

# 10K Pulse Tube Cooler

**T. Nguyen, R. Colbert, D. Durand, C. Jaco,  
M. Michaelian, and E. Tward**

Northrop Grumman Space Technology  
Redondo Beach, CA, USA

## ABSTRACT

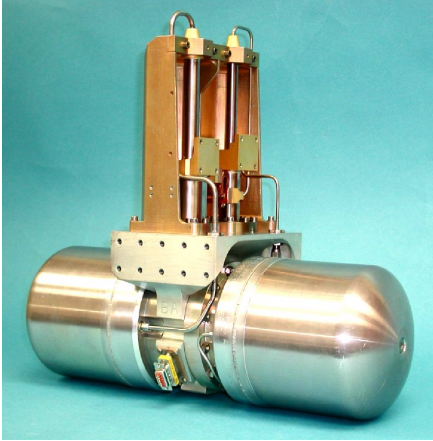
A 3-stage pulse tube cooler has been designed to operate at 10 K. The staged cooler uses the same compressor and parallel staging configuration for the 1<sup>st</sup> and 2<sup>nd</sup> stages as previously employed for our delivered High Capacity Cryocooler (HCC). The 2<sup>nd</sup> and 3<sup>rd</sup> stages are in a serial configuration. The addition of the third stage extends the performance of this cooler to lower operating temperatures below 10 K.

## INTRODUCTION

Northrop Grumman has manufactured a large number of flight cryocoolers designed to operate over a wide range of temperatures and cooling capacities. Our single and two-stage pulse tube coolers have demonstrated excellent efficiency and capacity at temperatures of 25 K and above. This three-stage pulse tube cooler was developed to provide a long life, low mass, and high cooling capacity space cryocooler for use in cooling Si:As focal planes operating at 10 K and below. The objective was to extend the performance of proven high efficiency, lightweight pulse tube cooler technology to lower temperatures solely by changing the cold head. This maintains the heritage of the higher temperature two-stage HCC cooler (and its electronics) that is now in life test at AFRL. In this way, payload designers would be able to employ a variety of focal plane technologies for their missions with low relative risk for the cooler because of its heritage components.

## CRYOCOOLER

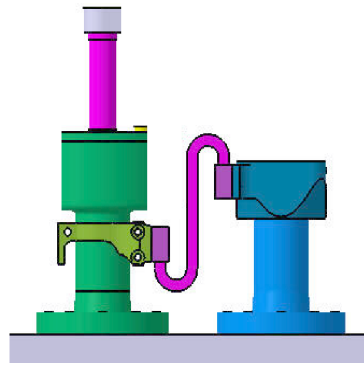
The cryocooler is based on the delivered 2-stage HCC cooler (Figure 1) that is currently in life test at AFRL.<sup>1</sup> This cooler employs a flexure bearing back-to-back compressor that is scaled from our flight proven HEC cooler (Figure 2).<sup>2</sup> The three-stage cold head is mounted onto a back-to-back compressor designed to achieve both long lifetime and vibration balance. The flexure springs are very stiff in the direction perpendicular to the driven motion (much stiffer than gas or magnetic bearings) so that close tolerance gas-gap seals can be maintained to eliminate wear. The flexures themselves are designed for maximum stress levels well below the material endurance limits. Their reliability is validated in the compressor, since the 10<sup>7</sup> cycles required to reach the asymptotic portion of the S-N curve are accumulated in 4 to 5 days of operation. The working fluid is dry helium with no lubricants. The drive is a direct voice coil motor similar to a loudspeaker drive, thereby eliminating linkages. NGST's high efficiency, low mass compressors have been scaled over two orders of magnitude. The 2-stage HCC cooler is implemented with two parallel linear configuration



**Figure 1.** Two-stage high capacity cryocooler (HCC).



**Figure 2.** High Efficiency Cooler (HEC).



**Figure 3.** Three-stage high capacity cryocooler model.

cold heads. This provides the opportunity for two cooling temperatures. In addition, the upper temperature stage is used as a precooler for the lower temperature stage with the use of a thermal strap from the 1<sup>st</sup>-stage cold block to intercept heat in the lower stage regenerator. A variant of this 2-stage cooler is being implemented using parallel coaxial cold heads.

