based design methodologies and CONOPS for rapid development of Active Thermal Control systems for Small Satellites



ACCS System: Test Cube

Project Goals and Objectives

Project Objectives:

- Further develop a 1U miniature mechanically pumped fluid thermal control system targeted at CubeSat's & Small Satellites via UAM fabrication.
- Develop a mechanism for deploying a stowed radiator panel from a 6U CubeSat.
- Develop a one-axis pointing system for a deployed radiator panel
- Develop a mechanical and thermal isolation system for an integrated cryocooler and an IR-detector assembly.
- Develop a relevant prototype of the system
- Test system performance in a relevant TVAC environment. Raise TRL to 5 or 6 (TBR).

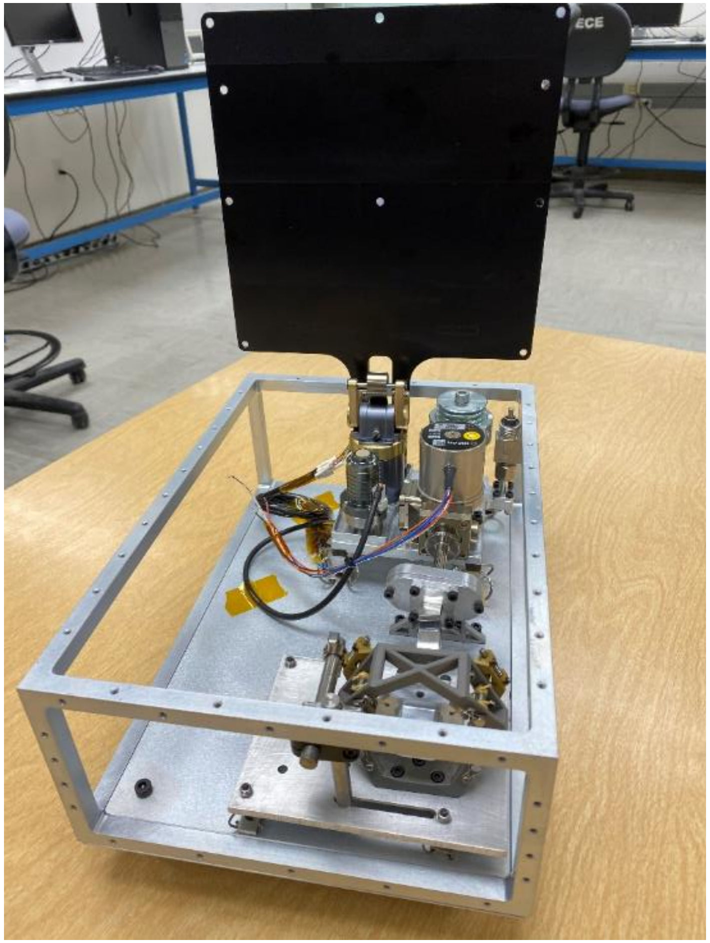
ATA Project Requirements	
Required Performance	Performance Goal
Two-Stage Flexible Fluid Joint/Hinge Deployed Radiator	
Fluid line dia.: ≥ 5mm **deploy distance: > 0** **Mass: < 0.3 kg** **Volume: < 3x3x10 cm**	Fluid line diameter: ≥ 6mm Deploy distance: > 20 cm Mass: < 0.2 kg Volume: < 2x2x3 cm
Tracking Radiator	
Pointing resolution: < 5° **Commanded tracking** **Turning Range: ±90°** **Avg. Power: < 50 mW**	Pointing resolution: < 2.5° Solar avoidance tracking Turning Range: Continuous Avg. Power: < 10 mW
Vibration Isolation/Cancellation	
Jitter Amp.: < 0.005° **Detector Thermal Parasitic: < 200 mW** **Mass: < 0.1 kg** **Volume: < 4x4x1 cm**	Jitter Amp.: < 0.001° Detector Thermal Parasitic:< 100 mW Mass: < 0.05 kg Volume: < 3x3x0.5 cm
Enabled Optical Instrumentation Capabilities	
Cryogenic Instrumentation: Detector Temperatures ≥ 60K **MWIR, LWIR Bands (3 – 15 μm)**	
IR optical instruments with IFOV > 0.01°	
IR Optical instruments with integration times < 20s	

ATA Basics

Fundamentally, the ATA system is an Active Thermal Control system with the intended use:

- Bus thermal environment management
- Payload or system thermal control
- High power rejection

Technology Readiness Level: <u>6*</u> (*As of June 2021)

