Northrop Grumman Coaxial HEC Flight and Next Generation Cryocoolers Performance

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ABSTRACT

The Northrop Grumman Aerospace Systems (NGAS) has expanded the cryocooler product line to include a single stage High Efficiency Cryocooler (HEC) cooler with a coaxial pulse tube cold head that operates at temperatures down to 45 K. The HEC coaxial pulse tube cooler has been adopted by several customers, and has completed acceptance testing to meet program flight requirements.

The NGAS TRL 9 HEC is a pulse tube cryocooler with a flexure bearing compressor which has been delivered for a number of flight payloads that are currently operating in space. To date, NGAS has delivered space cryocoolers in several configurations including single-stage with a linear cold head and two-stage with both linear and coaxial cold heads. The new HEC coaxial cooler uses the same TRL9 HEC compressor with a passive pulse tube cold head to maintain the flight heritage of the HEC linear cooler. The HEC coaxial cooler has demonstrated excellent performance in family with the flight qualified HEC linear cooler. The HEC coaxial cooler provides users with additional flexibility in selecting the cold head configuration to meet their particular applications.

The Northrop Grumman Cryocooler Control Electronics (CCE) unit is also TRL9 and a high efficiency product designed specifically for use with our cryocoolers. This CCE is also easily adapted to specific customer interface requirements. Three types of digital interfaces are available. Leveraging our many years of common US satellite bus interface power requirement experience, the CCE has recently undergone minor modifications to meet a higher standard ESA bus voltage. As with the cold head adaptations, the baseline product is maintained such that materials, processes and procedures are not changed, and the TRL9 maturity and high performance levels are protected.

NGAS has also designed, manufactured and tested in a laboratory environment a new cryocooler, which is scaled from the NGAS TRL 9 HEC pulse tube cryocooler architecture, for Space and non-Space applications. The hardware tests results correlate to performance modeling.

In this paper, we present the flight acceptance thermal performance, launch vibration and thermal cycling test data of the HEC coaxial cryocooler, the expanded capabilities to the Cryocooler Control Electronics and the thermal performance data of the new cryocooler class.

HEC COAXIAL COOLER SYSTEM DESCRIPTION

The Thermal Mechanical Unit (TMU) (Figure 1) consists of the compressor, interface plate and the coaxial cold head. The compressor is the same TRL9 HEC compressor that is used with NGAS's HEC linear coolers (1, 2, 3). The compressor has moving-coil linear motors, which drive the pistons at a near resonant frequency of 70 Hz.

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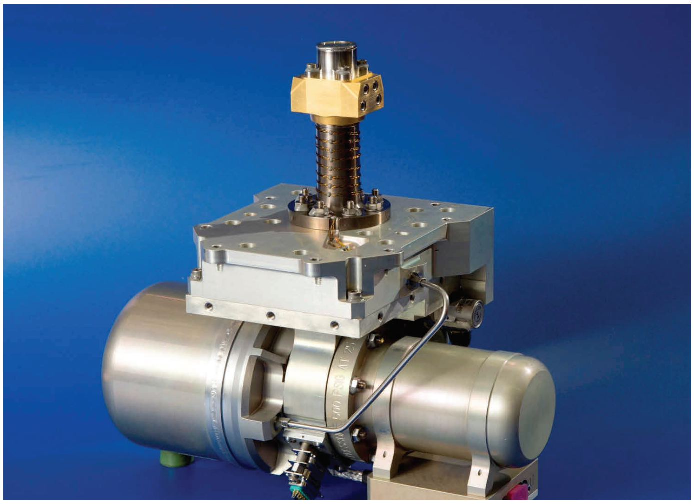

Figure 1. HEC Cryocooler, with a coaxial cold head configuration

The coaxial cold head is integrally mounted to the compressor through an interface plate. The interface plate allows the integration of the coaxial cold head to the flight qualified compressor with no modification. The interface plate also serves as the thermal and mechanical interfaces for the cooler. The mass of the cooler is 5.1 kg.

