

The Active Thermal Architecture (ATA): An Advanced and Scalable Single-Phase Pumped Fluid Loop Active Thermal Control Technology for The Next Generation of High-Powered Payloads and Small Satellites

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1 ABSTRACT

Small satellites and CubeSats are increasingly required to support high-performance payloads, advanced onboard processing, and coordinated constellation operations, enabling missions historically performed by larger spacecraft [1]. These capabilities introduce significant thermal management challenges, creating a need for advanced, scalable active thermal control (ATC) systems [2, 3, 4]. This work presents the Active Thermal Architecture (ATA), a compact ATC technology designed for high-power SmallSat and CubeSat platforms. ATA utilizes a mechanically pumped, single-phase fluid loop integrated directly into spacecraft structures using Ultrasonic Additive Manufacturing (UAM), producing a highly integrated and multifunctional thermal management system. Key features include specialized heat transfer fluids, dual fluid loops, micro-pumps, embedded heat exchangers, and deployable radiators with flexible rotary fluid joints.

The ATA system is designed to provide stable setpoint regulation, variable conductance, and scalable heat rejection, supporting up to ~150 W of thermal load while maintaining ± 2.5 °C temperature stability. ATA will provide thermal control for the HyTI 2.0 hyperspectral thermal imager aboard the upcoming ACMES technology demonstration mission. HyTI 2.0 [5] is a long-wave infrared hyperspectral instrument designed for high-resolution mapping of Earth's surface and atmosphere. This paper presents the ATA design, operational concept, performance modeling, and hardware characterization, along with an overview of the HyTI 2.0 instrument and the ACMES mission.

2 MISSION SUMMARY

ACMES is a NASA-funded (ESTO InVEST) CubeSat technology demonstration mission, see Figure 1, designed to enable high-resolution and accurate (onboard calibration) long-wave infrared (8 to 12 μm -LWIR) observations of the Earth's surface from a Small Satellite. The ACMES satellite features the ATA technology, a novel and advanced single-phase mechanically pumped fluid loop active thermal control system capable of high-power dissipation and precise thermal setpoint control. The ATA will demonstrate on orbit, MPFL active thermal control, 3D-printed UAM multi-functional structures, and deployed folding and tracking radiators that enable end-to-end spacecraft thermal control and variable heat rejection.

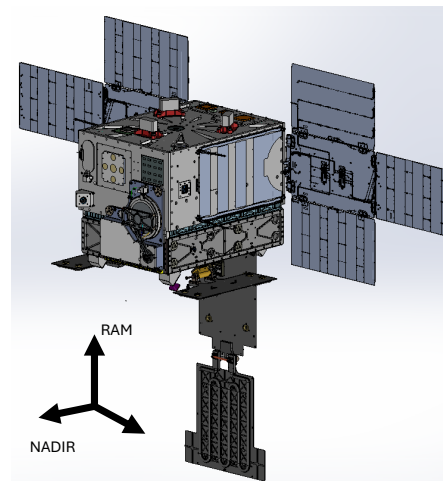


Figure 1. The ACMES Spacecraft.

3 THE THERMAL PROBLEM

The heart of thermal control is to maintain the temperature of a satellite system, payload, or instrument to within acceptable limits throughout the mission life [6]. Traditionally, this objective has been accomplished by passive techniques such as surface/material coatings, conduction paths, insulators, MLI, and even two-phase vapor technologies, aka passive Heat Pipes (HP). However, modern small satellites and CubeSats face a fundamentally different and far more challenging set of thermal problems. Specifically, that of high-power density, ever-expanding mission/environmental requirements, and restricted temperature limits for the next generation of advanced payloads.

The core of the issue is high power density. Advanced payloads—such as multispectral imagers, onboard edge processors, active RF systems, and cryogenically-cooled sensors—concentrate significant heat generation into very small volumes. Unlike larger satellites, CubeSats have limited volume, mass, and most importantly, surface area to radiate heat away, which leads to steep internal temperature gradients and localized hot spots. The Table (1) [7] below demonstrates the power density challenge faced by modern CubeSats. Of note is that the ATA system on the ACMES satellite is controlling a power density of 3,615 W/m³ or nearly a factor of 39x beyond the given GEO satellite while maintaining a setpoint temperature control of no more than ± 2.50 °C.

Table 1. Power density ratio of a standard GEO communication satellite with respect to a notional 3U CubeSat and the ATA technology on the ACMES spacecraft.

	GEO Communication Satellite	3U CubeSat High Power	ACMES: The ATA Technology	Ratio of the ATA to the GEO Satellite
<i>Satellite Dimensions [m]</i>	3.0 X 3.0 X 6.0	0.1 X 0.1 X 0.3	.52 X .38 X .21	
<i>Satellite Volume [m³]</i>	54.0	0.003	0.0415	1,301
<i>Radiator Surface [m²]</i>	42.88	0.06	^a 0.61	70.3
<i>Power [W]</i>	5000	50	150	33
<i>Power Density [W/m³]</i>	92.6	16,666.7	3,165	39
<i>Efficiency</i>	60%	60%	(Approx.) +95% ^b	
<i>Waste Heat [W]</i>	2000	20	142.5 W	
<i>Rejected Heat Flux [W/m²]</i>	46.6	333.3	233.6	5.01

^aDeck #1 primary radiator area 0.363 m² (Approx.) , Deck #2 otter paw radiator 0.247 m² (Approx.)

^bThe ATA technology operates as a self-contained payload support system. With an enclosed system and a waste heat efficiency of nearly 100%.

4 ACTIVE THERMAL CONTROL

An Active Thermal Control system (ATC) is any technology or method that relies on input power to maintain, control, or reject thermal energy. ATCs are a relatively new addition to the Small Satellite design portfolio and consist primarily of trim control heaters, cryocooler refrigeration, thermoelectric coolers, two-phase vapor compression heat pumps, and single-phase mechanically pumped fluid loops [8]. Certain types of pumped or variable heat pipes are also classified as active systems, along with dynamic space thermal radiators, or powered control of surface area, pointing view factor, or surface optical properties.

The technical advantages of an ATC include managing and dissipating large, variable heat loads, enabling sub-ambient cooling, and maintaining strict and precise setpoint temperature control despite challenging and extreme (environmental) mission parameters. The disadvantages of an ATC include the required power, reliability, additional system-level complexity, and volume/mass considerations.