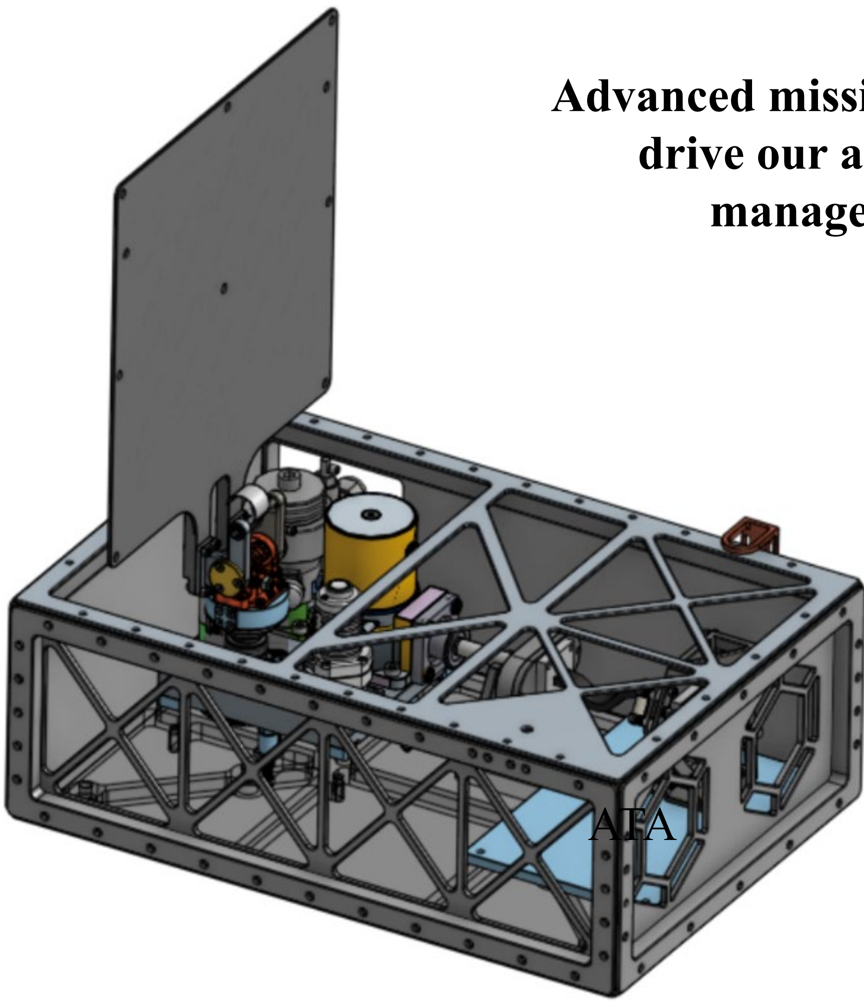


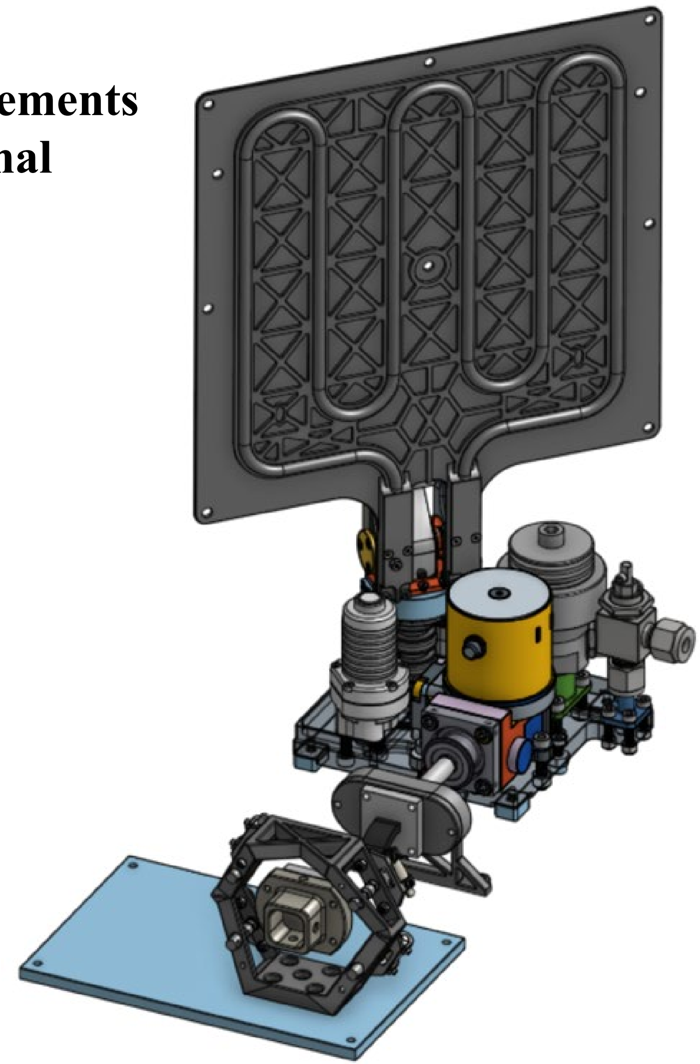
Applications:

- LEO Electro-Optical Instrumentation
- High powered payload support
- Cryocooler Integration and Support
- Heliophysics & Earth Science
- Lunar & Deep Space Missions

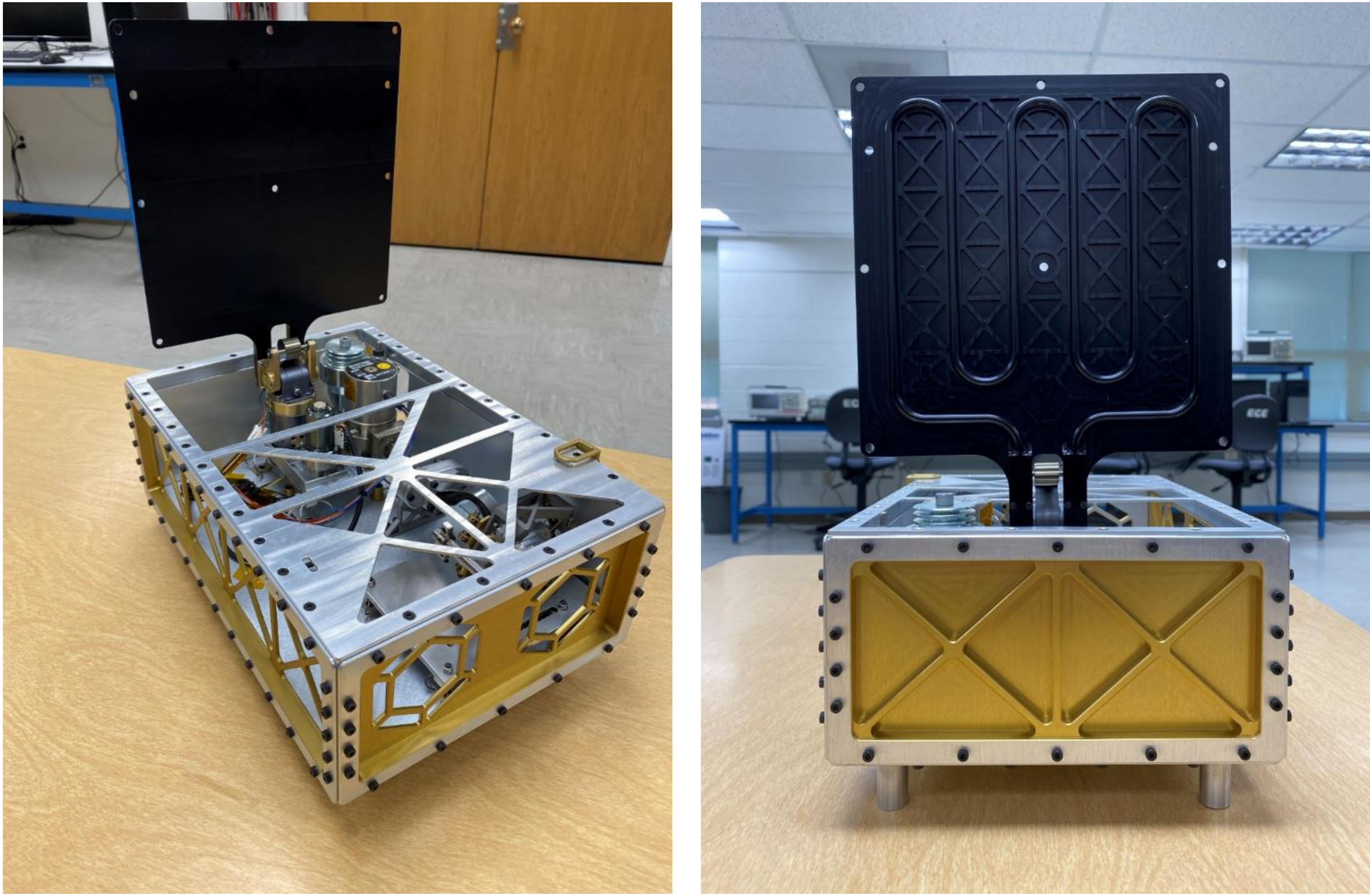
ATA Design

Advanced mission power requirements drive our approach to thermal management & Design.

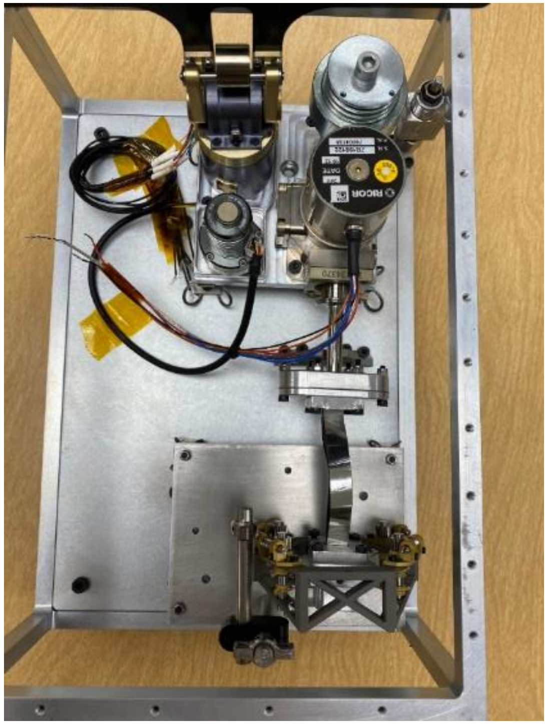




ATA Integrated Prototype & 6U Chassis



ATA Ground Based Prototype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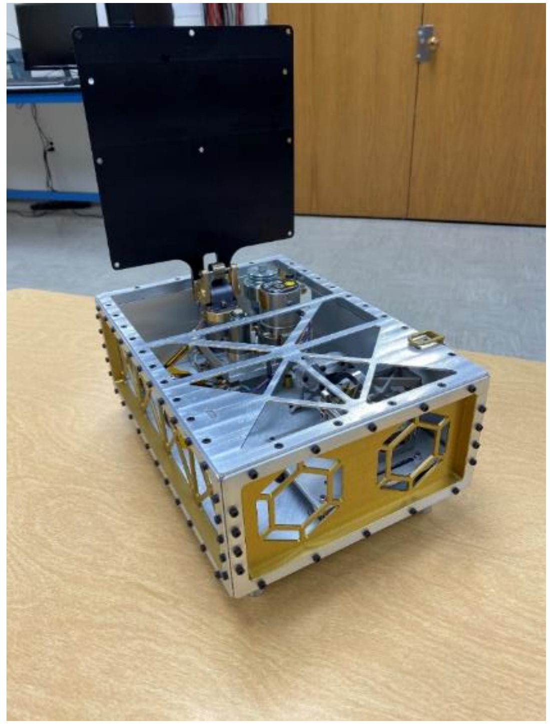

