TURBO-BRAYTON POWER CONVERTER FOR SPACEFLIGHT APPLICATIONS. J. J. Breedlove, D. Deserranno, and M. V. Zagarola, Creare Incorporated, 16 Great Hollow Rd., P.O. Box 71, Hanover, NH 03755, jfb@creare.com.

Introduction: Future NASA space missions require advanced systems to convert thermal energy into electric power. Closed-loop Brayton converters are attractive for these applications because they have high efficiency and specific power. They also consist of discrete components that can be packaged to fit optimally with other subsystems, and their continuous gas flow can communicate directly with remote heat sources and heat rejection surfaces without ancillary heat transfer components and intermediate flow loops.

Development of turbo-Brayton converter technology for space is under way at Creare. The approach builds upon a 35-year foundation of advanced turbo-Brayton components and systems Creare has developed for numerous NASA, DoD, and DoE applications; including the NICMOS Cryogenic Cooler on the Hubble Space Telescope. This prior work provides critical technology and expertise regarding spaceflight Brayton systems, which is now being leveraged to develop power converters for space. The technology is readily scalable for power levels from tens of watts to hundreds of kilowatts and beyond. Potential near-term NASA applications include Radioisotope Power System (RPS) devices, "Kilopower" spacecraft, and Fission Surface Power (FSP).

Technology Description: Figure 1 is a schematic representation of a closed-loop Brayton converter. In this configuration, the compressor pressurizes the cycle gas and forces it to flow through the system in a continuous loop. The temperature of the cycle gas increases as it flows through the recuperator and the hot interface heat exchanger. The hot, high-pressure gas then produces mechanical power as it expands through the turbine. The turbine exhaust stream transfers most of its heat to the high-pressure flow stream via the recuperator. The precooler then transfers waste heat to the heat rejection system before the gas is pressurized again. The compressor impeller and turbine rotor are attached to a common shaft with a permanent-magnet alternator between them. As a result, the mechanical power produced by the turbine drives the compressor directly, and excess shaft power generates electric power via the alternator. The power conversion electronics transform the high-frequency, three-phase, alternator output into regulated DC power for general use. A heat rejection system transfers waste heat from the precooler, turbomachine housing, and electronics to space via radiator surfaces.

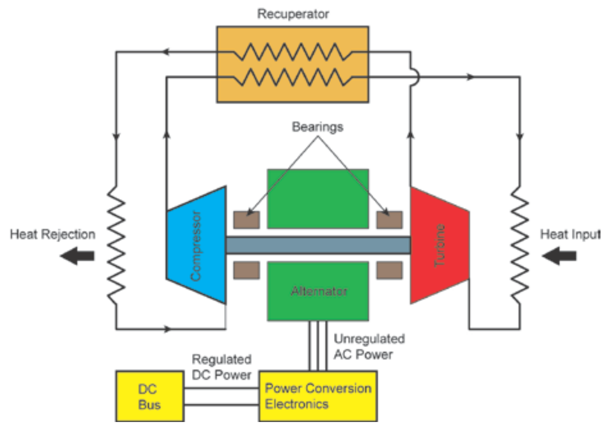

Figure 1. Schematic for Closed-Loop Brayton Converter

Creare Brayton cryocoolers have satisfied rigorous NASA and DoD requirements for reliability, endurance, vibration emittance, launch tolerance, electromagnetic interference and susceptibility, and environmental cycling [1], [2]. One such system operated on the Hubble Space Telescope for over 6.5 years while meeting all mission requirements [3]. More recently, Creare made significant improvements in manufacturing readiness level for another spaceflight program [4], and is continuing advanced component and system development work for several emerging space applications [5], [6]. Creare began applying turbo-Brayton technology toward the development of miniature power converters in 2001 with NASA projects directed at space exploration powered by radioisotope heat sources [7], [8]. These projects along with several others have demonstrated fundamental technologies required at relevant sizes, power levels, temperatures, and rotational speeds.