ATCs are enabling technologies for the next generation of CubeSats and Small Satellites, aiming to deliver efficient, scalable thermal control.

5 THE ACTIVE THERMAL ARCHITECTURE (ATA) Technology

The Active Thermal Architecture (ATA) [9, 10, 11, 12] is a novel and advanced Active Thermal Control technology developed by the Center for Space Engineering (CSE) at Utah State University (USU) and the Jet Propulsion Laboratory (JPL) through a series of NASA-funded Small Satellite Technology Partnership development efforts (ACCS & ATACOI). The ATA technology was developed to enable the next generation of mission-critical CubeSat and Small Satellite scientific payloads through direct thermal management and precise temperature set point control. Figures 2 & 3 show the ATA technology.

Fundamentally, the ATA is a miniaturized and integrated single-phase, mechanically pumped fluid loop (MPFL) ATC. The ATA serves as a direct payload support system to the Hyperspectral Thermal Imager 2.0 instrument. Two distinct ATA ATC systems service the HyTI 2.0 instrument. The top ATA, or DD #1, provides tight thermal control to the HyTI 2.0 optical assembly, integrated AIM SF-100 cryocooler, and Integrated Dewar Cooler Assembly (IDCA), the Saaz Gigabit Ethernet camera link board, and West Coast Solutions power control module. The second ATA, or DD #2, provides broader thermal management to the Blue Marble Space Edge Processor, which provides real-time level 0 to level 1 data processing for the ACME HyTI 2.0 mission. ACME is first and foremost a technology demonstration mission, with the qualification and operational demonstration of the ATA technology as a primary objective. To this end, the ATA payload will demonstrate several novel ATC technologies and capabilities from a CubeSat platform:

1. A scalable and controlled thermal ATC technology
2. Miniaturized & integrated MPFL
 - a. Variable thermal conductance through convective heat transfer
 - b. Setpoint temperature control to ± 2.50 °C
3. Integrated “Multifunctional” structures and components
 - a. Ultrasonic Additive Manufacturing (UAM) design & fabrication
4. Accommodation of an integrated cryogenic cryocooler (AIM SF-100)
5. Micro Centrifugal “Canned” pumps (low power and high flow rate)
6. Custom “Piston” variable-size (scalable) fluid accumulators
7. Deployable, tracking, and folding radiators
 - a. Deployable and thermally efficient (near isothermal operation) radiators
 - b. A variety of compact, three-axis, rotary fluid joints
 - c. Variable area and view factor radiators

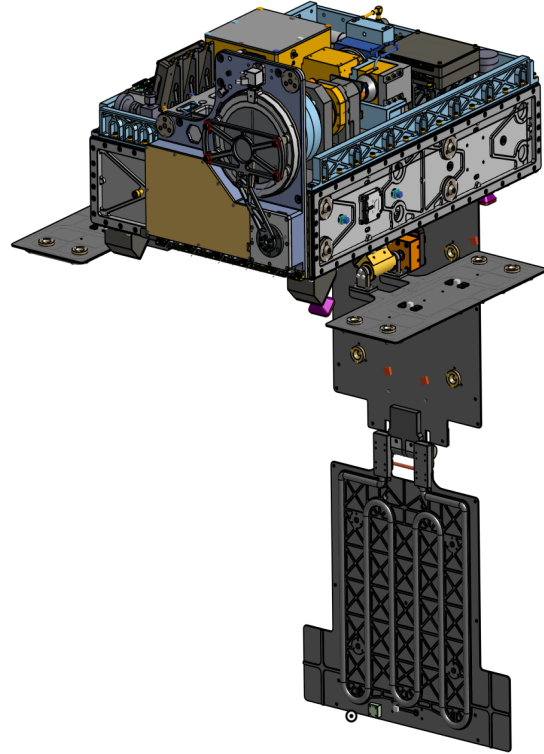


Figure 2. The ATA technology is shown as an integrated and standalone payload with the HyTI 2.0 instrument.

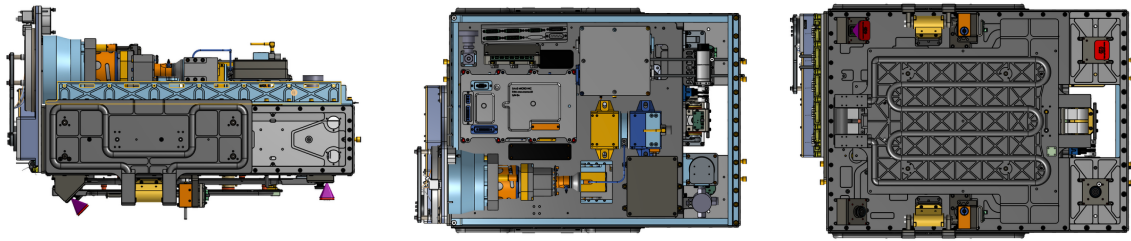


Figure 3. Additional views of the ATA technology and HyTI 2.0 payload. Left, port view with the HyTI 2.0 optical assembly and folded/stowed Port "Otter" paw radiator.. Middle, top-down view of the optical deck and HyTI 2.0 instrument shown. Right, bottom view of the DD#1 primary radiator folded and stowed for launch.

5.1 SINGLE PHASE MECHANICALLY PUMPED FLUID LOOPS

A mechanically pumped fluid loop (MPFL) is an active thermal control technology that relies on the transfer of heat through fluid convection (advection) [13]. A single-phase working fluid circulates in a closed loop between an internal heat exchanger and a distant thermal radiator. MPFL's rely on flow throttling and trim heaters to provide setpoint temperature control to local thermal zones and payloads, creating a direct, high-efficiency, and variable conductive thermal path within the spacecraft. Advantages of MPFL's include greater heat transport capacity, reduced thermal gradients (isothermal), improved efficiency, longer transport distances, and precise setpoint temperature control.