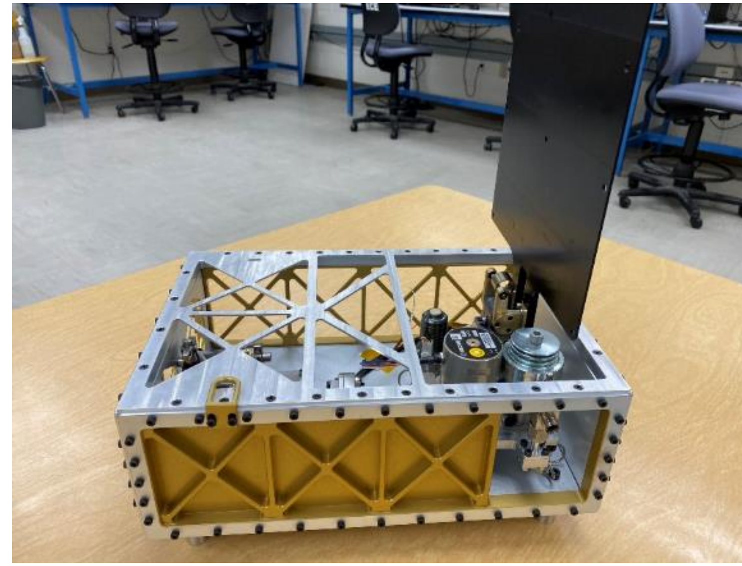

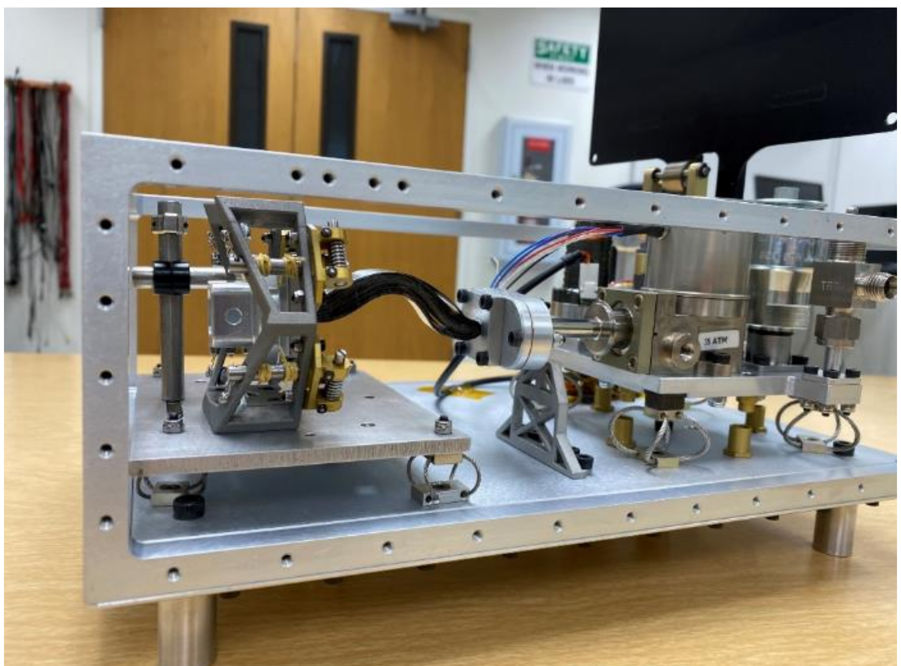
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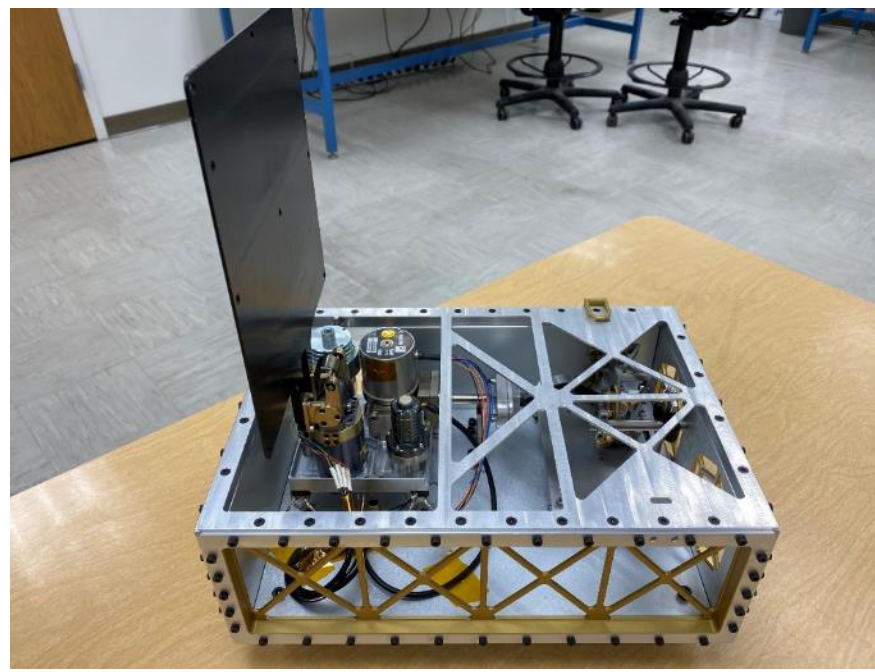
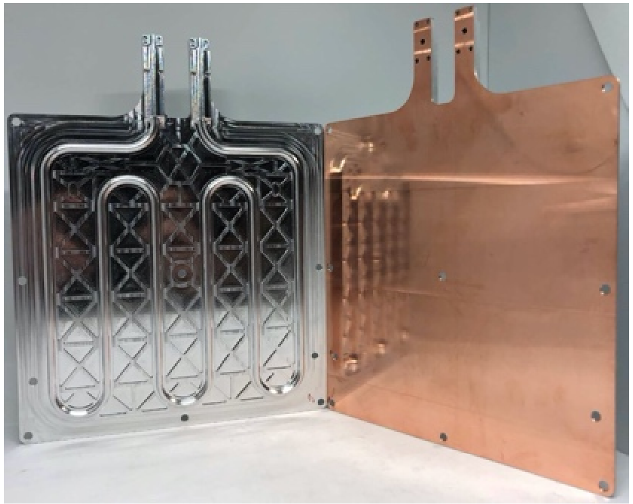
3 ATM

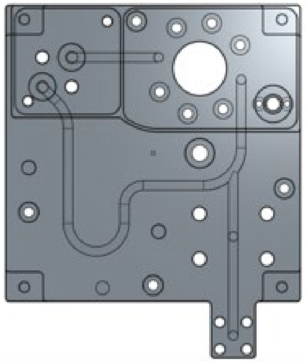


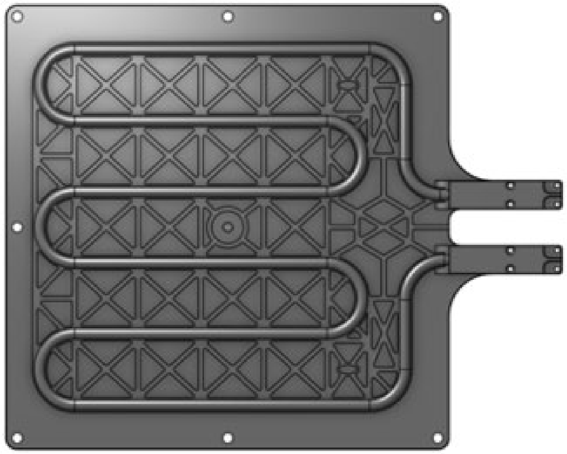
Ultrasonic Additive Manufacturing

UAM techniques allow the working fluid channels of the MPFL to be embedded directly into the CubeSat chassis and radiator. Additive/Subtractive 3D printing techniques such as UAM allow for:



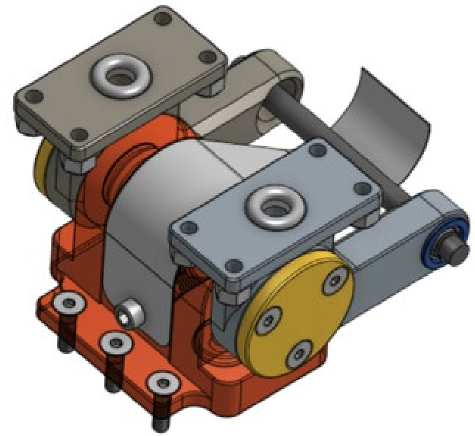
- Rapid design & fabrication
- Improved thermal performance
- Miniaturized & simplified flow paths
- The development of unique designs otherwise impossible with traditional fabrication techniques



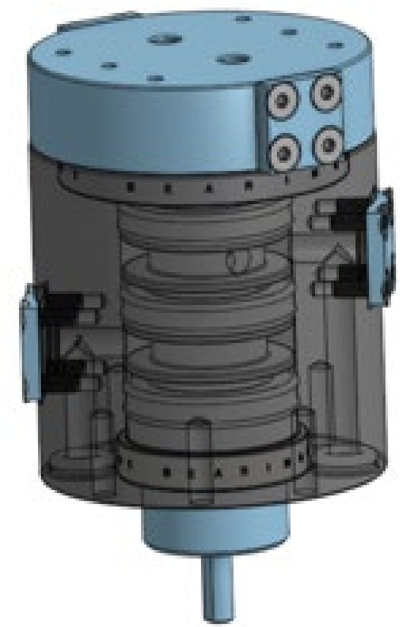


Rotary Fluid Joints & Deployment

The ATA MPFL system relies upon custom flexible rotary fluid joints to transport the working fluid to the external radiator.



One-time deployment of the radiator is accomplished via the use of stacked Contorque springs assembled in a fixed spool design.



Design highlights:

- Simple, integrated, compact design
- Continuous Rotation or 90°
- Robust with little chance of failure
- Constant torque throughout deployment
- Stackable (Tunable) springs and torque
- Full torque is maintained in deployed state
- Reliable two-axis deployment

Fluid Joints + Deployment Mechanism

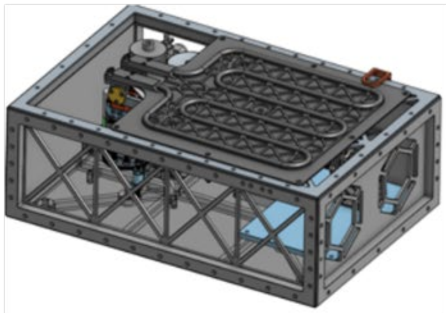
Continuous Rotary Union Core

Two-Axis Rotary Fluid Joint

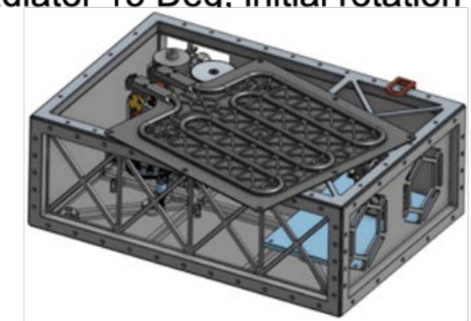
Integrated Two-Axis Rotary Fluid Joint + Deployment Mechanism

ATA Radiator Deployment

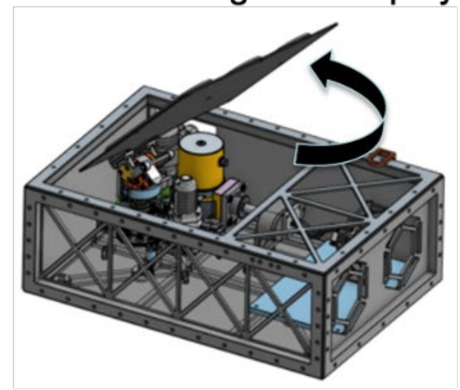
ATA System in:
Stowed State



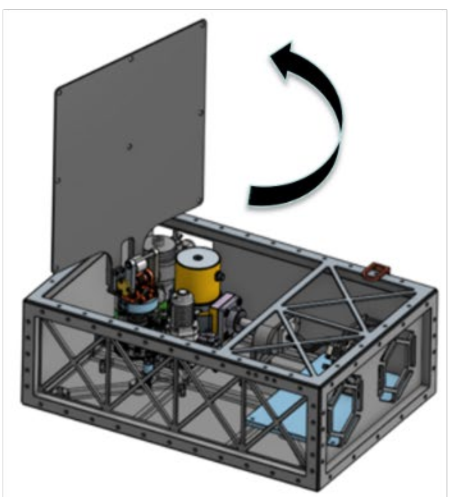
Release Launch Locks
Radiator 15 Deg. initial rotation



