

Space Technology

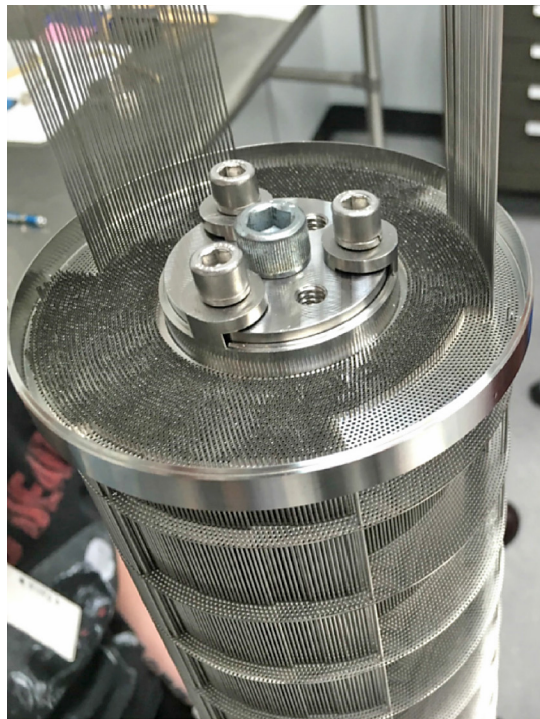
Game Changing Development

Cryocooler

Preventing Stored Propellant from Boiling Off in Space

To expand human presence into the solar system and onto the surface of Mars, NASA must store high-specific-impulse liquid hydrogen and oxygen (LH₂ and LO₂) in orbiting storage depots, on launch vehicle upper stages, and on Mars for months at a time. However, cryogenic propellants are liquids only at extremely low temperatures. Because heat radiated from the Sun and the Earth causes LH₂ and LO₂ to pressurize and because flight tanks weigh less if operated at lower pressures, the propellant tanks are vented and propellant is boiled off. This results in less propellant for propulsion. To make up for these losses during the long space missions envisioned, NASA would need to use oversized propellant tanks, but the cost to launch such tanks could very well be prohibitive. The application of zero boil-off (ZBO) technology using 20 K (−423.7 °F) cryocoolers for LH₂ propellant will prevent vaporization and keep reasonably sized tanks cold enough to store adequate propellant quantities for long periods of time.

The 20-Watt, 20-Kelvin (20-W, 20-K) Cryocooler for Thermal Control of Space-Based Liquid Hydrogen project objectives are to design,



In-process assembly of core for first recuperator.

fabricate, acceptance test, and deliver a prototype 20-W, 20-K cryocooler that can be used in a flight-representative NASA ZBO LH₂ test. Achieving 20 W of cooling is central to NASA's efforts to achieve ZBO, and as shown in the table, it will be a dramatic advancement over the state of the art.

The 20-W, 20-K cryocooler will use a reverse turbo-Brayton cycle, which expands (and cools) gaseous helium in a tubing network. The cooled helium will be distributed via broad-area tubing to the propellant tank heating sources.

In preparation for this 20-W, 20-K cryocooler development, the greatest technology challenge was addressed: advancing recuperator

Performance	20-W, 20-K	Comparison to SOA
Lift (cooling capacity of cryocooler), W	20	20 times >
Specific power (input electrical power needed per watt of lift), W/W	60	1/6th
Specific mass (mass of cryocooler per watt of lift), kg/W	4.4	1/4th

Comparison of 20-W, 20-K cryocooler with state-of-the-art (SOA).

heat exchanger technology. A microtube and shell configuration was designed, fabricated, and thermal performance tested. This is a design that has over 6600 tubes that are 0.56 mm in diameter in each of five recuperator modules in the cryocooler assembly. Laser welding trials optimized the process to eliminate leaks between the microtubes and face sheets, and all five recuperators have now been fabricated.

Recent testing in NASA Glenn Research Center's Small Multi-Purpose Research Facility (SMiRF) demonstrated the integration of a cryocooler with a cryogenic tank. Testing proved that there was only a small loss in cooling capacity when a reverse turbo-Brayton-cycle cryocooler was integrated with a cryogenic tank. The results were encouraging—the cryocooler system kept the propellant pressures and temperatures nearly constant throughout the tank and fluid. The tests successfully demonstrated reduced boil-off with LH₂ as well as ZBO and robust tank pressure control of LO₂ by a 15-W, 77-K reverse turbo-Brayton-cycle cryocooler system of the same technology that is used in the current development.

Upon completion of the 20-W 20-K cryocooler development, expected to be 2.5 years, NASA's plans are to verify the contractor's performance test of the 20-W, 20-K prototype cryocooler across a broad range of flow impedances, representing a range of tank sizes, as well as across a range of heat rejection temperatures that could be encountered in space.

The tests are expected to result in a verified prototype cryocooler that can be used as the technological foundation for the larger cryocoolers needed to keep a large LH₂ propellant tank at 20 K with ZBO. Results will be used to calibrate cryogenic propellant storage performance models and to estimate the performance of future, higher capacity versions of the cryocooler.

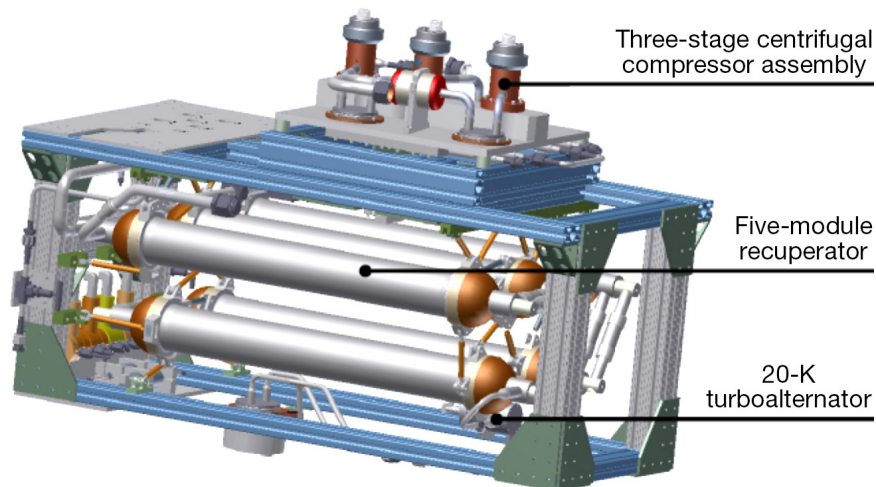
In December 2014, NASA awarded Creare the contract to design, manufacture, and test a 20-W, 20-K cryocooler. The 20-Watt, 20-Kelvin Cryocooler for Thermal Control of Space-Based Liquid Hydrogen Project is funded by the Game Changing Development Program. The Game Changing Development (GCD) Program investigates ideas and approaches that could solve significant technological problems and revolutionize future space endeavors. GCD projects develop technologies through component and sub-system testing on Earth to prepare them for future use in space. GCD is part of NASA's Space Technology Program.

For more information about GCD, please visit <http://gameon.nasa.gov>

Contacts:

Michael P. Doherty/NASA Glenn Research Center
michael.p.doherty@nasa.gov

David W. Plachta/NASA Glenn Research Center
david.w.plachta@nasa.gov



Three-dimensional model of the 20-W, 20-K cryocooler, showing its main components. The model does not show the broad-area tubing that distributes the cooled helium.

National Aeronautics and Space Administration

Glenn Research Center
Cleveland, OH 44135

www.nasa.gov