The ATA thermal control MPFL relies on dual, primary + backup, semi-custom TCS M510 micropumps [14] mounted in series. The M510 is a long-life, low-power, high-flow centrifugal pump. Based on a "Canned" design, the M510 does not have any dynamic seals, greatly improving wear resistance and lifetime. In addition, the ATA M510 pumps feature a triple-seal design on all static leak paths. The ATA features a 0.25-inch hydraulic diameter design, circulating a specialized heat transfer fluid, a perfluorinated liquid called Galden HT-110, with a flow rate of between ~100 mL/min (Laminar Flow) to ~500-600 mL/min (Turbulent). The ATA fluid loop working pressure is monitored by an integrated pressure transducer and maintained by a custom-made piston fluid accumulator operating at a nominal pressure of 75 psia. A leak rate of $<10^{-7}$ atm cc/sec can be compensated for by the fluid reservoir throughout the mission life. A 440-micron inline particle filter is mounted inline (preceding) the pump assembly to mitigate debris-based failures. Filling and purging the ATA fluid loop is done under vacuum conditions with specialized safety GSE. The ATA features a triple-seal design on all jointed parts and MPFL to vacuum leak paths. Prioritizing material compatibility, vacuum safety, and redundant, low-leak rate operation. See Figures 4 and 6 for the ATA MPFL CONOPS and major fluid components.

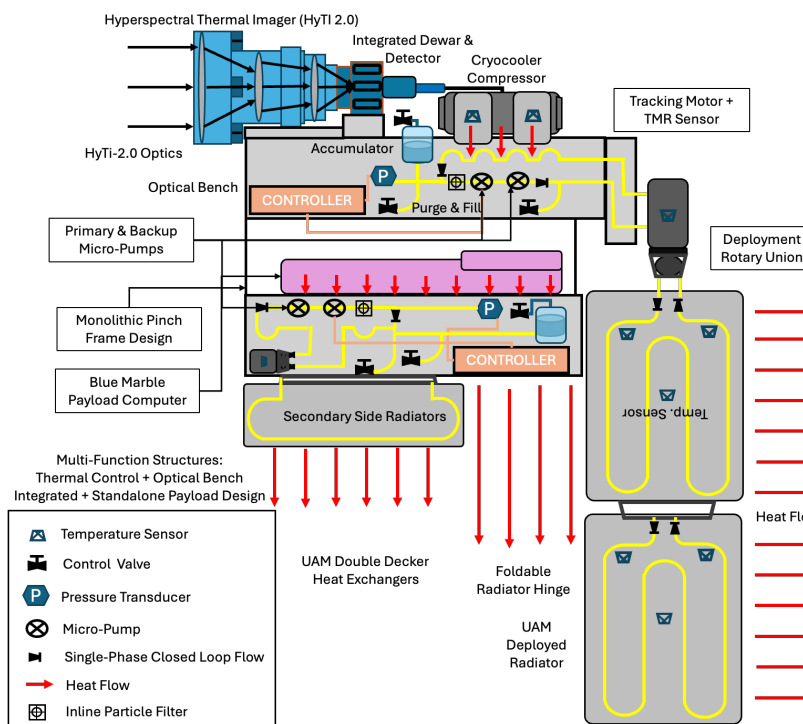


Figure 4. Operational concept for the ATA MPFL.

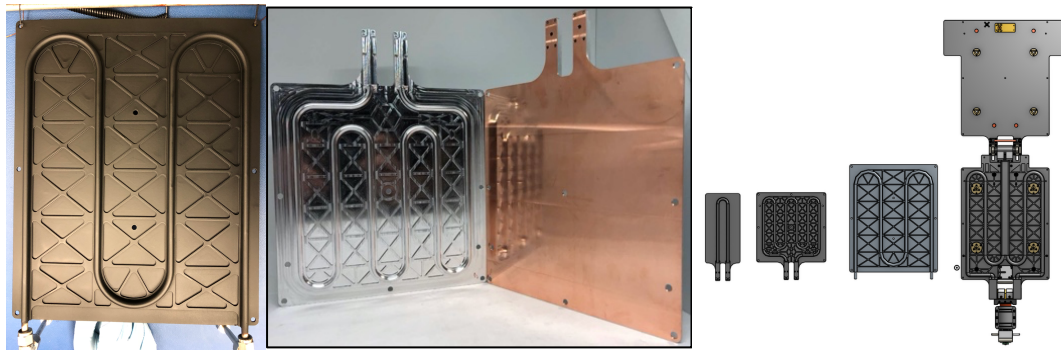


Figure 5. A comparison of the various UAM thermal radiators. Left, the original ACCS 6U UAM radiator. Middle, a dual metal (Aluminium 6061 & Copper) 4U ATA radiator. Right, a CAD comparison of the ATA radiators, from smallest to largest, with the modern folding ACMES primary radiator on the far right.

5.2 Ultrasonic Additive Manufacturing

The ATA leverages Ultrasonic Additive Manufacturing (UAM) [15] as a key enabling technology. UAM builds monolithic 3D metallic structures through ultrasonic welding and sequential layering of metal foils. The UAM process (additive + subtractive) is uniquely suited to forming voids within metallic structures. As a low-temperature atomic bonding process, UAM can mix metal types, creating a metallic composite substrate. UAM produces unique thermal transfer systems by embedding complex internal features—such as flow channels and thermal pathways directly into fully formed parts and structures. Therefore, creating multi-functional components.

The ACMES ATA system utilizes UAM for the HyTI 2.0 heat exchanger (DD #1) and Blue Marble SEP heat exchanger (DD #2) decks. Each of the radiators is also formed from a UAM process. Figure 5, above, shows a variety of UAM thermal radiators produced for the ACCS, ATACOI, and ACMES programs throughout the years. By enabling monolithic, highly integrated designs, UAM delivers substantial programmatic and performance advantages over traditional fabrication approaches. These include significant reductions in manufacturing schedule and overall cost, as well as meaningful decreases in system mass through part consolidation and optimized geometries. The key advantage, however, is the improvement in thermal performance through metal-bonded conductance. The advantages of UAM heat exchangers and radiators were characterized by JPL during the ATACOI program and are listed below.

Ultimately, UAM as a process fundamentally transforms how integrated thermal systems are designed and produced, allowing for the development of unique, complex, and thermally ideal designs that would be impossible with traditional fabrication techniques.