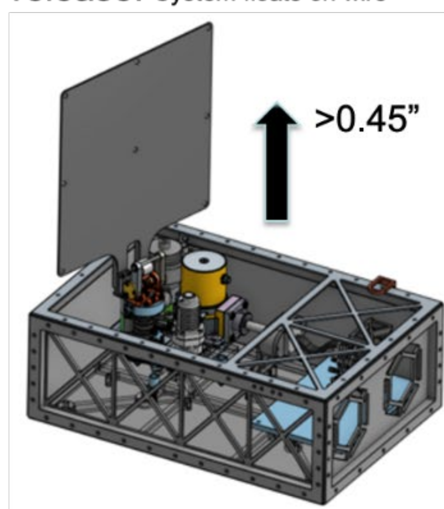
Radiator begins to deploy



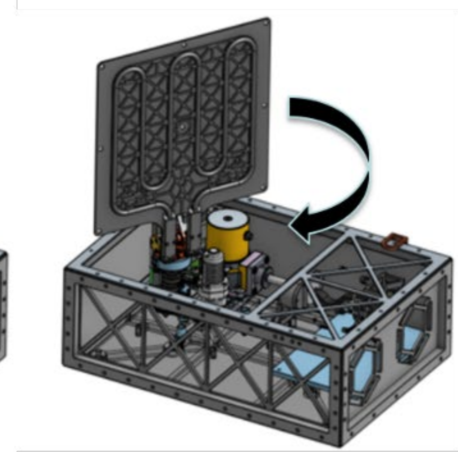
Radiator Full Deployment



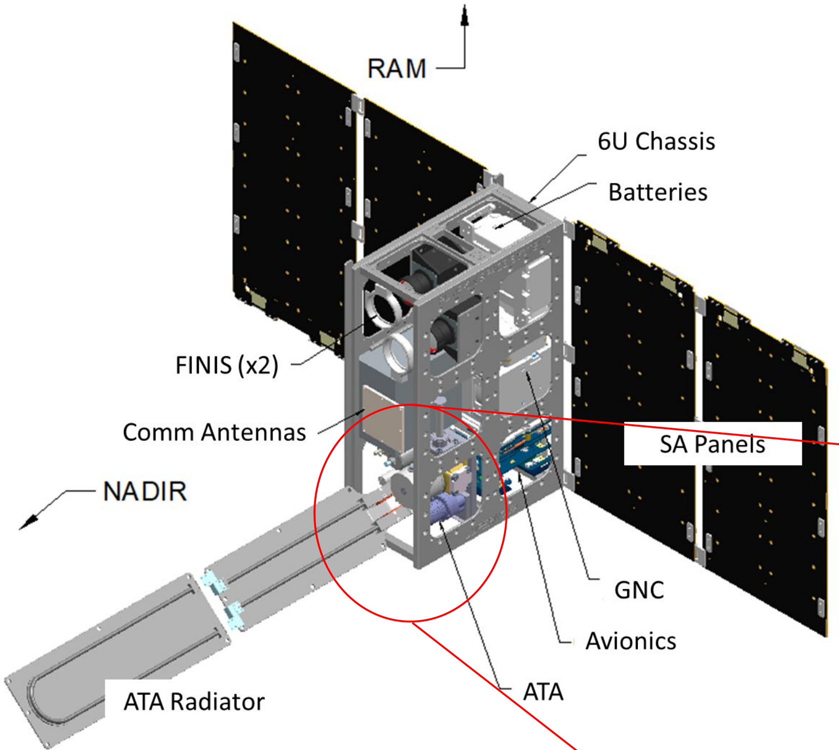
HX Launch Locks
release. System floats on wire

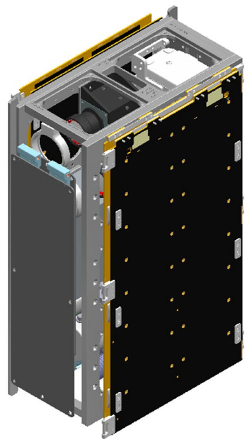


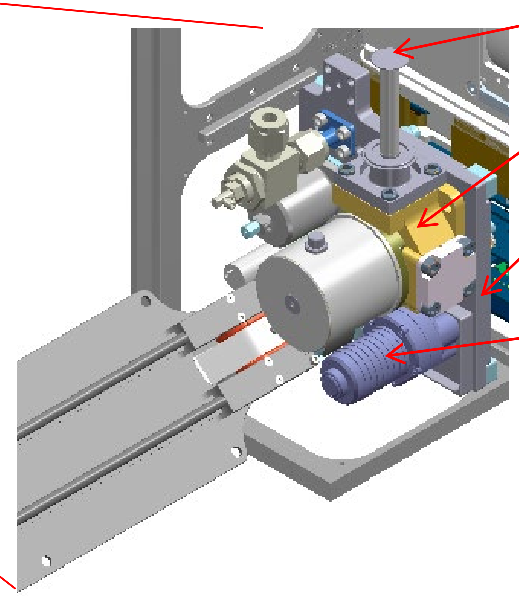
Radiator Continuous
dual direction rotation



ATA Radiator Alternate Configuration

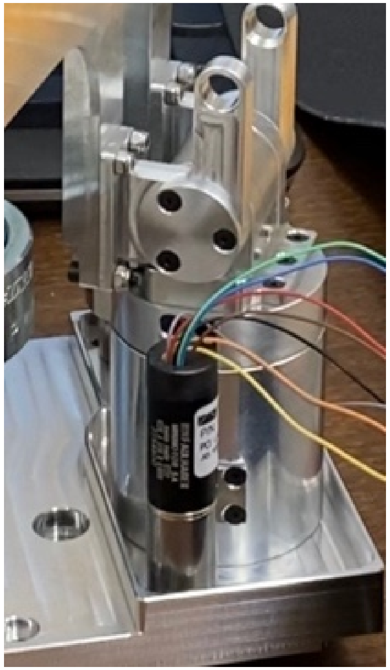


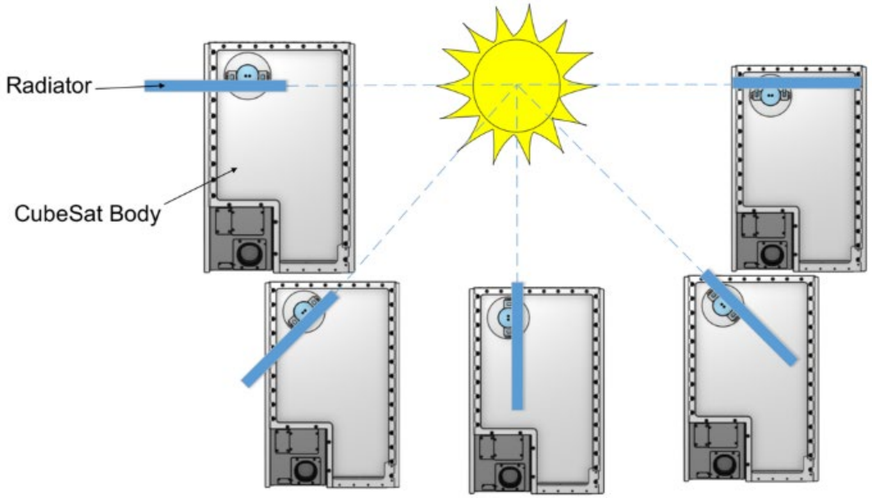


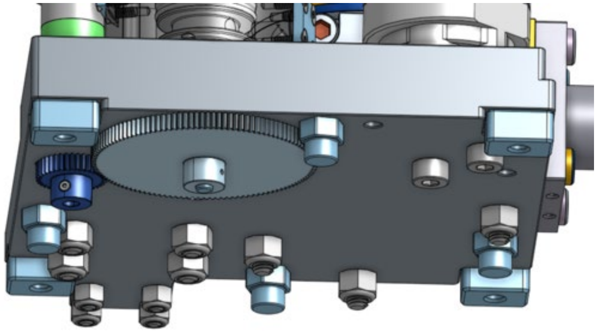


ATA Radiator Tracking

- Once deployed the ATA radiator is tracked with a rotary union stem-core design that allows a micro-motor to continuously drive the core of the rotary union and therefore the deployed radiator.
- A 3x-to-1x spur gear system located under the heat exchanger along with a planetary gear system in the micro-motor provide the necessary torque.
- The radiator can be tracked edge-on to the sun to minimize the impact of the space thermal environment, or angled face on to the sun to act as a control/feedback power input.





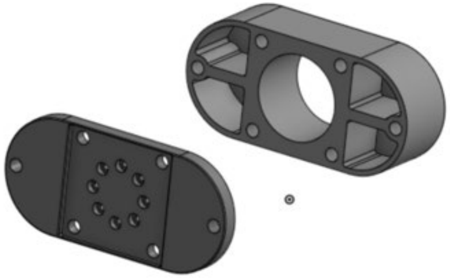


Vibration Isolation & Damping

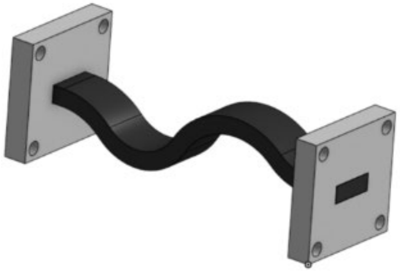
The ATA is an active system and therefore generates and exports vibration. To mitigate the effect of this vibration on the CubeSat the ATA system features several passive isolation & damping technologies.

- Wire rope vibration isolation for the heat exchanger plate and optical bench. These isolators allow the system to float with respect to the CubeSat chassis.
- A cold tip particle damper to absorb vibrational energy from the active cold finger of the cryocooler.
- A Pyrolytic Graphite Sheet (PGS) thermal link to conduct heat from the detector to the cryocooler while mechanically isolating the detector.

