# NASA Phase II Project Summary

**Firm: Creare LLC**
**Contract Number: NNX11CA95C**
**Project Title: Micromachined Active Magnetic Regenerator for Low Temperature Magnetic Coolers**

### Identification and Significance of Innovation:

The overall technical objective is to develop a lightweight, efficient cooler for advanced cryogenic detectors used in NASA's future science missions. The approach is to develop a highly efficient, lightweight Active Magnetic Regenerative Refrigeration (AMRR) system that can continuously provide remote/distributed cooling at temperatures in the range of 2 K with a heat sink at about 11 to 15 K. In this program, the specific aim is to develop a highly effective Micromachined Active Magnetic Regenerator (MAMR) to enable the AMRR to achieve high thermal efficiency. The MAMR is comprised of a stack of Gadolinium Gallium Garnet (GGG) disks with microchannels fabricated by unique microfabrication process to enhance heat transfer. The regenerator core has a unique configuration to enhance flow distribution and reduce axial conduction. The regenerator also has a unique structural design to enable the fragile micromachined GGG disks to withstand launch vibration and cyclical compression force induced by the strong magnetic field on the MAMR stack. The resulting MAMR from this program enables subsequent demonstration of a brassboard AMRR.

### Technical Objectives and Work Plan:

The overall objective is to build an MAMR for a brassboard AMRR to the system to achieve high thermal performance when lifting heat from about 2 K to 15 K. The specific technical objectives are to develop (1) a reliable microfabrication process for microchannels in GGG disks, (2) a channel configuration for high thermal effectiveness and low pressure drop, and (3) a robust support structure for the GGG stack to enable the GGG disks to withstand launch vibrations and magnetic force during normal operation.

To achieve these objectives, we performed a series of microfabrication trials to identify the practical approach to machine high-aspect-ratio microchannels in Gadolinium Gallium Garnet (GGG) disks. We developed an MAMR configuration based on the practical constraints of the selected microfabrication process. We conducted a series of design analyses to optimize the regenerator design to enhance its thermal and structural performance. We conducted separate effects tests to verify the design analysis. Finally, we assembled an MAMR prototype with 150 micromachined GGG plates. Based on the thermal and pressure drop test data, we optimized the circulation flow rate through the regenerator in a brassboard AMRR system and predicted its performance.

### Technical Accomplishments:

In Phase II, Creare identified a unique microfabrication process that can machine very uniform microchannels with a diameter of about 250 microns in very brittle GGG disks with a very high yield rate (>99%). We developed a regenerator configuration with a stack of GGG

plates. CFD simulation and test data show the regenerator configuration achieves higher heat transfer and a much lower axial conduction heat leak with a given pressure drop than a conventional packed-bed regenerator. Our structural design analyses and static and dynamic structural test data show that the internal structural support for the GGG stack will enable the GGG plates to survive launch vibrations and cyclical magnetic body forces during normal operation, and, the required preload to support the GGG stack is less than 50% of the effective ultimate compressive strength of the GGG plates. The overall mass of the prototype regenerator is 470 g (including VCS fittings and non-prototypical flange) for an AMRR lifting 30.6 mW of heat from 2.3 K to 11 K. Our analysis model predicts that the COP of an AMRR incorporating Creare's MAMR and reversible cryogenic circulator technologies will be about 42.8 % of that of a Carnot cycle.

**NASA Application(s):**

The lightweight magnetic cooler with a continuous circulation loop will be a key enabling technology for NASA's future advanced infrared, X-ray, and gamma-ray detectors.

**Non-NASA Commercial Application(s):**

Private sector applications will include microanalysis, low cryogenic particle detectors, and biomolecule mass spectrometry.

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