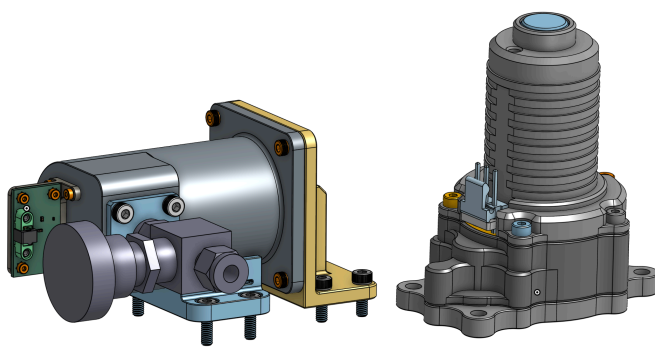


Figure 6. ATA fluid accumulator (75 mL) with TMR linear piston positioning sensor & the low-power, high-flow rate semi-custom TCS M510 centrifugal "Canned" micropump. Note, the ATA micropump has no internal rotary dynamic seal and features triple seal redundancy for all leak paths.

Improved thermal performance: >200% improvement over traditional bonded tubing methods
Miniaturized & simplified flow paths: >30% mass savings
Rapid design & fabrication: >50% improvement on schedule

5.3 The ACMES ATA Deployed Tracking & Folding Radiators

A key capability of the ATA ATC is to combine the variable conductance pathway of the convective MPFL to a deployable radiator system, greatly improving the overall thermal performance of the ATA. Without deployable radiators, the thermal rejection would be limited to the available surface area of the spacecraft. By including deployable radiators, the available surface area of the ACMES CubeSat is increased from $\sim 0.15 \text{ m}^2$ to $\sim 0.61 \text{ m}^2$, a factor of nearly 4.1x increase. In addition, by deploying rotationally flexible, tracking, and foldable radiators, the quality and efficiency of the available thermal radiator area are unmatched.

5.4 Rotary Fluid Joints

The ATA rotary fluid hinges are loosely based on similar terrestrial rotary sealing joints. A core and sleeve assembly is rotationally sealed with dynamic elastomeric O-Rings. The ATA features a triple-seal design on all dynamic fluid hinges, with the two internal seals focused on fluid compatibility and primary/backup sealing. The outermost seal is a specialized Teflon O-Ring, providing extreme cold tolerance to the space environment.

The ATA features three distinct and unique rotary fluid hinges that, when combined, allow for complex operation, including folding, dynamic deployment, 360° tracking, and variable control of the ATA's thermal radiative area and view factors. The primary ATA radiators are deployed with specialized Contorque springs, while tracking is motorized with a worm gear-driven stepper motor. The secondary "Otter Paw" radiators deploy and refold against the secondary UAM heat exchanger. This maneuver reduces the effective radiative area of the second deck ATA by a factor of nearly $\sim 72\%$.

The ATA rotary fluid joints are an enabling technology, that can easily be scaled and modified to support a wide variety of hydraulic, thermal, and fluidic-based applications.

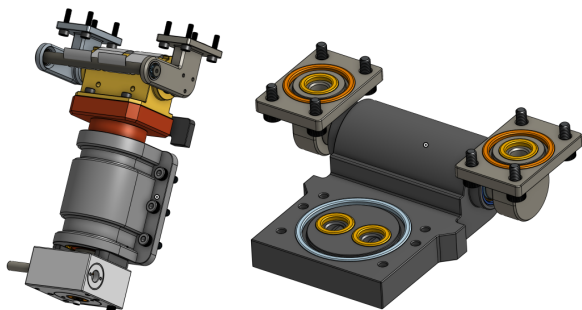


Figure 8. Left, a two-degree-of-freedom rotary fluid joint. The lower fluid hinge allows for continuous 360° rotation, while the upper joint serves as the deployment hinge. Center, is a UAM-designed low-profile 180° fluid hinge. The combined deployable and folding radiator assembly is shown on the Right. Propel space HDRMs, kicker springs, and cup-cone mounts serve as structural supports during launch.

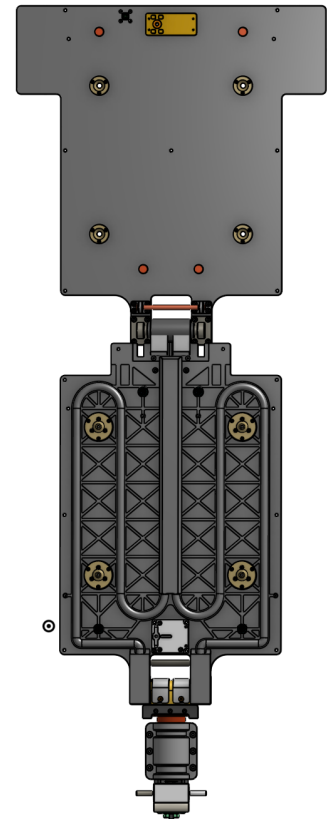
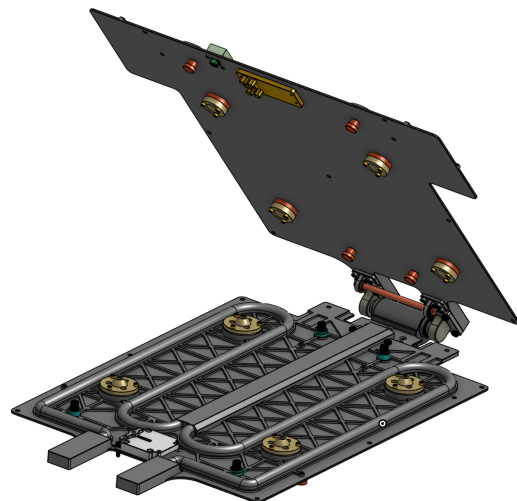


Figure 7. The assembled ATA primary DD #1 radiator. This radiator is a foldable, deployable, and continuously tracking radiator system.



5.5 ATA Heat Exchanger Decks #1 & 2

For the ACMES mission, two ATA systems are integrated with the HyT 2.0 Payload. These independent MPFL ATCs operate with separate and redundant fluid loops, pumps, and unique independently controlled radiators.

The top deck of the ATA system thermally manages the HyTI 2.0 optics. Including the camera, optical assembly, IDCA, AIM SF-100 cryocooler, Saaz camera link, and power control module. The second deck accommodates the Blue Marble SEP. Allowing for real-time processing and on-orbit edge computing within the ACMES platform. See figures 9 & 10.

Two unique ATCs were required because of the overall power load of the HyTI 2.0 instrument. The high energy density of the top optical assembly, and the fact that the AIM SF-100 cryocooler and optical assembly require a very precise and well controlled setpoint temperature, while the BM SEP operates at a wider and elevated temperature range.

