

Efficient High Capacity Space Microcooler

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ABSTRACT

The Northrop Grumman space micro pulse tube cooler is a split configuration cooler incorporating a coaxial cold head connected via a transfer line to a vibrationally balanced back to back linear flexure bearing compressor. Scaled from the TRL 9 HEC cryocooler and designed for > 10 year operation with no performance change, the 900 gram mechanical cooler incorporates a new cold head that has substantially increased its efficiency and cooling power over a range of temperatures above 40K. The very small, low vibration, high frequency cooler is designed to be directly integrated into space SWIR, MWIR and LWIR payloads or into an integrated detector cooler assembly (IDCA) similar to those used with shorter lived tactical coolers. Despite its small size the tested cooler is capable of providing near 5W of cooling at 150K or > 0.3W at 45K when rejecting heat to 300K. At lower reject temperatures it is more efficient and has even greater cooling power. This paper reports on the performance of this cooler.

INTRODUCTION

The Northrop Grumman space micro pulse tube cooler (micro) is a split configuration cooler that incorporates a coaxial cold head connected via a transfer line to a vibrationally balanced back to back linear compressor.^{1,2} The micro compressor is scaled from the flight proven TRL 9 high efficiency cooler (HEC) compressor and contains non-wearing gas gap seals for pistons suspended on flexure bearings. The HEC compressor has been scaled both to larger and in this case to smaller sizes over a two order of magnitude capacity range. Designed for > 10 year continuous or intermittent operation with no performance change, the 900 gram mechanical cooler with its new cold head can cool sensors and optics to temperatures between 40 K and 300 K while rejecting heat to radiators over a wide range of reject temperatures. The very small, low vibration, high frequency cooler is designed to be readily integrated into space and aircraft payloads with custom focal planes with or without an integrated detector cooler assembly (IDCA)³ similar to those used with the shorter-lived tactical coolers. This cold head design was also intended for use with the IDCA that we developed and tested and reported previously.³ The cold head is shown in Figure 1 together with its micro compressor. In Figure 1A the cooler is shown without its integrated inertance line and reservoir tank in a configuration allowing their packaging elsewhere. A model of the space version micro pulse tube cooler is shown in Figure 1B with its integrated inertance line and reservoir tank.

As shown in Figure 1 the flight micro cooler has been implemented with an all welded compressor and in the flight configuration shown has an estimated mass of 900g. The cold finger is designed to interface with infrared focal planes either through a thermal strap as is typical of space

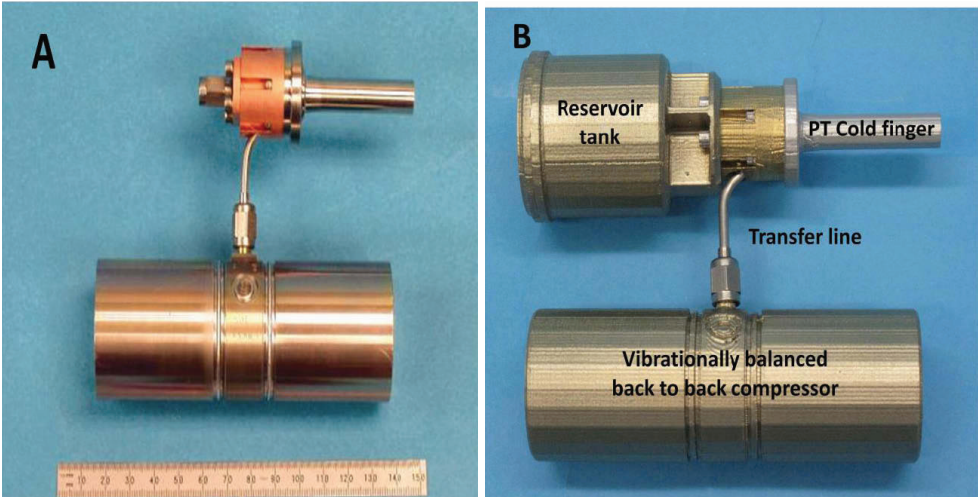


Figure 1. Flight design PT microcooler and its flight configuration with attached reservoir tank

cryocoolers or as in this case into an IDCA as is typical of tactical cryocoolers. The reservoir tank and inertance line assembly shown in Figure 1B is designed to be integrated with the cold head or alternatively to be located elsewhere if required by instrument packaging constraints. The transfer line can also be lengthened or re-oriented as required by payload packaging constraints.

TESTS

Our approach was to design and test an advanced pulse tube cold head that we integrated and tested with our existing micro compressor. The performance of the previous cold head was limited by the physical dimensions of its retrofit application and by its optimization for near 80°C reject temperature. In this case the cold head was optimized for performance in space with less than 27°C reject temperature and no restriction on the physical dimension of the cold finger. Its configuration was very similar to that of Figure 1A using a laboratory version of the inertance and reservoir tank as shown in Figure 2. The tests were conducted with varying input power, cooling load and reject temperatures of 273K and 300K.

