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Dragonfly Multi-Mission Radioisotope Thermoelectric Generator Secondary Cooling Chiller Cart

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Abstract

In 2028, NASA plans to launch the Dragonfly mission to explore Saturn's largest moon, Titan. This rotorcraft lander is powered by a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) which produces electric current from the heat generated by the radioactive decay of its radioactive plutonium-238 radioisotope. A heat load is produced continuously after the MMRTG is activated, making thermal control a challenge and critical for integration into the spacecraft.

Advanced Cooling Technologies (ACT), working closely with the Johns Hopkins Applied Physics Laboratory (APL), has designed and analyzed a Chiller Cart System that will control the MMRTG temperature by providing coolant to the secondary cooling loop of the unit. There are several design challenges and decisions to consider for this application which created challenges for a generally well understood cooling cycle. The author will discuss these challenges and how they were addressed in the context of the Dragonfly mission. The key points are more broadly applicable for general considerations as use of MMRTGs is expected to increase.

The Chiller will preheat the fluid to match the initial temperatures of the MMRTG fins preventing thermal shock to the system. The initial fin root temperatures can reach up to 191°C, so careful consideration had to be taken when choosing a fluid that can withstand this extreme temperature. Temperature range, boiling point, specific heat capacity, toxicity, dynamic viscosity, and cost were all characteristics that needed to be researched to select the appropriate fluid.

After connecting to the MMRTG secondary loop, the chiller will decrease the fluid temperature, lowering the MMRTG temperature to a safe level for operators to work around and charge any spacecraft systems. The desired inlet fluid temperature can range from 15°C to 130°C during the cooling operation. Since there is a significant difference between the initial secondary loop temperature and ambient conditions, a preconditioning coil will be utilized to reduce the overall size and capacity needed by the chiller. When a desired fluid temperature near or below ambient conditions is required, the chiller's Direct Expansion (DX) cooling system will be activated. The transition to active cooling must be

smooth to maintain a stable temperature.

Maintaining the MMRTG secondary cooling temperature is critical for safety, so the chiller system needs to be designed with redundancy, simplicity, and reliability. Multiple chillers are used in parallel to provide redundancy in case a chiller fails. Each chiller utilizes separate PID controls for simplicity and robustness, and manual switches are used to select heating or cooling modes. Keeping the controls separate also helps maintain redundancy in the system. The chillers feed into a common manifold where the fluid can be monitored and manually switched via ball valves. Switching the flow from one chiller to another must be quick and easy, and the switchover cannot affect the entering fluid temperature to the MMRTG. An auxiliary manifold near the MMRTG is necessary to monitor the temperature and control flow as close to the inlet as possible. This manifold could potentially be located inside the radiation zone (Class 1 Div. 2). For this reason, only manual valves are utilized, and no electronics are used for controls.

The chiller cart system is currently in the design phase working towards the critical design review in mid-July. The layout has been designed, controls strategy refined, and all components are specified. The fabrication process for the chillers and manifolds will begin in late September. Each chiller will complete performance testing before shipping out near the end of 2025 and beginning of 2026.