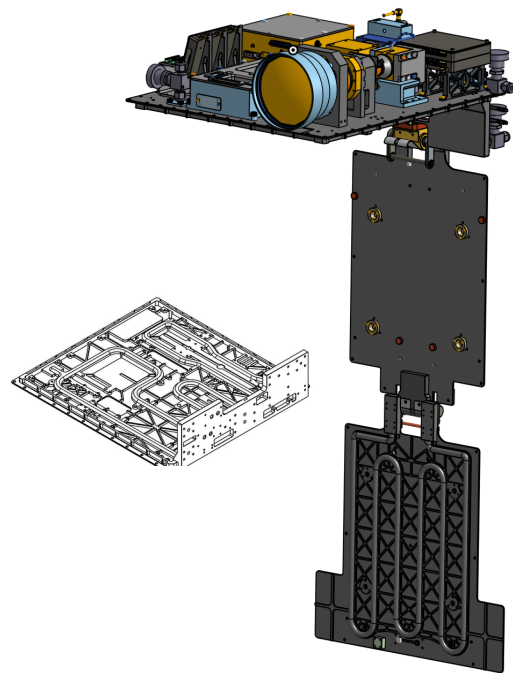


Figure 9. Top heat exchanger of the ACMES ATA payload. Supporting the HyTI 2.0 optical assembly, AIM SF-100 cryocooler and IDCA, Saaz camera link electronics board, and WCS power control module. Inset, ATA DD #1 HX.

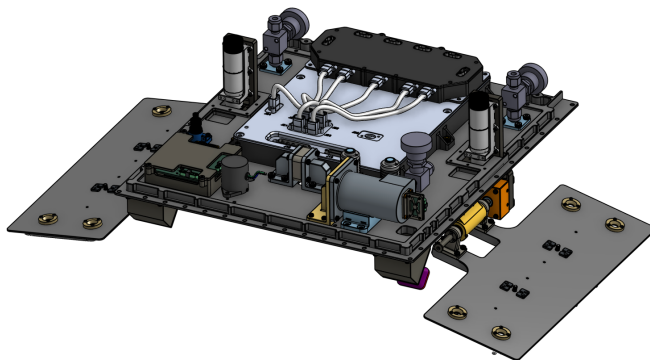
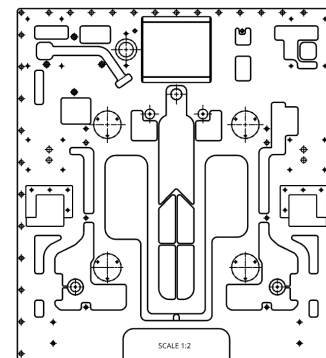


Figure 10. Bottom heat exchanger of the ACMES ATA payload. Supporting the Blue Marble space edge processor. Right, ATA DD #2 HX.



6 Thermal Performance of the ATA Technology

The thermal performance of the ATA system has been demonstrated and characterized within a laboratory setting and qualified to a TRL of ~6 (ACCS & ATACOI programs). In addition, the thermal performance of the technology has been modelled both from an analytical perspective and numerically through ANSYS (C&R Technologies) Thermal Desktop.

The ATA TD model was built considering: MMA ~230 W tracking solar arrays, the HyTI 2.0 instrument, ATA ATC decks 1 & 2, deployable tracking & folding radiators, the ATA Titanium pinch frame, and operational trim heaters. The TD model was built from AutoCAD primitives, while the MPFL was modelled using TD's built-in FLOCAD software.