Wire-Rope isolators and particle damper



Custom ATA cold tip particle damper

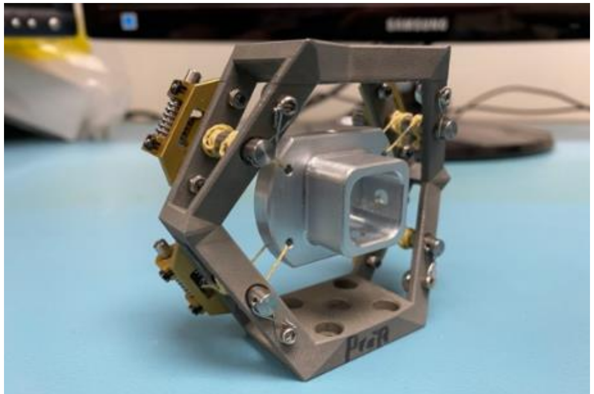


PGS Thermal Strap

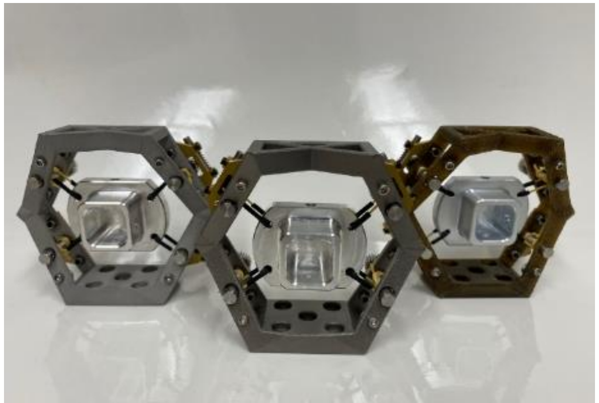
Electro-Optical Detector + Accumulator

The ATA features a prototype Kevlar-wire isolation mount for a dummy detector. The Kevlar string provides an excellent stiff & strong mechanical support while providing unmatched thermal isolation. The Kevlar can be tensioned/adjusted via worm-gear machine screws and a custom DMLS 3D printed frame.

The team also developed a custom piston fluid accumulator designed for manifold applications such as the ATA. Lightweight, compact, and easily scalable the ATA accumulator will be integrated with future prototypes.



ATA Kevlar Isolation Detector Mount



Aluminum, Titanium, and PEEK

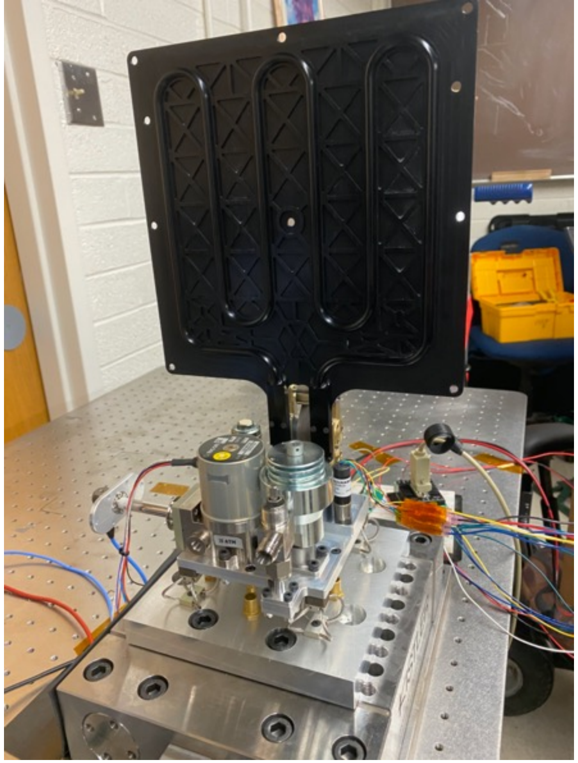
Fluid Accumulator + Breakout

Results & Status

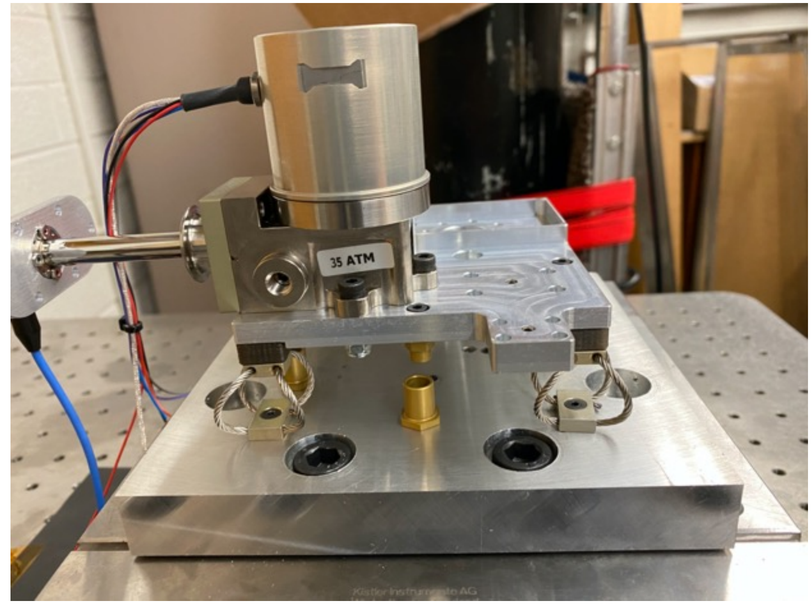
The ATA system has undergone numerous benchtop and relevant ground-based testing, characterization and technology demonstrations:

- Benchtop component and system level testing
- Helium leak rate testing
  - $6.8e^{-6}$ mbar cc/sec He
  - $1.8e^{-8}$ mbar cc/sec corrected for Novec 7000
- Exported force/vibe characterization
  - Force dynamometer + Accelerometer
  - Capacitive sensor displacement
- GEVS launch load + Resonance testing
  - System + component level testing
- TVAC technology demonstration
  - Cold Deployment & Tracking
  - Thermal control & performance