The 10 K 3-stage pulse tube cooler incorporates a 3-stage pulse tube cold head mounted directly on the compressor center plate. This integral configuration allows all the heat to be rejected from the single compressor centerplate. A model of the 3-stage cooler is shown in Figure 3. The 1<sup>st</sup> and 2<sup>nd</sup> stages use a parallel coaxial 2-stage cold head very similar to the coaxial HCC variant cooler to precool the gas to approximately 40 K. The 3<sup>rd</sup> stage is implemented through the addition of a third stage in a serial configuration with the 2<sup>nd</sup> stage in a U-tube cold head configuration, mounted on the cold block of the 2<sup>nd</sup> stage. The parallel configuration of the 1<sup>st</sup> and 2<sup>nd</sup> stages has the advantage that there is minimal interference in the thermal performance of the two stages with the 1<sup>st</sup> stage. These upper stages can also be independently changed depending on the cooling requirement at that temperature on different projects.

## COOLER PERFORMANCE

The 3-stage cold head performance has been characterized under a number of operating conditions. The 3-stage cold head was instrumented with silicon diode thermometers and resistance heaters to simulate the cooling load. The cooling capacity of each stage was measured as a function of the compressor input power.

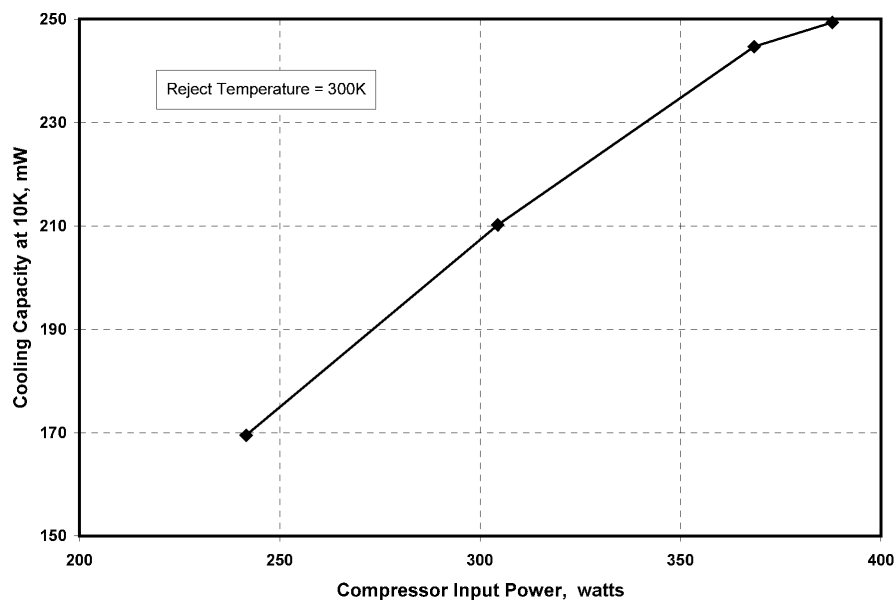


Figure 4. The cooling load at 10 K is proportional to the compressor input power.