THERMODYNAMIC PERFORMANCE

Testing of the HEC coaxial cooler was performed in the Cryocooler Flight Integration and Test Laboratory at NGAS. Thermodynamic performance tests were performed with the cooler mounted in a vacuum enclosure designed to support a full range of thermal-vacuum operational conditions. During thermal performance testing, the cooler reject temperature is maintained at the required set points by a dedicated chiller. Thermal controlled fluid is circulated from the chiller to the heat exchanger at the compressor thermal interface to regulate its temperature

The cooler thermal performance map at 300 K reject temperature is shown in Figure 2, and load lines at different reject temperatures are shown in Figure 3. Figure 2 shows that the HEC coaxial cooler can

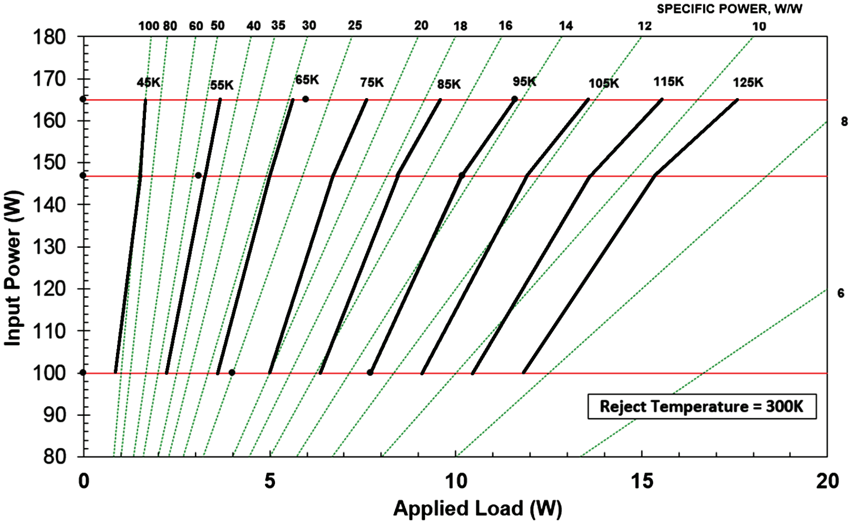

Figure 2. Thermal Performance Map of the HEC Coaxial Cooler

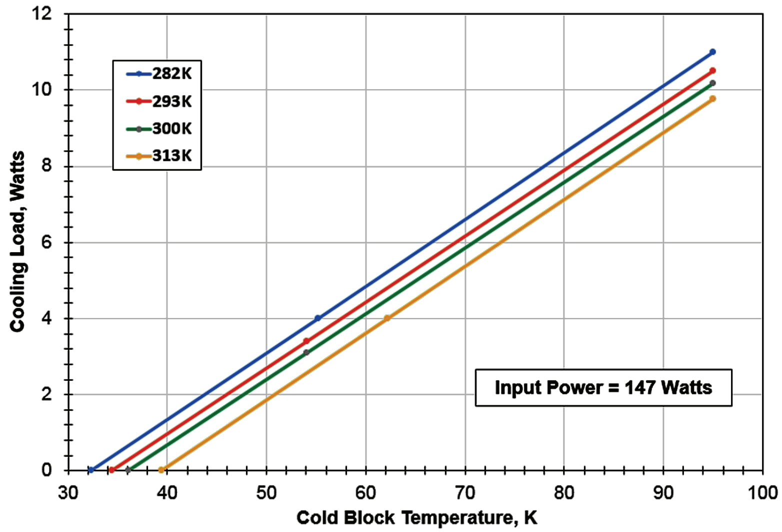

Figure 3. Load lines of the HEC Coaxial Cooler at varying reject temperatures

operate at temperatures down to 45 K with up to 180 W of input power at the compressor. The cooling capability ranges from 1.8 W at 45 K to 19 W at 125 K for an input power of 180 W. Figure 3 shows that the effect of reject temperature is to increase the no load temperature by 7K between 282 K and 313 K reject temperatures for a fixed input power of 147 watts.

RANDOM VIBRATION TESTING

Launch vibration testing of the HEC coaxial cooler was performed in the Launch Vibration Test Facility at NGAS. The TMU was tested while mounted to a vibration test fixture designed to minimize transmissibility amplification in the applied vibration range of 20 – 2000 Hz. The vibration fixture with the TMU affixed is mounted onto a slider plate for X- and Y- axis excitation; the fixture is mounted directly atop the vibration table for the Z- axis excitation. Photos of the X and Y test configurations is shown in Figure 4. The HEC coaxial cooler was successfully tested to random vibration level of 17.4 g_{rms} in all directions.

