

## Project Abstract

The Shape-Morphing Adaptive Radiator Technology (SMART) project builds off the FY16 research effort that developed a flexible composite radiator panel and demonstrated its ability to actuate from SMA's attached to it. The proposed FY17 Shape-Morphing Adaptive Radiator Technology (SMART) project's goal is to 1) develop a practical radiator design with shape memory alloys (SMAs) bonded to the radiator's panel, and 2) build a multi-panel radiator prototype for subsequent system level thermal vacuum tests. The morphing radiator employs SMA materials to passively change its shape to adapt its rate of heat rejection to vehicle requirements. Conceptually, the radiator panel has a naturally closed position (like a cylinder) in a cold environment. Whenever the radiator's temperature gradually rises, SMA's affixed to the face sheet will pull the face sheet open a commensurate amount – increasing the radiator's view to space and causing it to reject more heat. In a vehicle, the radiator's variable heat rejection capabilities would reduce the number of additional heat rejection devices in a vehicle's thermal control system. This technology aims to help achieve the required maximum to minimum heat rejection ratio required for manned space vehicles to adopt a lighter, simpler, single loop thermal control architecture (ATCS). Single loop architectures are viewed as an attractive means to reduce mass and complexity over traditional dual-loop solutions. However, fluids generally considered safe enough to flow within crewed cabins (e.g. propylene glycol-water mixtures) have much higher freezing points and viscosities than those used in the external sides of dual loop ATCSs (e.g. Ammonia and HFE7000).

## Project Full Description

The Shape-Morphing Adaptive Radiator Technology (SMART) project's focus is to produce a higher fidelity radiator design by 1) integrating the SMAs into the radiator panel, 2) bonding the radiator panel to its flow tube, and 3) developing new SMAs that open/close the radiator at temperatures (about +8 to -10C) required by a single loop active thermal control system for future manned spacecraft to Mars. The FY16 radiator panel had a composite laminate structure and mechanically fastened the SMAs to the radiator's outer diameter. Integration of the SMA into the panel itself can increase the radiator's robustness, decrease assembly complexity, and improve heat transfer between the SMAs and the panel. Likewise, integration of the flow tube into the radiator panel can improve its heat rejection efficiency. Custom SMA development is required as there is no known SMA material that is able to fully actuate within this application's narrow temperature range.

This technology addresses two of the Evolvable Mars Campaign's (EMC) needs, primarily 1) variable heat rejection for thermal control systems, and secondarily 2) reliable mechanisms for long-duration missions beyond low earth orbit (LEO). These missions require an active thermal control system (ATCS) with a maximum to minimum heat rejection ratio (i.e. *turn down ratio*) of 6:1, according to NASA's thermal technology roadmap [TA14]. The highest turndown ratio a state-of-the-art ATCS can achieve is 3:1. Developing non-consumable variable heat rejection technologies is imperative as current manned spacecraft have only achieved turndown ratios of 3:1. Incorporation of a regenerative heat exchanger into an ATCS can increase its turndown ratio to >3:1 but requires a dual-loop ATCS. Adopting a single loop over a dual loop architecture may reduce the ATCS mass by about 25% while simplifying vehicle design. This technology is currently at a TRL2 - its concept has been formulated and its feasibility demonstrated with analysis, bench top, and vacuum experimentation of SMA wires attached to a flexible composite radiator panel in cold/hot ambient environments. An FEA/thermally coupled radiator engineering model has also been developed for this technology. This project's effort aims to increase the SMART technology to a TRL3.

(Sources: 1) Fumagalli, L., Butera, F., and Coda, A. "SmartFlex NiTi Wires for Shape Memory Actuators." *Journal of Materials Engineering and Performance*, Volume 18(5-6). August 2009. 2) Cognata, Thomas, Hartl, Darren, Sheth, Rubik, and Dinsmore, Craig. "A Morphing Radiator for High-Turndown Thermal Control of Crewed Space Exploration Vehicles." *AIAA/AHS Adaptive Structures Conference*, AIAA SciTech. 2015. 3) E. K. Ungar, "Spacecraft Radiator Freeze Protection Using a Regenerative Heat Exchanger with Bypass Setpoint Temperature Control," 01-Jan-2008.)