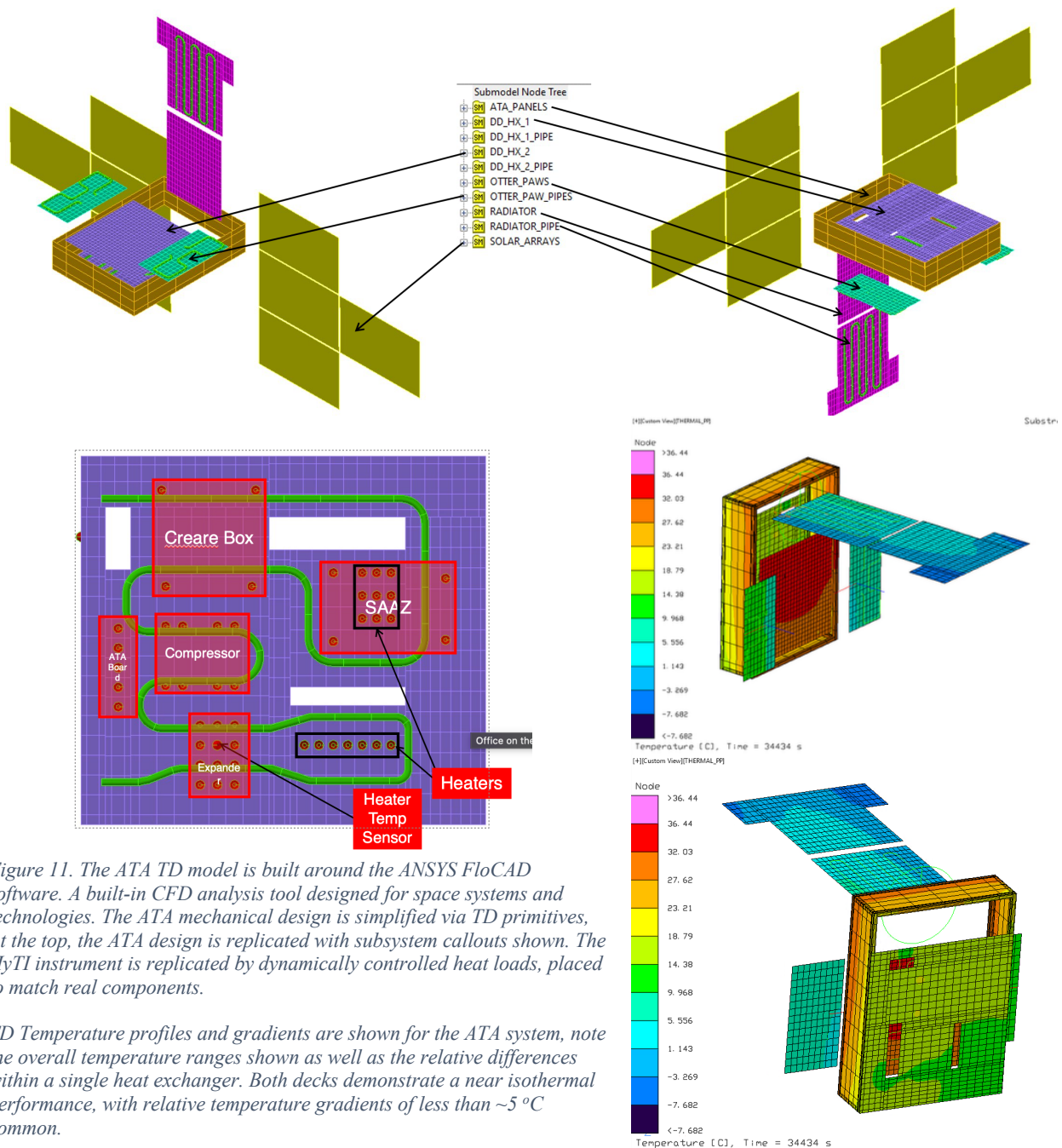


Figure 11. The ATA TD model is built around the ANSYS FloCAD software. A built-in CFD analysis tool designed for space systems and technologies. The ATA mechanical design is simplified via TD primitives. At the top, the ATA design is replicated with subsystem callouts shown. The HyTI instrument is replicated by dynamically controlled heat loads, placed to match real components.

TD Temperature profiles and gradients are shown for the ATA system, note the overall temperature ranges shown as well as the relative differences within a single heat exchanger. Both decks demonstrate a near isothermal performance, with relative temperature gradients of less than $\sim 5^\circ\text{C}$ common.

While several mission profiles were analysed, the transient worst-case “Hot” scenario is shown below. For this case, the HyTI 2.0 instrument is fully operational, dissipating up to $\sim 150\text{ W}$ of thermal energy, with an average “up-time” of approximately 20 minutes defined by the ground coverage results of an STK orbital model. The top deck ATA ATC has a pre-defined setpoint of 20°C , while the lower deck is set to operate below 46°C (BM operational limit, with SMC-16 margin). The transient power profile of the HyTI 2.0 instrument and the controlled (feedback) response of the ATA are modelled from the same STK profile, demonstrating the transient response and control of the fluid PID. The flow rate of each MPFL is controlled between $\sim 100\text{ mL/min}$ (idle) and 500 to 600 mL/min. Covering fully laminar to turbulent flow (Turbulent $\text{Re} > 2900$). The flow vs. pressure vs. power curve of the TCS M510 pumps was provided by the vendor.

The simulation results of the ATA system are shown below in Figure 12, while the TD design and temperature colour maps of the same transient profile are shown above in Figure 11.

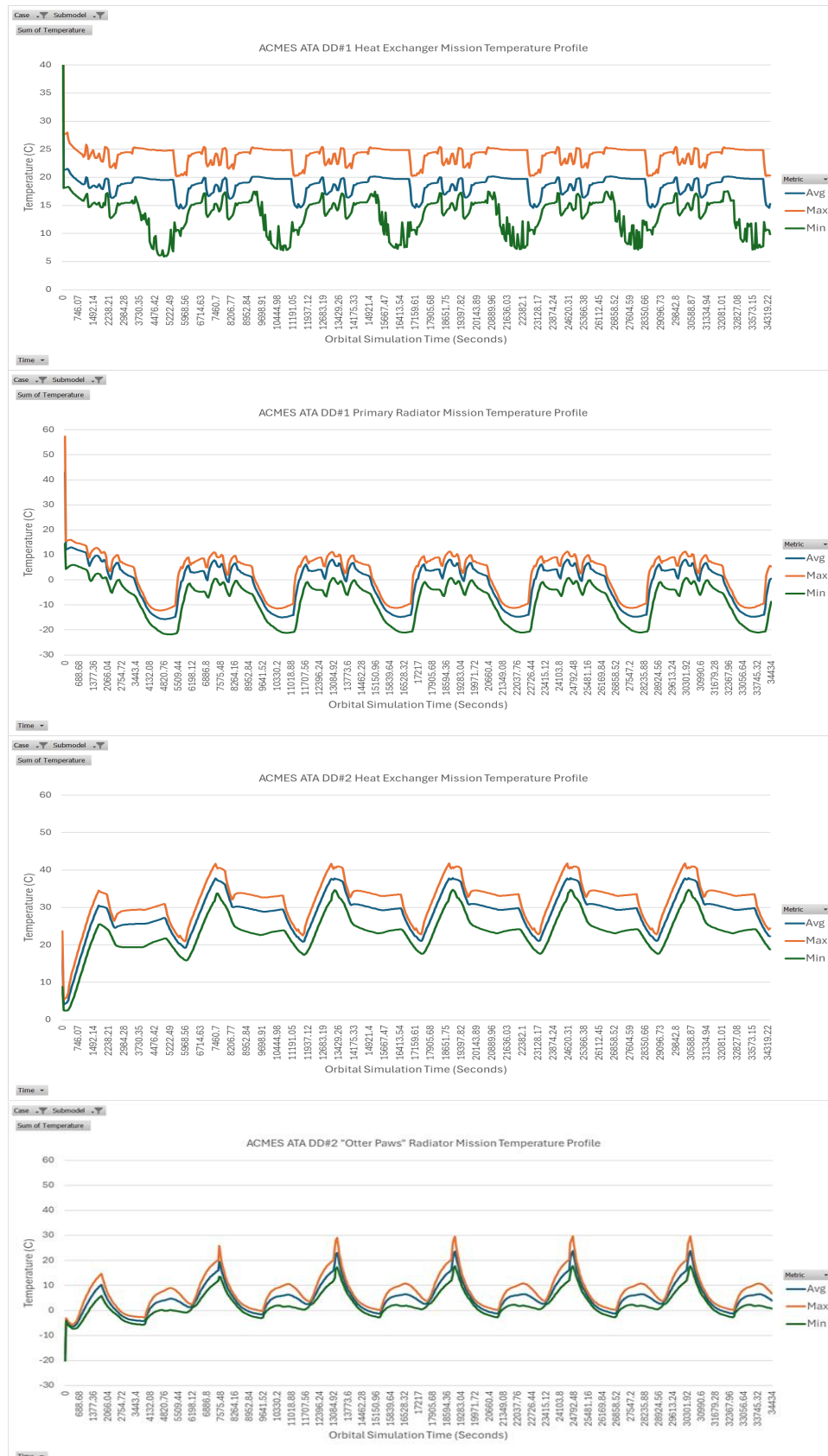


Figure 12. TD Analysed temperatures for the ACMEs ATA. Profiles represent a worst case transient hot mission profile. The max, min, and average temperatures are shown from top to bottom: ATA HX #1, Deck #1 radiator, HX #2, Deck #2 "Otter Paw" radiators.

