Northrop Grumman next generation Mini Cooler Plus performance

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Abstract. Northrop Grumman Aerospace Systems (NGAS) has expanded its cryocooler product line with the introduction of the Mini Cooler Plus (MCP) pulse tube cryocooler. The cooler is developed to provide a long-life, low-mass, high cooling capacity cryocooler for hyperspectral and infrared imaging payloads in tactical airborne and space applications.

The MCP is a split configuration pulse tube cooler with a passive coaxial cold head connected through a transfer line to a vibrationally balanced back-to-back linear compressor. Designed for space and non-space applications, the MCP’s compressor is scaled from NGAS’ larger flight proven TRL9 family of compressors and contains non-wearing pistons suspended on flexure bearings. The reliability and ten-year lifetime are among the features of this class of pulse tube cryocooler, and have been verified by in-orbit operation of NGAS space flight cryocoolers.

At 300 K reject, this 2.7-kg thermal mechanical unit can lift 1.5 W at 46 K with 150 W electrical input. This cooler is capable of cooling hyperspectral, LWIR (Long-Wave Infrared) and HOT (High Operating Temperature) IR payloads. This paper describes the MCP, its components and interfaces and presents the test data obtained in its laboratory configuration over a range of input powers and reject temperatures.

1. Introduction
The Mini Cooler Plus (MCP) has evolved from existing and proven Northrop Grumman (NG) products, including spaceflight coolers and developmental coolers for space and airborne applications. The evolution of the NG coolers to the MCP configuration resulted from scaling the compressor technology from the High Efficiency Cooler (HEC) compressor design to a smaller compressor that would be capable of achieving the performance requirements. The configuration of the cold head (split configuration) evolved from developmental coolers that were designed for tactical airborne applications with integrated cooler-dewar assembly (IDCA) arrangement. The initial motivation for the MCP was a tactical airborne application, scaled from spaceflight heritage that can provide the intrinsic high reliability in the NG design.

The compressor uses second-generation flexure compressor technology that is carried over and scaled from the space qualified HEC compressor [1]. The same scaling relationships were previously employed successfully in scaling the HEC compressor up to a 26cc compressor [2] and down to a 0.65cc compressor [3]. Using the same proven non-contacting compressor design in conjunction with NGAS state-of-the-art pulse tube cold head technology, the MCP is projected to have an operating life of over 10 years.
2. System description

The MCP is a split configuration thermal mechanical pulse tube cooler, with a remote coaxial cold head connected through a transfer line to the MCP Compressor, although it can be readily reconfigured for an integral cold head. Figure 1 shows the MCP’s Thermal Mechanical Unit (TMU). The modular split configuration allows flexibility in the compressor and cold head placements to meet the available cooler envelope. The cold head assembly can be oriented at any position relative to the compressor assembly and the transfer line (length and shape) can be customized to individual applications.

The estimated mass of the mechanical cooler in a flight configuration is about 2.7 kg, without the mounting provisions and/or the drive electronics.

![Figure 1: MCP’s Thermal Mechanical Unit](Image)

The compressor was scaled from the space qualified HEC compressor with special consideration given to the choice of material, design tolerances and fabrication processes to reduce the manufacturing cost. The compressor assembly processes were optimized for high volume productions. The same heritage HEC flight proven compressor technology (second-generation flexure bearings), which was previously developed with Oxford University and productized for Northrop Grumman by Honeywell Hymatic [2], was adopted by the MCP compressor design. The MCP compressor was designed for both airborne and space applications. To meet the airborne environment, the compressor is designed to operate at reject temperatures up to 70°C. The compressor dimensions are 59 mm in diameter and 183-mm in length, which is sufficiently compact to fit in small volumes generally required by tactical airborne applications. The compressor’s end caps are welded to the center plate to provide the hermetic seal and a good thermal contact between the end caps and the center plate. The compressor’s mechanical and thermal interfaces are along the circumference of the end caps for a uniformly distributed and low heat flux.

The coaxial cold head design and the cooler fill pressure in this work were optimized for cooling a focal plane to 47 K with 1.5 W lift requirement. The design of the copper cold tip allows heat removal by connecting a strap to the cold tip. The input power to the MCP can be up to 150 Wac (depending on the reject temperature). The cold head and compressor are connected through a 4-inch transfer line with AN fitting connections.

Figure 2 is a photograph of the MCP mounted onto the thermal vacuum chamber bed in its laboratory configuration, e.g. with bolted reservoir rather than welded reservoir and ground support test equipment. In this test configuration, the compressor and the cold head have independently adjustable thermal interface temperatures. The locations of the measured reject temperatures are shown with red circles in figure 2. In these tests, both reject temperatures were maintained at the same desired value. A cartridge heater block and two temperature sensors are mounted onto the cold tip for the performance measurements.
3. Results and discussion
The MCP has been tested with a coaxial cold head which was designed and optimized for 47 K operation. Because of the dependence of the optimum frequency on the thermal profile of the cooler, the testing operation includes determination of the optimal frequency for each operating condition. Figure 3 shows the frequency optimization for three representative operating conditions. The vertical axis is the scaled cold tip temperature based on the minimum cold tip temperature achieved for a given load. As illustrated in figure 3, the optimal operating frequency (defined by the minimum cold tip temperature) is found for three different cooling loads (no-load, 1.5W, and 10W) at a fixed input power (power into the compressor) and reject temperature. The three data points are then used to obtain lift vs temperature ‘load-lines’ for different input powers and reject temperatures. This operation was similarly done for other reject temperatures and input powers, producing the load lines shown in figure 4 and figure 5.

Figure 2: The MCP mounted in the thermal vacuum chamber with ground support test equipment. The locations of the reported reject temperatures are shown with red circles.
The load lines at three different input powers are plotted in figure 4 for 300 K reject temperature. As the input power increases from 60 W to 150 W, the no-load temperature decreases from 42 K to 35 K. The load lines shown in figure 4 demonstrate useful cooling for low temperature applications in the 40-K to 50 K range. The cooling capacity of this cooler, with 150 W input power, ranges from 1.5 W at 46-K to 7 W at 80 K and 19 W at 150 K (projected using a 2nd order polynomial curve).

Figure 4: The MCP load lines at different input powers

Figure 5 shows the effect of reject temperatures on the cooler performance in the range from 283 K to 313 K for a fixed input power of 90 W.

Figure 5: The MCP load lines at different reject temperatures
The data from the load lines (heat lift vs cold tip temperature lines at constant power, similar to figure 4) are plotted as isotherms of input power versus heat lift in charts which are commonly known as Ross plots. These charts also include line of constant specific power for reference. The cooler performance at 300 K is shown as a Ross plot in figure 6 indicating the ac input power required to achieve a given cold tip temperature for a given user load. The cooler specific power is fairly constant for input powers below 90 W.

![Cooler performance map at 300 K reject temperature](image)

Figure 6: Cooler performance map at 300 K reject temperature

4. Conclusion and future work
NGAS has expanded its cryocooler product line with the introduction of the MCP pulse tube cryocooler. Performance data of the MCP demonstrates its high cooling capacity at a very low cooler mass. The MCP shows performance improvement over the minicooler [4], with performance comparable to that of the coaxial HEC cooler [5] at temperatures around 45 K. The MCP is capable of cooling hyperspectral and infrared payloads for airborne and space applications. Near term testing of the MCP will continue through qualification testing for a planned upcoming spaceflight mission.

5. References
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