## Description of Technology

A future flight variable geometry (variable heat rejection) radiator could use a design to the one this project develops. The radiator panel consists of SMA's bonded to a flexible carbon composite cylindrical panel. The panel opens/closes based on the temperature dependent behavior of its shape memory alloys (SMAs). When the radiator's temperature rises, the SMAs pull the face sheet open a commensurate amount – increasing the radiator's view to space and causing it to reject more heat. As the radiator cools, the SMAs reduce their pull and a bias spring force built into panel closes it. SMA materials have been used in a number of aerospace applications and are robust, with an actuation fatigue life exceeding 1E4-1E6 cycles. SMAs can also be manufactured and trained to actuate at an application's desired temperatures. For optimal heat rejection, the panel will be structurally and thermally optimized to provide the best variable heat rejection performance possible. (Sources: 1) Bargsten, Clayton, and Gibson, Malcom. "NASA Innovation in Aeronautics: Select Technologies That Have Shaped Modern Aviation." NASA/TM-2011-216987. 2011. 2) Fumagalli, L., Butera, F., and Coda, A. "SmartFlex NiTi Wires for Shape Memory Actuators." Journal of Materials Engineering and Performance, Volume 18(5-6). August 2009.)

## Capabilities provided

This technology provides the following capabilities to future manned spacecraft thermal control systems:

### 1. Increased turndown ratio

This project will produce a radiator design that can change shape based on its temperature. This opening/closing may enable the radiator to reject a large range of heat loads based on changing mission needs. Previously, a joint study conducted by Jacobs, Texas A&M, and NASA showed the potential benefits of morphing radiator technology to manned spacecraft. (Source: Cognata, Thomas, Hartl, Darren, Sheth, Rubik, and Dinsmore, Craig. "A Morphing Radiator for High-Turndown Thermal Control of Crewed Space Exploration Vehicles." AIAA/AHS Adaptive Structures Conference, AIAA SciTech. 2015.)

### 2. Ability to employ a lighter and more robust single-loop manned spacecraft thermal control system

The highest turndown ratio an ATCS has employed in current manned spacecraft is 3:1. This limits the current architecture for crewed vehicles to a two loop design because only toxic heat transfer fluids (e.g. Ammonia on the ISS) will not freeze at the ATCS's minimum temperature and piping within the crewed cabin cannot carry toxic fluid. Improved variable heat rejection capability can enable a shift in ATCS design from the conventional dual loop to a single loop architecture by decreasing the required temperature range of an ATCS and thus increasing the ATCS's minimum temperature. Adopting a single loop over a dual loop ATCS could reduce a system's mass by about 25% while also simplifying vehicle design. (Source: Cognata, Hardtl, Sheth, and Dinsmore, "A Morphing Radiator for High-Turndown Thermal Control of Crewed Exploration Vehicles." JSC-CN-32425. 2015)

### 3. Increased reliability of ATCS

A future ATCS could use a SMA radiator for passively controlled variable heat rejection to increase the reliability of the system by avoiding more complex control systems or moving parts.

## Potential Applications

The Shape Morphing Adaptive Radiator technology is envisioned to be used within active thermal control systems of crewed vehicles that travel beyond Low Earth Orbit because. Missions beyond LEO are subject to large variations in the external thermal environment and internal heat loads. This radiator's

## Shape Morphing Adaptive Radiator Technology (SMART) Updates to Techport Entry.

passive ability to change its shape based off its temperature provides these missions with a zero power, consumable free, and reliable method for variable heat rejection.

### **Benefits to NASA Funded Missions**

#### Benefit to Future Crewed Missions

A future flight Shape Morphing Adaptive Radiator could use a lightweight composite face sheet (lighter than a conventional radiator face sheet) similar to the one this project develops. This radiator's variable heat rejection capabilities may 1) reduce the number of additional heat rejection devices in an ATCS and 2) help achieve the turndown ratio required to enable manned spacecraft to shift from a dual loop to a single loop ATCS architecture. The shift from a two loop to a single loop system is desired for future missions to significantly reduce the mass, volume, and therefore cost of the system.

#### Benefit to NASA Technology Development

NASA gains access to a Texas A&M subject matter expert in constitutive modeling, design, and optimization of SMA materials and components. He has worked in the development of SMA-based applications for noise reduction, airframe sensing, and aerodynamic performance adjustment, including devices for full-scale flight testing.

NASA GRC will provide technical oversight of SMA materials selection, analysis of SMA's behavior, and SMA's integration into prototype radiator. (Includes: SMA selection and material training (conditioning) of SMA wires).

NASA JSC Structural Engineering Division (ES) Materials & Processing Group will also be involved. They will provide technical oversight in development of radiator design to ensure it is suitable for space applications. (Includes: assistance in selecting the SMA to composite panel and flow-tube to composite panel bonding methods, review of preliminary designs to provide feedback on best practices associated with space structures and materials, and review radiator assembly method considering the requirements of manned spaceflight).