Helium Leak “Bag” Characterization

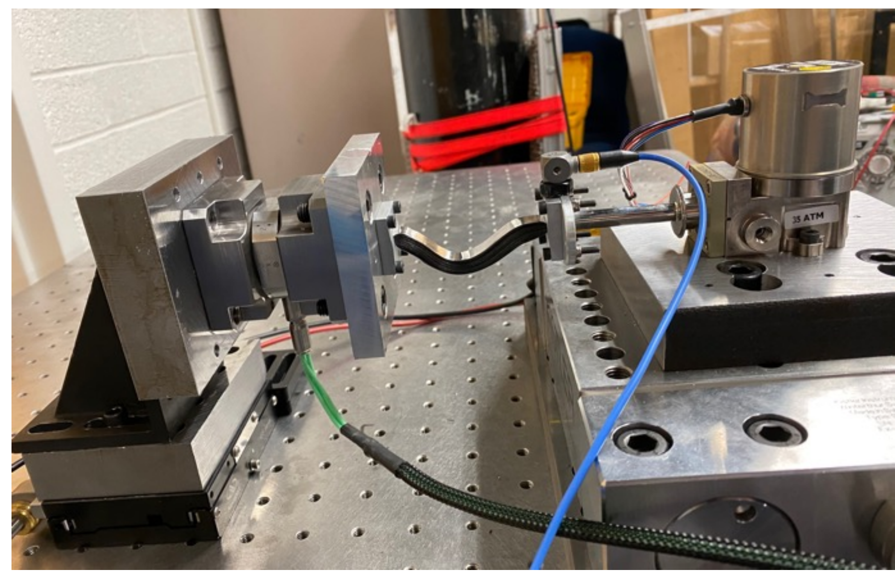


ATA Kistler exported vibe testing



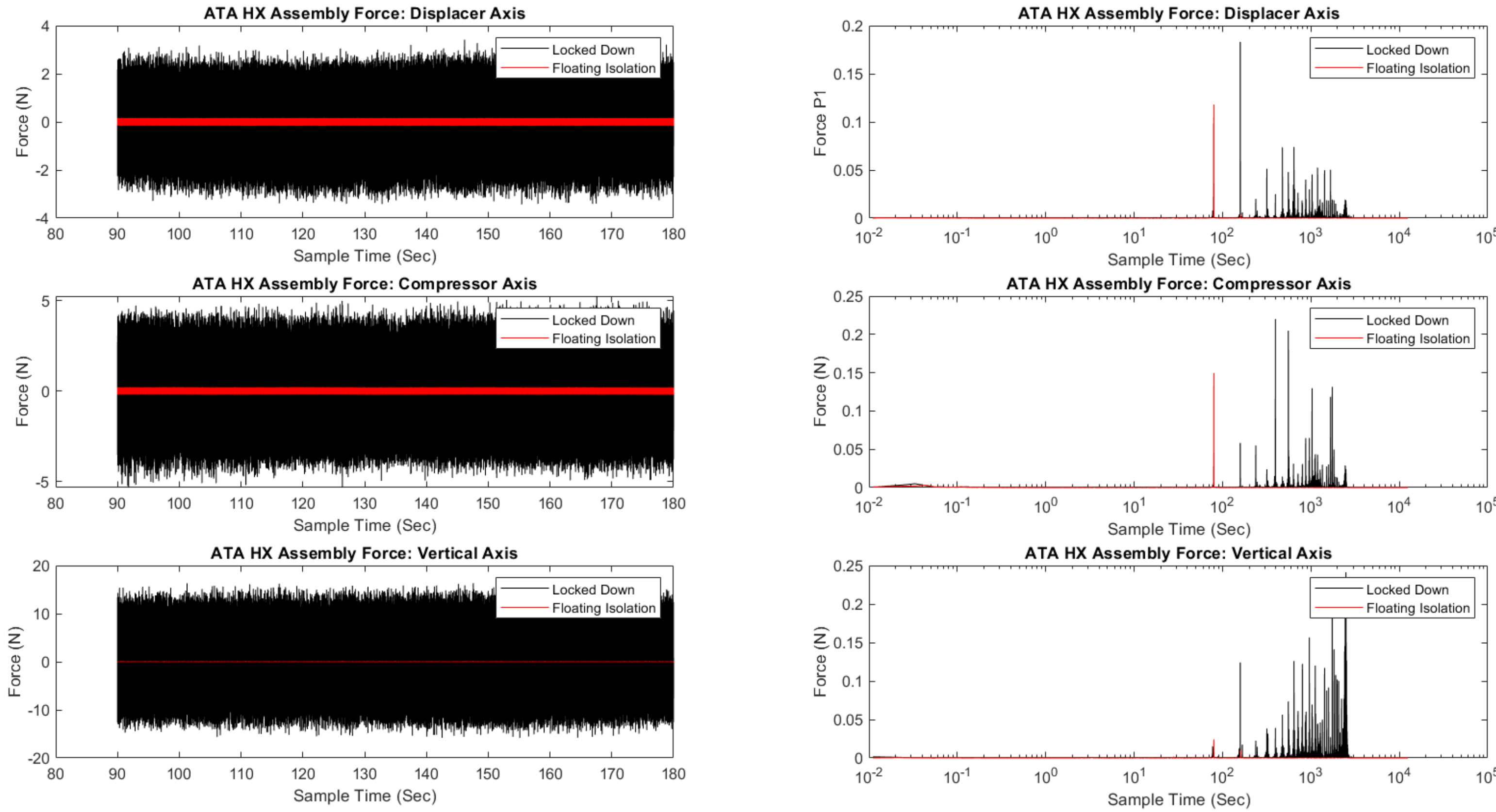
ATA Wire Rope Isolation

ATA Particle Damper



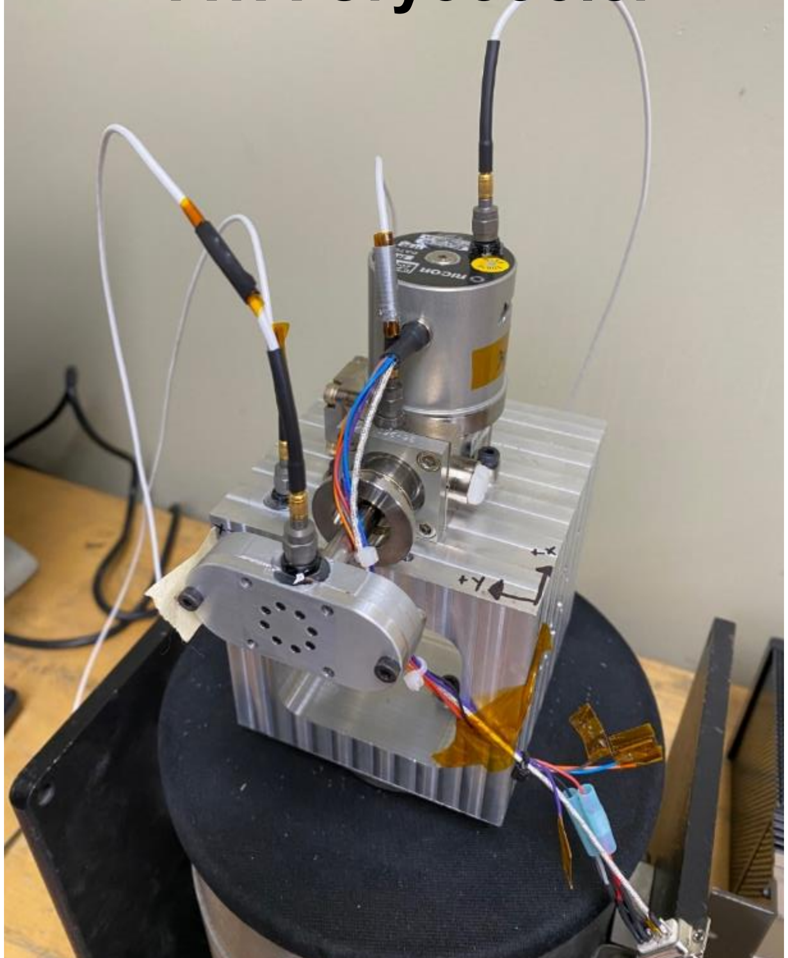
ATA Thermal Link

Cumulative Exported Vibration

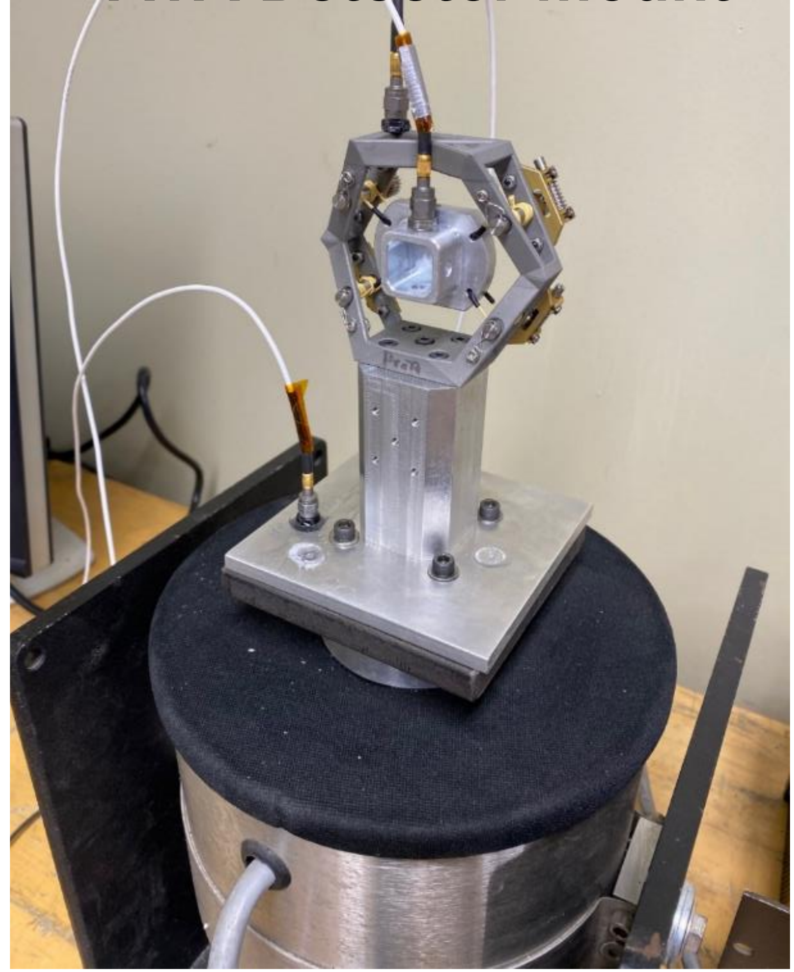


Component GEVS + Resonance

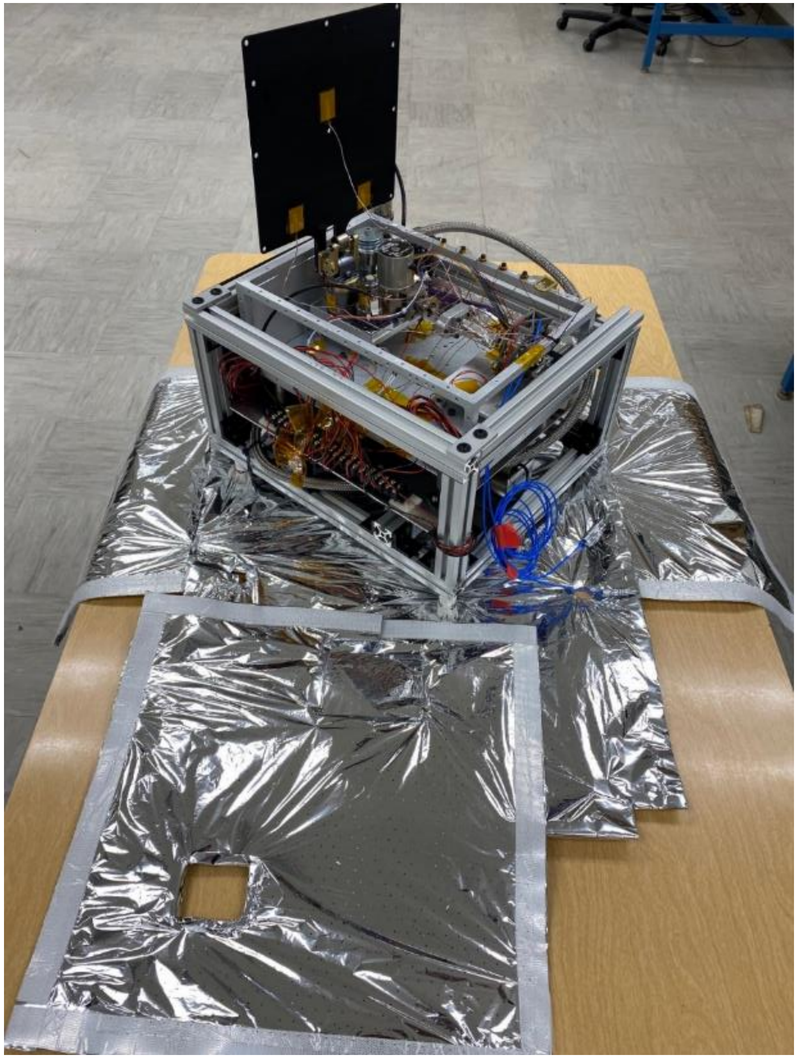
- ATA Cryocooler



- ATA Detector mount



ATA TVAC Technology Demonstration



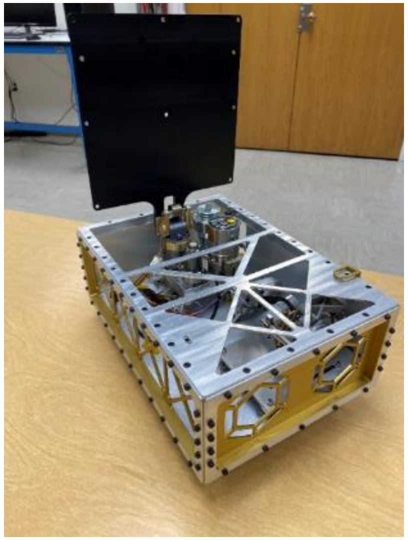
Current “Space Readiness”

The ATA system has currently been integrated into a realistic prototype, which has undergone extensive relevant ground-based testing and characterization. The ATA system is ready for integration into a space mission.

- The ATA system could benefit from further refinement and could potentially be miniaturized further to 0.5U and optimized for integration with a CubeSat bus.
- Further development of an ATA control/feedback algorithm is on schedule for Fall of 2021.

The ATA system is currently space ready

- Fully assembled
- GEVS/TVAC qualified
- Packaged for integration with a CubeSat bus



Future Work

Recommended future work & Tests

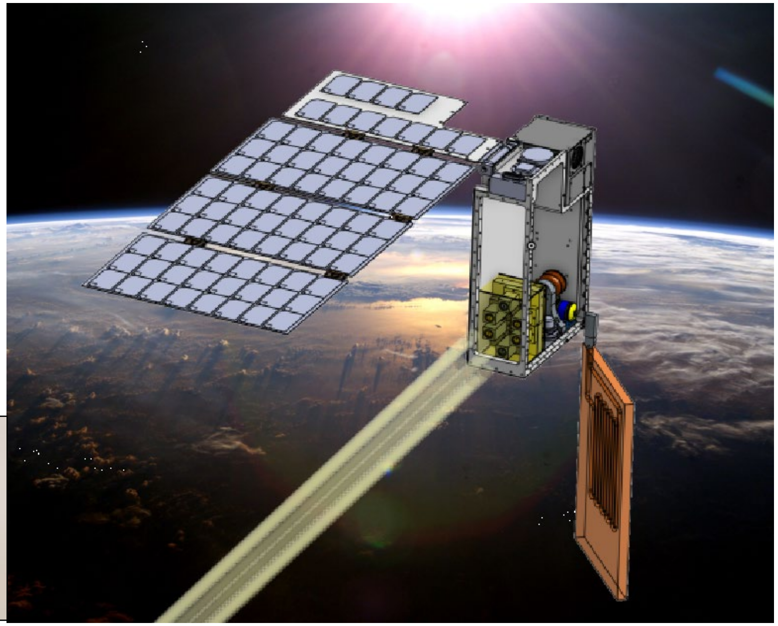