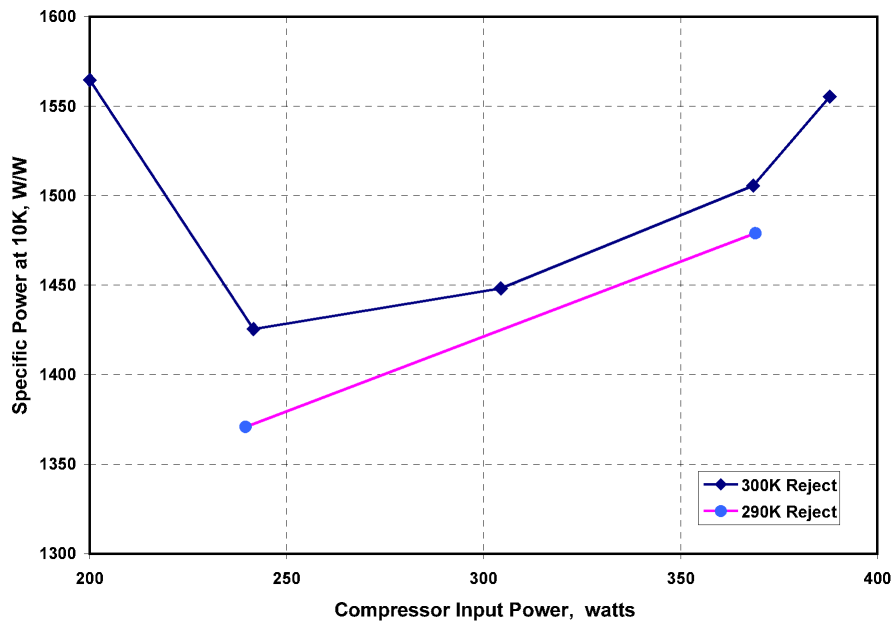


Figure 5. Specific power at 10 K is less than 1500 W/W for input powers between 250 and 350 watts.

Measured data have shown that this is a very efficient cooler with high cooling capacity at 10 K. A cooling load of 250 mW at 10 K has been measured. The cooling capacity at 10 K as a function of the input power between 200 and 385 W is shown in Figure 4. The cooling capacity follows a linear relationship with input power up to 400 watts. This linear relationship between cooling load and input power implies that the specific power at 10 K is fairly constant over a wide range of input powers. The specific power as a function of input power for two reject temperatures is given in Figure 5. Figure 5 demonstrates an efficiency optimum near the 250 W input power design point.

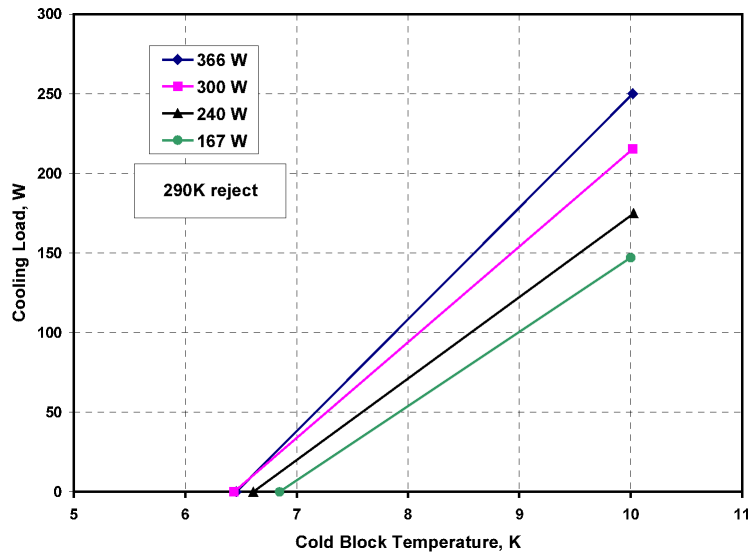


Figure 6. Load line of the 10K pulse tube cooler at different input powers.