Figure 3 shows the performance of the cooler over a range of temperatures and input powers for reject temperatures of 300K. The measured data points are shown. The input power is the measured power to the mechanical cooler not including any power dissipated in its drive electronics. The heat consisting of the input electrical power plus the cooling load was rejected at both the

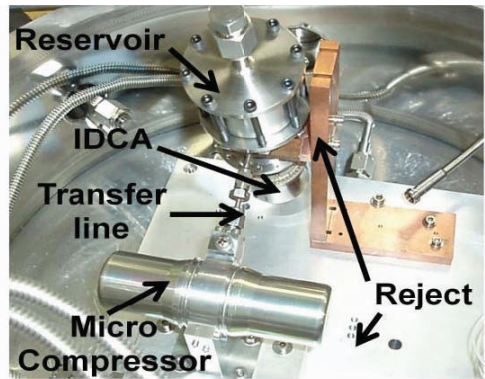


Figure 2. Test configuration

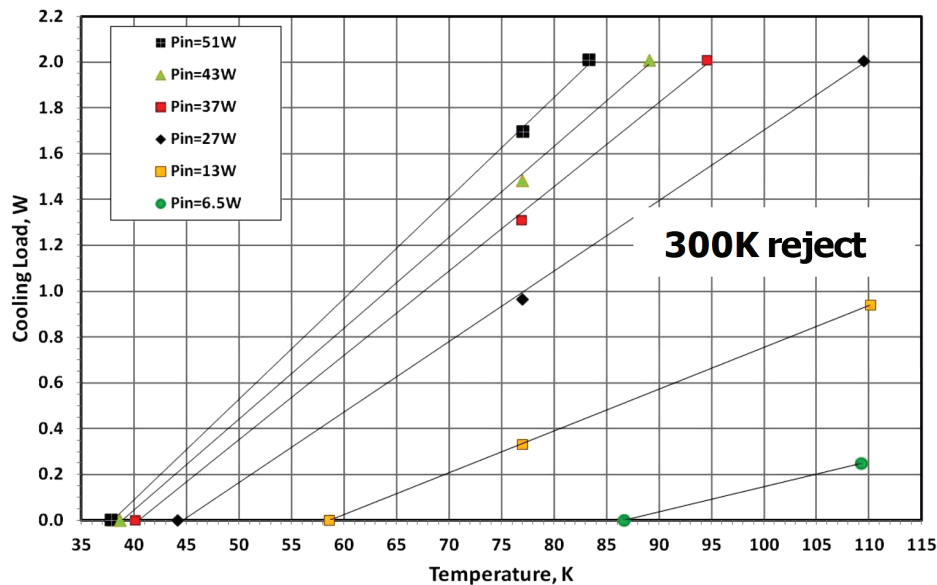


Figure 3. Microcooler performance data at 300K reject

compressor and cold head warm interfaces. Note the excellent specific power of ~25 W/W at 110 K, ~30 W/W at 77 K and ~40 W/W at 65 K for this very small cooler. The data taken was limited to a maximum of 2 W cooling load because of the current limitations of the test heater circuit.

Figure 4 shows the load lines and the data points for 273 K reject temperature. Note that for both the 273 K and 300 K reject temperatures the minimum cooler temperature is <40 K and that it has substantial cooling power at 45 K making this very small cooler useful for some LWIR applications. Figures 5 and 6 replot these data as isotherms and extrapolate the performance to 150 K (and cooling powers approaching 5 W) by making the very good assumption (as shown in previous pulse tube coolers to room temperature) that the load lines of Figures 3 and 4 are linear.