The temperature of the top deck ATA heat exchanger, optical bench, does not exceed $\sim 25^{\circ}\text{C}$, while the deck #1 primary radiator operates at $\sim 0^{\circ}\text{C}$. These results indicate that the ATA system can successfully maintain the temperature of the HyTI 2.0 optical instrument and cryocooler below the required temperature of 40°C , which is the thermal runaway point of the cryocooler, considering an additional 10°C , thermal gradient within the cryocooler mount. When combined, this predicts an operational temperature of the HyTI cryocooler of $\sim 35^{\circ}\text{C}$, holding an additional $\sim 5^{\circ}\text{C}$ margin. In addition, the variation in the temperature of the top deck is less on average less than $\sim 5^{\circ}\text{C}$, providing an ideal operational environment for the camera, IDCA, and cryocooler. A tight interface temperature also improves the on-orbit focus of the optical assembly.

The second deck of the ATA operates over a much wider temperature range, with the ATC PID controller simply ensuring that the Blue Marble SEP interface temperature does not exceed $\sim 46^{\circ}\text{C}$ during long processing applications. The temperature of the second deck heat exchanger rarely exceeds 40°C , while the “Otter Paw” radiators operate up to 30°C .

The most temperature-sensitive component of the HyTI 2.0 instrument is the head of the cryocooler expander, mounted to the back of the HyTI IDCA and focal plane (camera). This mount is formed from a large, segmented block of Copper and is referred to as the “Tombstone” mount. The setpoint “sense” node of the ATA HX #1 MPFL PID loop is set to the interface of the optical bench to this Tombstone mount. At this interface and along the optical assembly of the HyTI instrument, the interface temperature requirements are elevated (restricted) to $\pm 2.50^{\circ}\text{C}$. To ensure suitable environmental stability for the IDCA, focal plane, and non-thermal optical assembly. As can be seen from the data plot shown in Figure 13, the ATA technology can successfully maintain the critical interfaces to the HyTI instrument with a setpoint precision of $\pm 2.50^{\circ}\text{C}$. This temperature is maintained and controlled despite large swings in the payload power, operational regimes, and day-to-night cycles. Note that the cyclic variation in temperature shown in Figure 13 represents operational, processing, and idle cycles as the HyTI instrument overflies various simulated landmasses. This control is maintained by the tuned PID loop and the dynamic variation in the relative conductance of the ATA (MPFL convection), trim cold-biased heaters, and the orientation of the primary UAM radiator assembly.

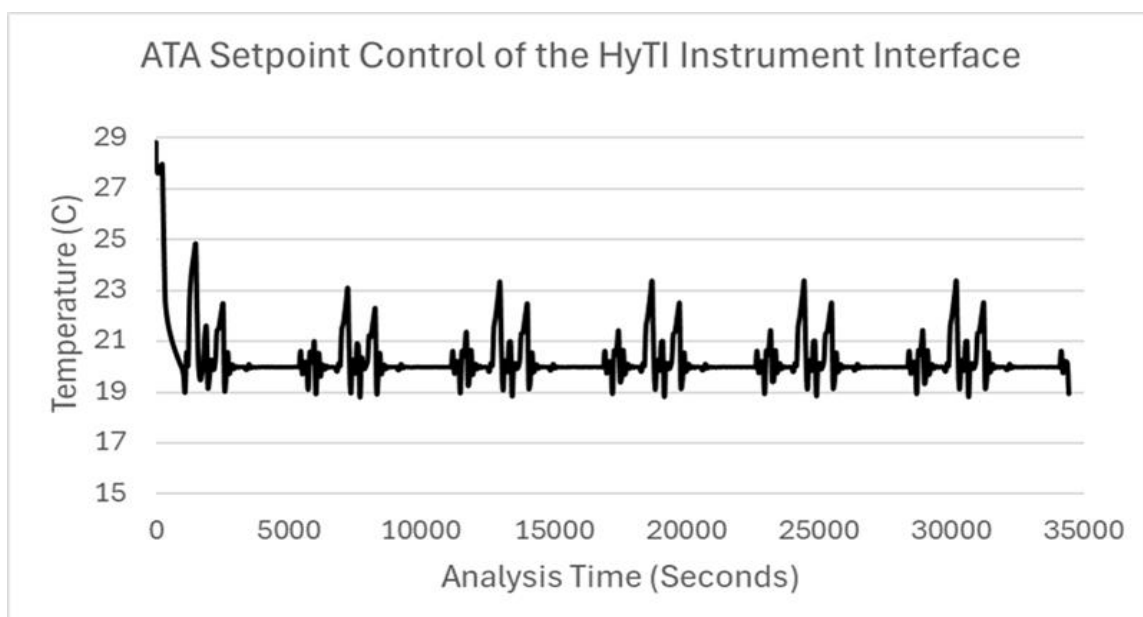


Figure 13. Temperature profile of the ATA HyTI “sense” node for the top deck heat exchanger. The ATC PID control loop was set to 20°C . Note, the variation of less than $\pm 2.50^{\circ}\text{C}$ over the transient mission profile.

7 THE ACTIVE COOLING FOR MULTISPECTRAL EARTH SCIENCE MISSION

HyTI is a push-broom, Fabry-Perot style interferometer, operating as a Long Wave IR (LWIR) optical imager, with up to 25 distinct spectral channels, an optical range of 8 to 12 μm , and a bandpass of 26 cm^{-1} [16, 17, 18]. HyTI 2.0 is a land imaging instrument with a ground sampling distance/resolution of better than 45 meters. The HyTI FLIR optical assembly is interfaced with the JPL HOT-BIRD detector via an AIRS Integrated Dewar Cooler Assembly (IDCA), maintaining the focal plane at an operating temperature of $\sim 65\text{ K}$ through an AIM SF-100 Stirling cryocooler. The HOT-BIRD focal plane array incorporates a 12 μm pixel pitch across a 1280×1024 format, enabling high spatial fidelity in the long-wave infrared (LWIR). The system is designed to achieve a noise-equivalent differential temperature (NE ΔT) of $<0.3\text{ K}$, supporting high-sensitivity radiometric measurements.