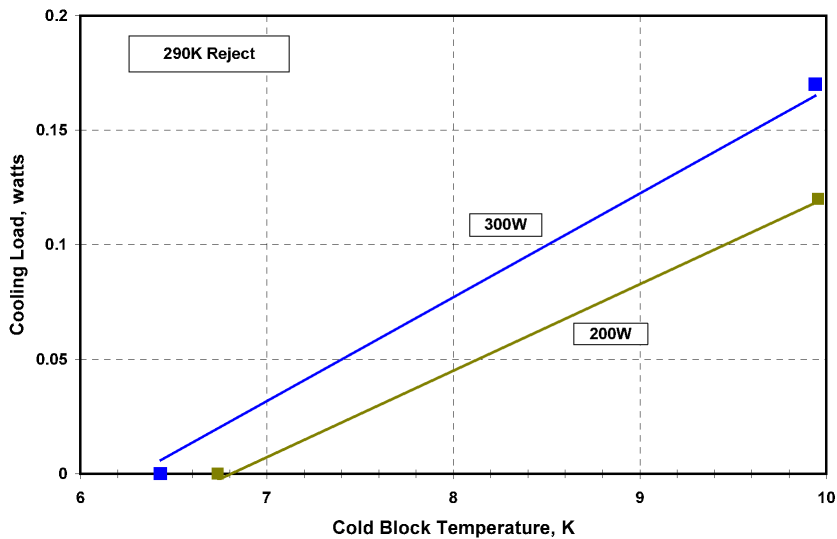


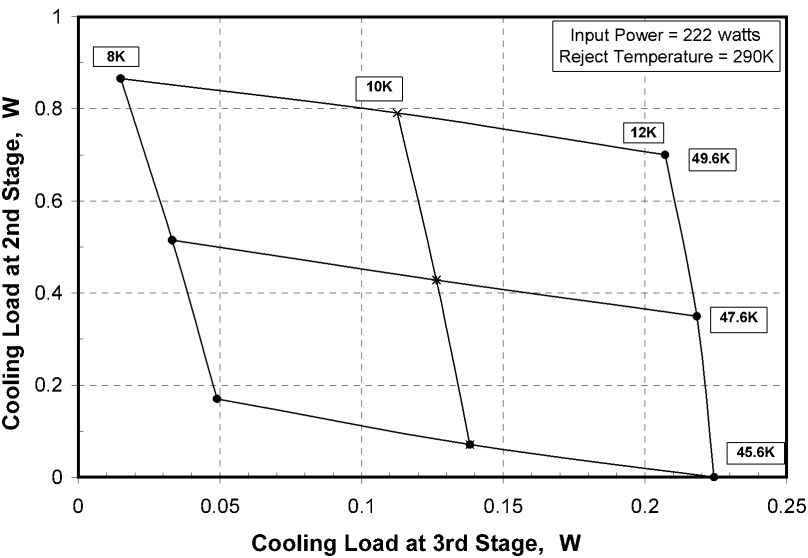
Figure 7. Analytical model matches test data over a wide range of input power; continuous lines are model prediction, solid points are measured data.

The load lines for different input powers are shown in Figure 6. In the development of the 3-stage cold head, we used an analytical model to size and optimize the cold head components. The cooler was designed for maximum cooling power at 10 K and this resulted in a minimum no load temperature of 6 K. Figure 7 compares the measured and predicted load lines at two different input powers. The cold head model predicts the cooler performance well.

The performance of the 3-stage cold head with cooling load applied to all stages is summarized in Table 1—the third stage was operated at 18 K for another application. Table 1 shows that the extra cooling at the intermediate temperatures requires a much lower incremental input power than would be inferred based on specific power predictions for three independent stages. Figure 8 further illustrates this with a constant 222 W input power map for the cooling at the 2<sup>nd</sup> and 3<sup>rd</sup> stages of the cooler.

**Table 1.** Cooler performance with simultaneous cooling load at 3 stages, 315 K reject.

Temperature, Stage 1 K	Temperature, Stage 2 K	Temperature, Stage 3 K	Cooling Load, Stage 1 W	Cooling Load, Stage 2 W	Cooling Load, Stage 3 W	Input Power W
151	59	18	0	0	.213	109.2
151	59	18	.296	0	.213	110.4
151	59	18	.296	.134	.213	113.6



**Figure 8.** Performance map of the 2<sup>nd</sup> and 3<sup>rd</sup> stages.

**CONCLUSION**

An efficient 3-stage pulse tube cooler has been built and tested. The cooler has demonstrated good efficiency and cooling capacity at 10 K and higher temperatures. This cooler extends the Northrop Grumman cryocooler line of products to coolers that operate at low temperature and high cooling capacity.

**ACKNOWLEDGMENTS**

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