Hydrodynamic gas bearings and clearance seals are key features. Gas bearings support the turbomachine rotor with no mechanical contact between moving surfaces. This lack of contact enables extremely high rotational speeds, which is important for high efficiency and low mass. In addition, gas bearings eliminate wear and the need for lubricants, which enables extremely long maintenance-free lifetimes and makes the resulting systems ideal for space applications. Similarly, clearance seals limit internal bypass leakage without mechanical contact. Several reliability demonstrations have been completed, including a 14-year endurance test with no maintenance or wear, and compressor and turbine assemblies each exposed to 10,000 start/stop cycles with no maintenance or wear.

Current Work: The near-term focus is to demonstrate a laboratory-grade converter with a viable path for future spaceflight versions. This achievement will demonstrate the most critical elements of the technology at prototypical operating conditions. A power level of 1 kW_e was selected for the initial prototype to provide a relevant demonstration with capability to scale up or down in the future.

Creare completed two preliminary design projects for NASA GRC in 2011 and 2013. The first project designed a 1-kW_e converter for spacecraft missions, and the second project designed a 12-kW_e converter for FSP. Both designs are relatively simple with significant emphasis on low-risk features. Low-risk designs were specified to limit development effort and help ensure successful technology demonstration within budget limitations. Future development efforts are envisioned to push operational limits further and create more advanced features for greater power conversion efficiency and specific power.

Critical fabrication trials have been completed for the initial 1-kW_e prototype converter. Figure 2 shows a Ti6Al4V compressor impeller, Figure 3 shows a Rene 41 turbine rotor, and Figure 4 shows partial fabrication of a Mar-M-247 turbine rotor. The Rene 41 rotor provides acceptable creep life for conditions associated with FSP, while Mar-M-247 is required for long-life operation at higher temperatures.

Creare is now ready to fabricate, assemble, and test the prototype converter. A future paper will document the results of this work.

Figure 2. Ti6Al4V Compressor Impeller with Prototypical Aerodynamic Features

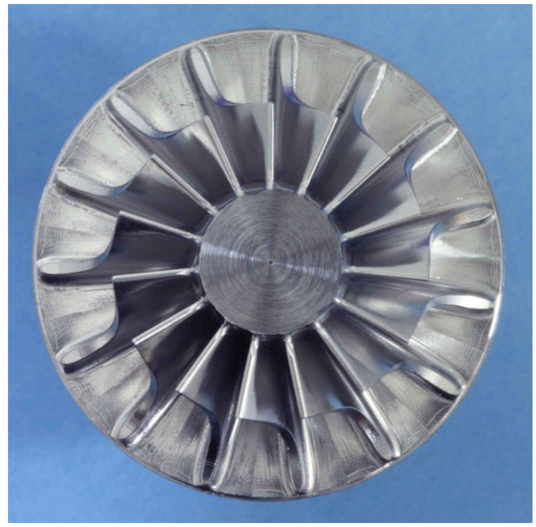

Figure 3. Rene 41 Turbine Rotor with Prototypical Aerodynamic Feature

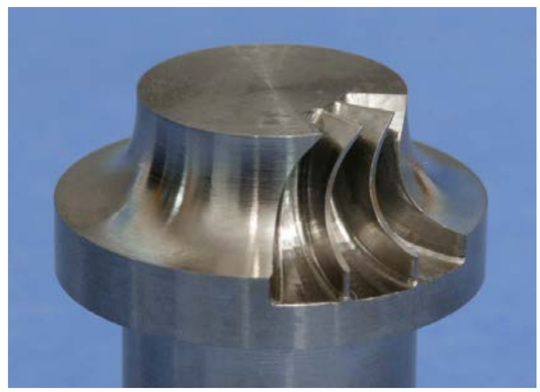

Figure 4. Partial Fabrication of Mar-M-247 Turbine Rotor

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