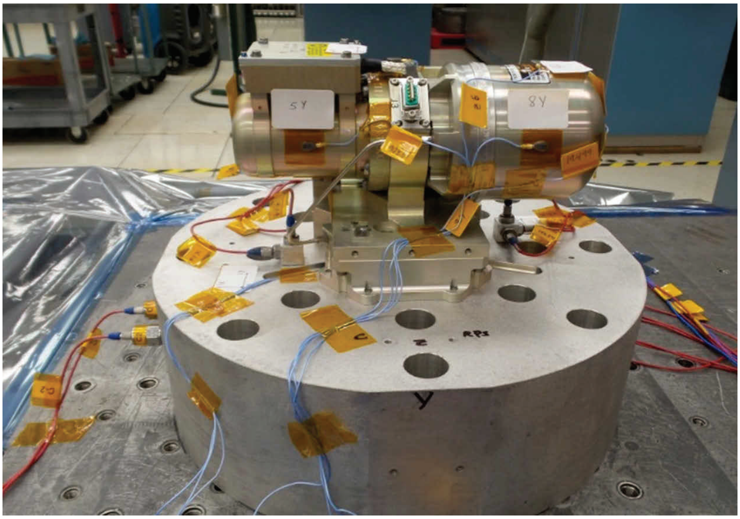

Figure 4. Random vibration testing of the HAEC coaxial cooler

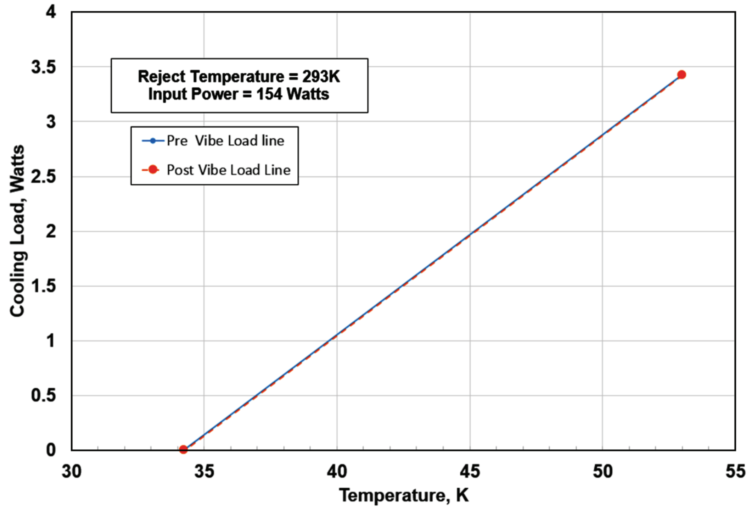

Figure 5. Load lines do not change after random vibration testing

Performance measurements on the HEC coaxial cooler indicated no change in performance after exposure to the protoflight qualification levels of launch vibration as shown in Figure 5.

COOLER EXPORTED VIBRATION

The exported vibration testing was conducted at Northrop Grumman's Cryocooler Dynamic Test Facility. The cooler is mounted on a fixture attached to a Kistler 9257B Dynamometer which measures forces and torques in three directions with background noise force magnitudes below a few mN. The mechanical cooler and dynamometer fixture are mounted on a 2 inch thick steel plate which is bolted to a 70-ton seismic mass beneath and decoupled from the floor. The test setup is shown in Figure 6 and the exported vibration data are shown in Figures 7 to 9.

COOLER SYSTEM SURVIVAL AND OPERATIONAL TEMPERATURE

The HEC coaxial cryocooler has the capability to survive non-operational temperature extremes of 223 K to 343 K. The cooler system must also operate without degradation after exposure to the temperature extremes of 243 K to 333 K.