As a hyperspectral imager, HyTI produces spectrally resolved, radiometrically calibrated data cubes, requiring computationally intensive real-time onboard processing to transform Level 0 data into Level 1 products. This processing pipeline is executed by the Blue Marble Space Edge Processor (SEP) flight computer. Under nominal operations, HyTI 2.0 is expected to generate approximately $\sim 129\text{ GB/day}$ of L1 data, imposing significant demands on onboard processing, power, and thermal management systems. The instrument operates at an average power of $\sim 105\text{ W}$, with peak power consumption reaching $\sim 131\text{ W}$ to beyond $\sim 145.6\text{ W}$, driven primarily by cryocooler operation and high-throughput data processing requirements.

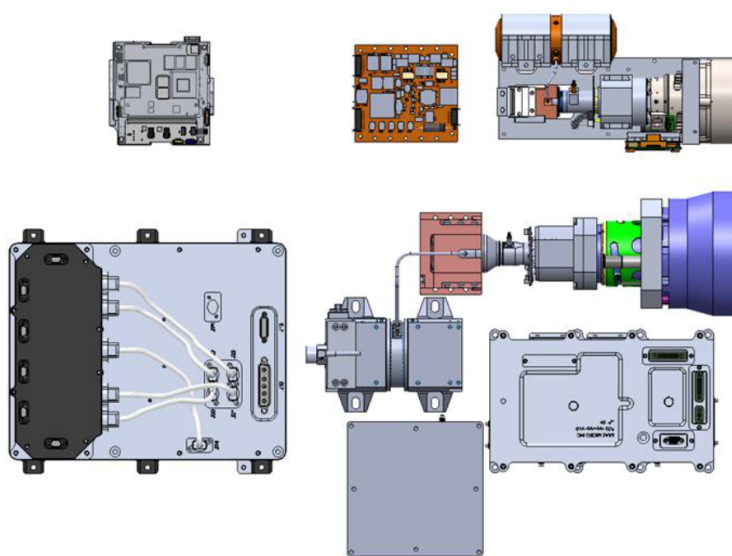


Figure 14. The HyTI instrument. The original HyTI instrument, flown in 2024 is shown on top along with the AIRS camera link board and the UniBAP IX5 onboard computer. The second-generation HyTI instrument, shown as the bottom assembly, offers substantial performance improvements and is larger.

The HyTI 2.0 instrument represents the next generation of compact long-wave infrared (LWIR) imaging systems. Mission objectives include demonstrating high-performance thermal spectroscopy in a small satellite form factor, while scientific returns include high-impact Earth science applications. HyTI-2.0 enables mineralogical and geologic mapping, soil moisture assessment, and volcanic monitoring. The resulting payload is a highly capable, compact LWIR imaging system that advances the state of the art in small satellite remote sensing. The predecessor to HyTI 2.0, HyTI 1.0 was deployed on a 6U CubeSat in 2024.

8 The ACMES MISSION

The Active Cooling for Multispectral Earth Sensors (ACMES) [19, 20, 21] is a combined technology demonstration and scientific mission, with a minimum lifetime requirement of 1 year, for demonstration and qualification of the onboard payloads, instruments, and technologies, and a stretch goal of 4 years, which includes at least three years of scientific operation. ACMES will launch to a $\sim 550\text{ km}$ sun-synchronous (SSO) orbit with an LTAN of between 10:00 and 14:00. The ACMES satellite is a custom CubeSat bus produced by Orion Space Solutions as part of their Triton platform

line of satellite buses. In addition to the ATA technology and HyTI 2.0 instrument, ACMES will host two student-developed payloads. FINIS, a compact and low-power tilted filter spectrometer for daytime methane detection. FINIS will detect and characterize atmospheric Methane (CH₄) as plumes, point sources, and total column densities, providing a significant contribution to global climate observations. PLAID, a planar style ionospheric sensor package, will measure in situ electron density and spacecraft charging [24]. The ACMES STM specifies the following objectives:

Primary Goal: Enable the operation of cryogenic optical instruments on CubeSats.

- Demonstrate the Active Thermal Architecture (ATA) technology in the space environment.
- Demonstrate on-orbit the active thermal control of a cryogenic instrument.
- Demonstrate on-orbit the thermal control of a high-power CubeSat.

Secondary Goal: Provide LWIR observations of the Earth's surface.

- Effectively operate a multispectral sensor as if it were part of a scientific mission to observe the land masses of the Earth for one year.
- Demonstrate the effectiveness of non-mechanical scanning multispectral sensor technology.

Tertiary Goal 3.0: Create opportunities for students to contribute to NASA's work in exploration and science.

- Provide work and research experiences that enable students to contribute to the ACMES mission.
- Inspire students to contribute to NASA's work in exploration and science.

The ACMES mission is funded by NASA through the Earth Science Technology Office (ESTO) through an InVEST grant. The mission is led by the Center for Space Engineering (CSE) at Utah State University, with development and production through Orion Space Solutions, an Arcfield company, and the Hawaii Space Flight Laboratory (HSFL). When launched, the ACMES satellite will be one of the most technologically advanced and capable Small Satellite missions to date.

9 CONCLUSIONS

The challenge of thermal control for the next generation of Small Satellites and CubeSats is an ongoing topic of discussion and research. Driven by the requirements and needs of modern instrumentation, large power densities, and the ever-present challenge of the space thermal environment. Additional considerations are total cost, development schedule, and drive to standardize thermal control technologies to support large constellations and swarms of CubeSats. The Active Thermal Architecture technology was developed as an integrated and scalable solution to these thermal problems. The ACMES mission and ATA technology will also demonstrate several key technologies, including:

- Micropump operation
- Scalable MPFL thermal control (variable conductance)
- Piston-based fluid accumulators
- Triple seal elastomer “Soft Goods” sealing design
- Rotary fluid joints
- Deployable fluid radiators
- Folding and tracking radiators
 - Dynamically controlled view factors & total radiative area.

The ATA technology is currently undergoing production, with ground-based characterization and qualification scheduled for Spring/Summer of 2026. The ATA technology will serve as a thermal payload support system to the Hyperspectral Thermal Imager (HyTI) 2.0 instrument and will launch as part of the upcoming Active Cooling for Multispectral Earth Sensors (ACMES) mission.

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