- ATA fluid accumulator characterization---Summer 2021
- ATA pump curve characterization---Summer 2021
- ATA Electro-Optical vibration testing---June 2021
- ATA UAM thermal conductivity testing---Fall 2021
- ATA Control & Feedback algorithm development---Fall 2021

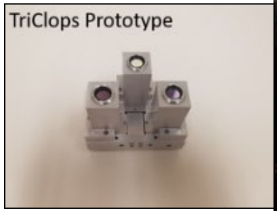
- Further miniaturization of the ATA system to <0.5U
- 3D “Zero-Gravity” wire rope isolation harness
- Foldable radiator design + testing
- Miniaturization of the ATA pump
- Development of an ATA analytical/numerical thermal model---Included in the ACCS work
- Further TVAC characterization

ATA Mission (1)

The ATA team would propose either a technology demonstration flight in LEO or an integrated reference mission with payload.

- A technology demonstration could raise the TRL of the ATA system from a 6 to a 7 with a standard bus and an integrated diagnostics package
- The ATA could also serve as a support subsystem for a payload
  - General bus thermal management
  - High power rejection
  - Payload thermal control





A concept mission for the ATA system in support of a limb viewing electro-optical instrument. Inset shows the prototype of the Tri-Clops broadband IR instrument developed at USU.

Further Questions

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