The cooler thermal performance was measured before and after exposure to the non-operational (NOP) survival cycle and after the operational (OP) cycle to demonstrate cooler system operation without

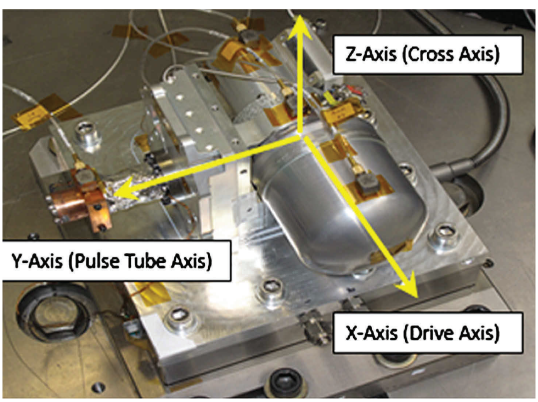

Figure 6. HEC cryocooler exported-vibration test setup with cooler hard mounted on force table.

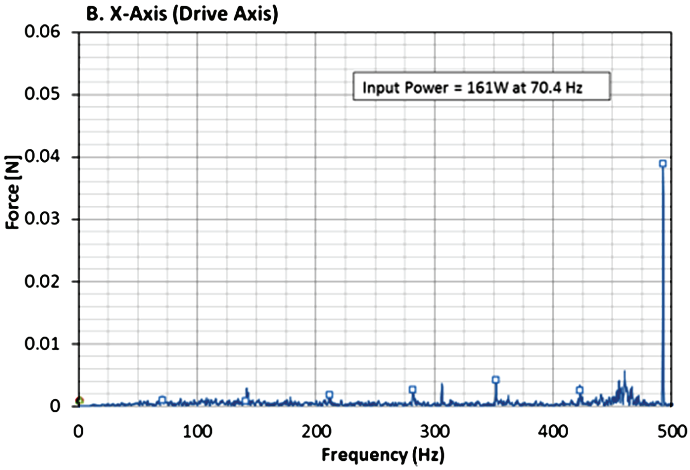

Figure 7. Exported force in the compressor drive direction

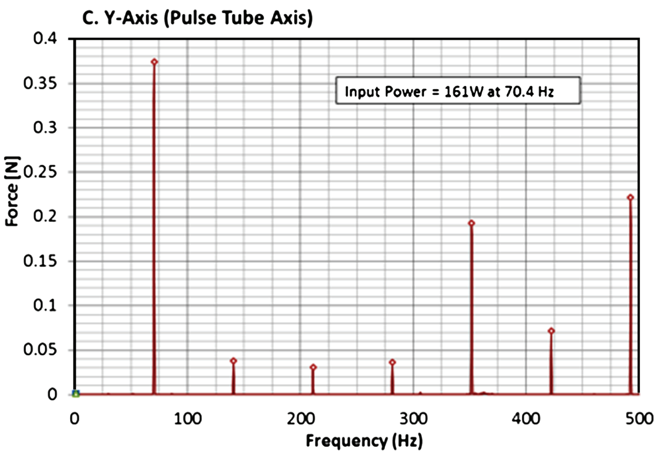

Figure 8. Exported force in the pulse tube axis direction

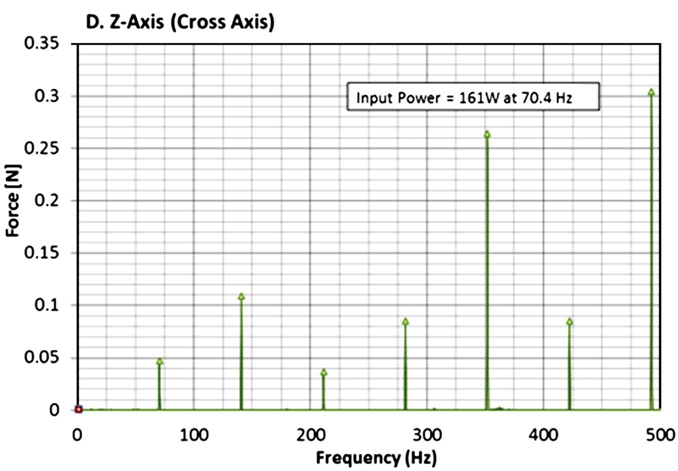

Figure 9. Exported force in the cooler cross-axis direction

Table 1. Cooler thermal performance did not change during the acceptance testing

Test Case	Reject Temp	Cooling Load	Cold Block Temp	Input Power
Pre Random Vibration	293K	3.42W	53K	154.75W
Pre Random Vibration	293K	3.42W	53K	154.7W
Post Thermal Cycling	293K	3.42W	53K	154.4W

degradation. Table 1 shows that the cooler does not display any change in performance after exposure to the thermal-vacuum test.

