Progress on Ultra-Miniature 4 K Turbines for Low Temperature Turbo-Brayton Cryocoolers

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Future NASA astrophysics missions will require high-performance, multistage cryocoolers for cooling infrared and x-ray detectors. These missions include the Habitable Worlds Observatory, Origins Space Telescope and Lynx. Cooling loads at the coldest temperatures are 50 to 200 mW at temperatures of 4 to 10 K. Many missions also require that these cryocoolers produce extremely low vibration at frequencies below approximately 500 Hz. Turbo-Brayton cryocoolers are ideal for these applications due to low vibrations at low frequency and high efficiency at low temperatures. Turbo-Brayton cryocoolers utilize miniature, high-speed, gas bearing turbomachines for the compression and expansion process.

Turbomachine operating speeds are over 2 kHz limiting vibrations at low frequencies to those produced by low speed and density helium gas flowing in tubes. Creare has been developing component technologies under support from ONR and NASA for use in these cryocoolers. Compressors, recuperators, and intermediate temperature expansion turbines have been built and demonstrated at the required size, operating conditions, and performance. The remaining key cryocooler component, the cryogenic expansion turbine, has been demonstrated at temperatures as low as 10 K but sized for >200 mW of cooling. Operation at lower temperatures and cooling capacities results in poor cryocooler performance and high input power. Recent work has focused on scaling of the space-qualified turbine technologies to a size that permits efficient cryocooler operation at lower cooling loads and temperatures. This paper reviews progress on the fabrication and testing of two miniature, cryogenic expansion turbines – one optimized for a cryocooler producing 200 mW at 4 K, and the other optimized for a cryocooler producing 50 mW at 4 K. Both turbines represent landmarks in turbomachine miniaturization at Creare with the smaller unit utilizing a 1.3 mm diameter shaft.