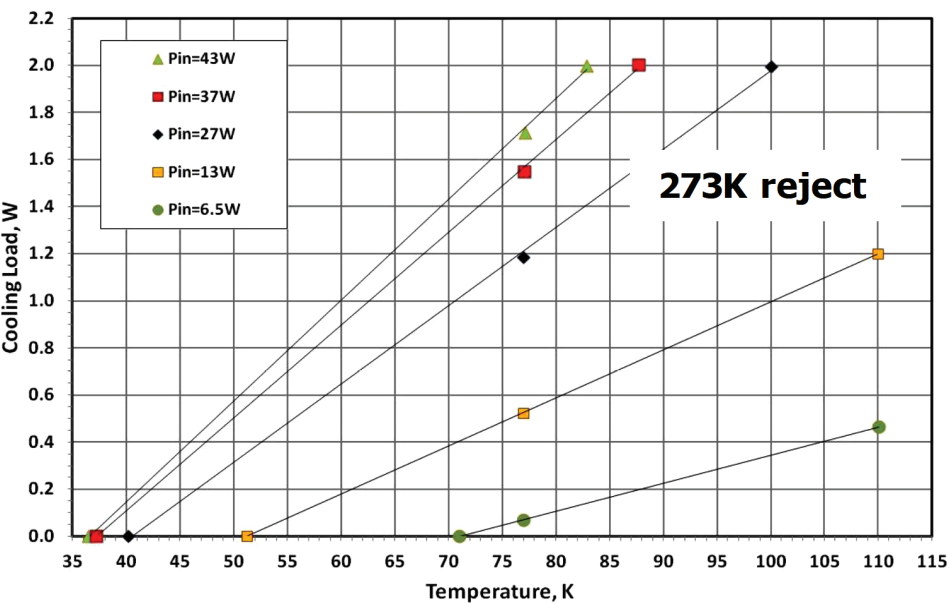


Figure 4. Microcooler performance data at 273K reject

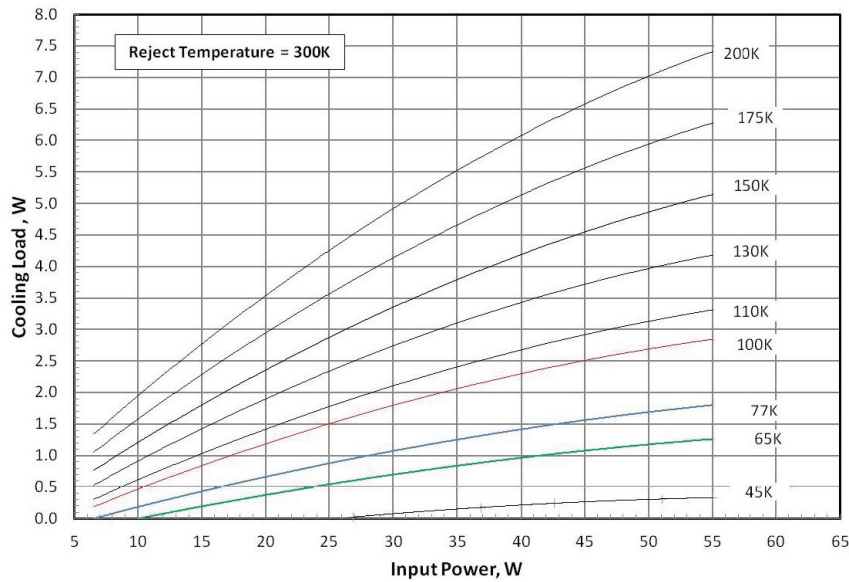


Figure 5. Microcooler performance at 300K reject

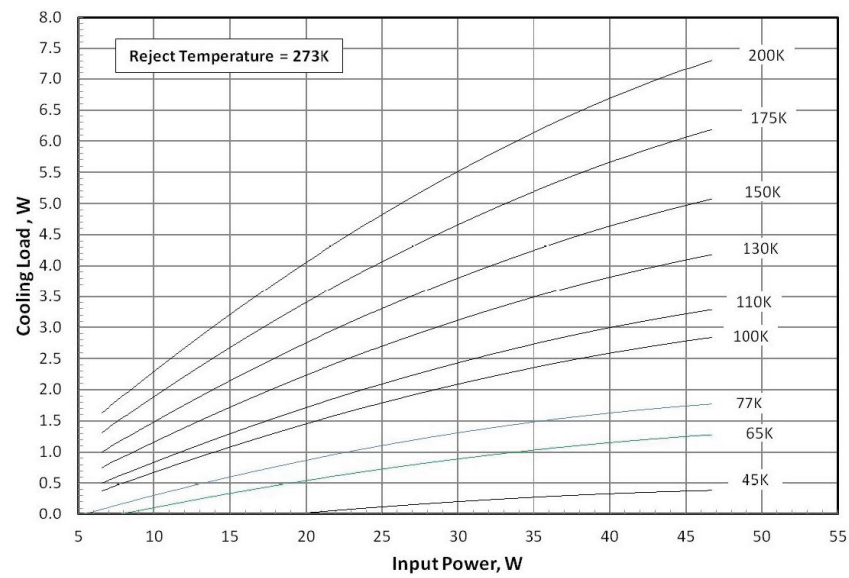


Figure 6. Microcooler performance at 273K reject

Figure 7 compares the previous Micro 1 cold head to this Micro 2 cold head. We had previously tested an IDCA with the original Micro 1 cold head design.³ The IDCA incorporated and integrated four key components; the dewar, focal plane, pulse tube cold finger, and long life flexure bearing compressor. The dewar assembly is a hermetically sealed evacuated dewar containing an optical window, a cold shield, provision for a cold filter, a 640x480 pixel InSb focal plane, wiring to the 41 pin hermetic connector, and the pulse tube cold finger as shown in Figure 1. The IDCA is a variant of previous devices that have been built in quantity for tactical applications whose environmental requirements exceed those typically found for space optical hardware. The dewar incorporates the key component that we greatly improved, the coaxial configuration pulse tube cold finger that cools the focal plane.