TEMPERATURE STABILTY PERFORMANCE

The HEC coaxial cooler has the capability to provide short term stability temperature control within ±25mK and long term stability within ±250mK. Temperature control stability data were measured over a two (2) hour period in which the reject temperature was varied from 293 K to 300 K, at a rate of 0.6 K/min. Test data, shown in Figure 10, illustrate this capability for the short term stability. Figure 11 illustrates this capability for the long term stability.

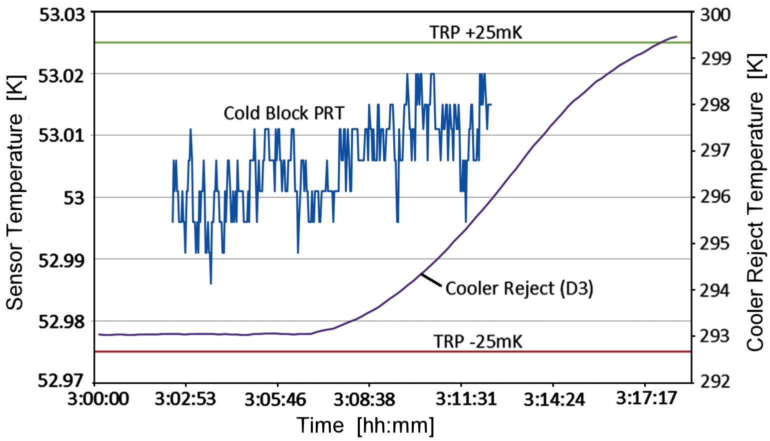

Figure 10. Demonstrated short-term temperature stability of ±25mK

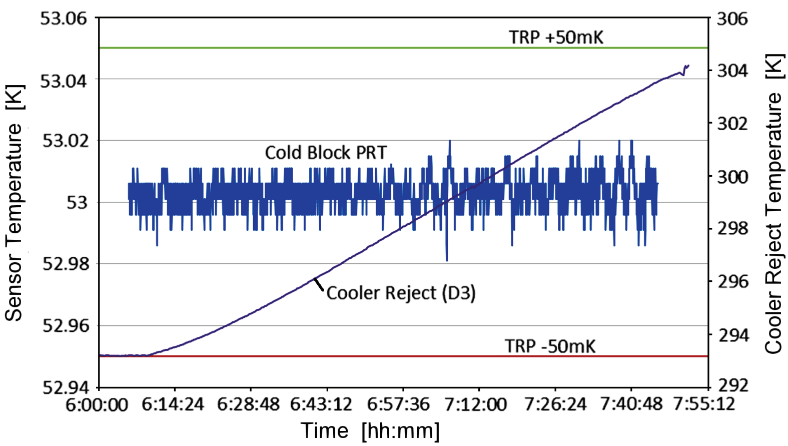

Figure 11. Demonstrated long-term temperature stability of ±250mK

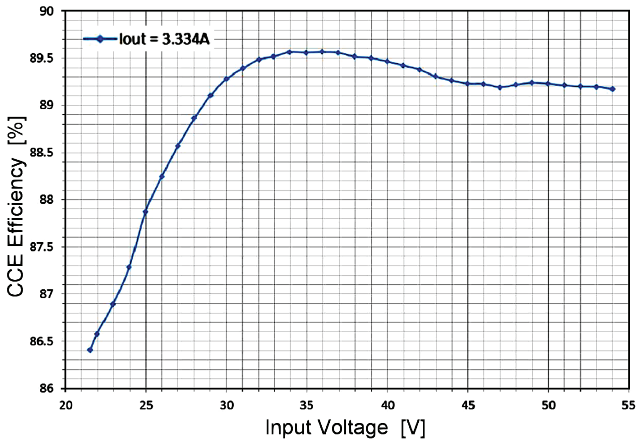

Figure 12. CCE efficiency at high input voltage

50V CRYOCOOLER ELECTRONICS (CCE)