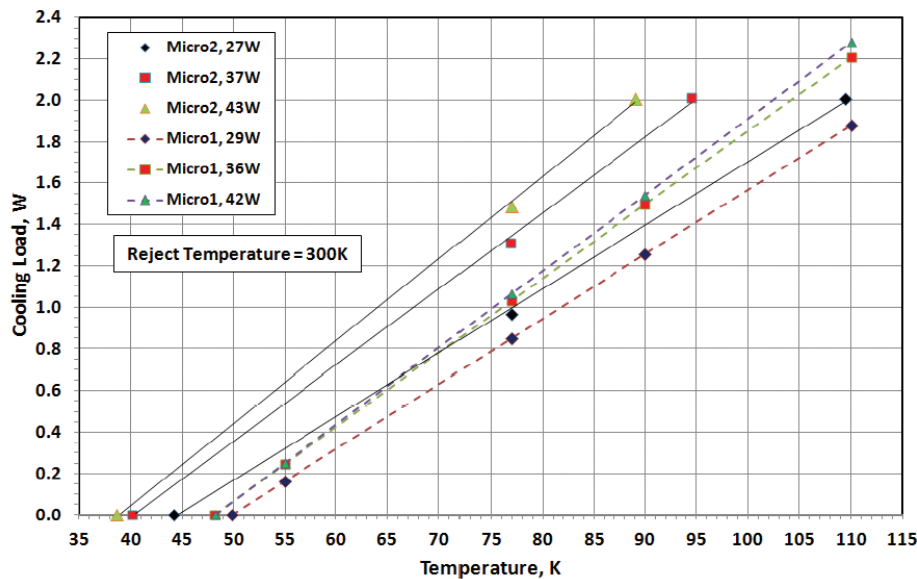


Figure 7. Comparison of the performance of the 2 cold heads.

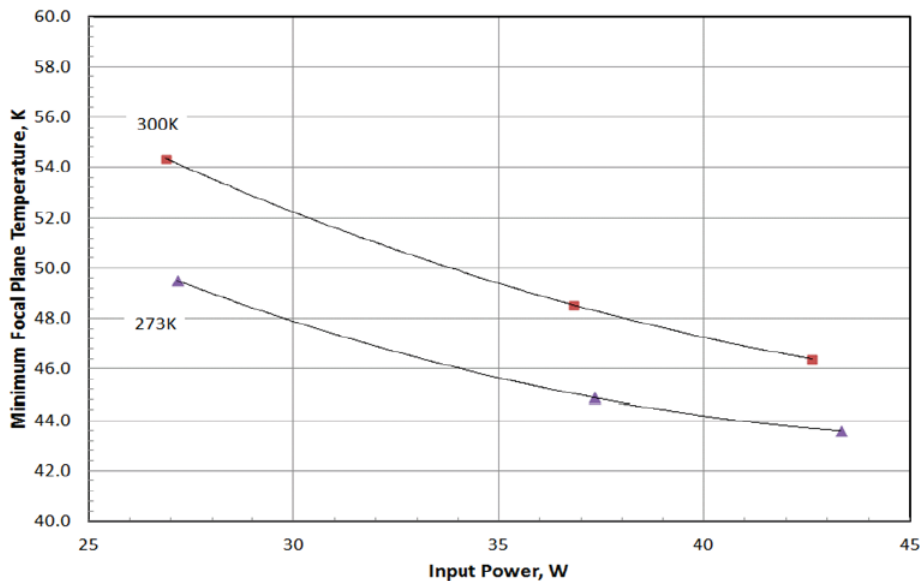


Figure 8. Performance of the IDCA if the improved cold head was incorporated.

In Figure 8 we project the minimum temperature cooling performance that we would expect in the IDCA including the internal parasitic loads but not the focal plane dissipation if we replaced its current cold finger with the improved cold finger. Despite the very small size of this cooler it is apparent that for a typical focal plane dissipation in the <100mW range the focal plane could operate to temperatures as low as 45K to 50K.

CONCLUSIONS

The microcooler with an improved cold head has been characterized for thermal performance in order to determine its range of application and use with various focal planes, both large and

small. Because of its increased cooling capability at low temperatures this very small system appears capable of cooling focal planes to temperatures as low as 45 K i.e. temperatures characteristic of LWIR focal planes. With its large near 5 W cooling power at 150 K, its small envelope, low mass and very long life makes it attractive as a subsystem that is easy to integrate into many small and large payloads.

ACKNOWLEDGEMENTS

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