Northrop Grumman has expanded the input voltage to operate over an input voltage range of 21.5VDC to 52VDC. This expanded capability provides 52Volts while retaining backwards compatibility. Electrical efficiency remained above 89% and stable once the input voltage rose above 30 Volts. Figure 12 summarizes the testing performed

NORTHROP GRUMMAN NEXT GENERATION CRYOCOOLER

Figure 13 summarizes the Northrop Grumman family of cryocoolers with four sizes of compressors driving a wide range of pulse tube cold heads to operate at different temperatures and cooling loads. Northrop Grumman has designed, assembled and tested a new pulse tube cold head to use with an improved version of the minicompressor. The improved minicompressor is scaled from the HEC compressor with a similar envelope as the minicompressor. The improved minicompressor can operate at higher input power than the original mini compressor and the cold head is designed to provide cooling in the same range of temperature (45K and above) as the HEC cooler.

To provide flexibility for space and non-space applications, the improved minicooler, called the MinicoolerPlus, is designed with a split configuration between the cold head and compressor. The design of the transfer line (length and shape) is customized to individual applications. The MinicoolerPlus cold

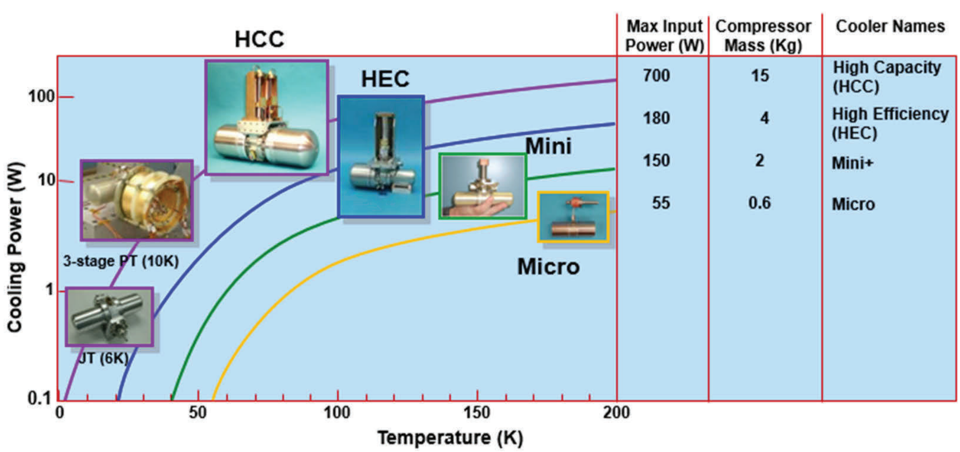

Figure 13. Northrop Grumman family of cryocoolers

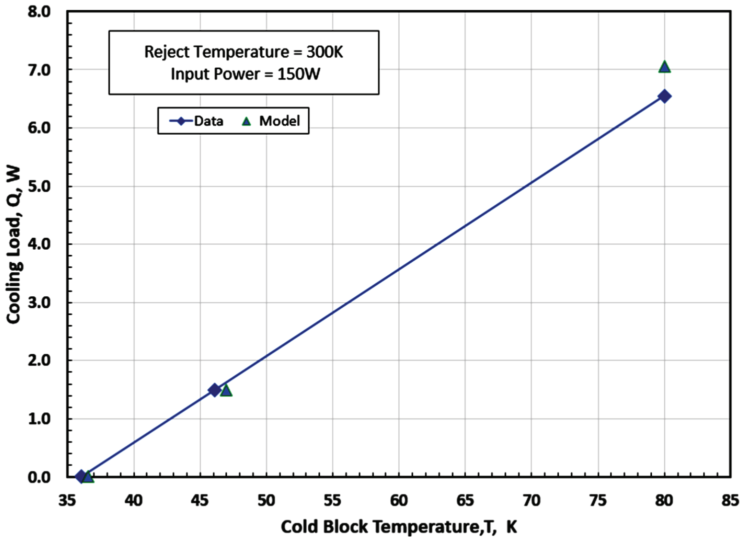

Figure 14. MinicoolerPlus load line for 300 K reject temperature

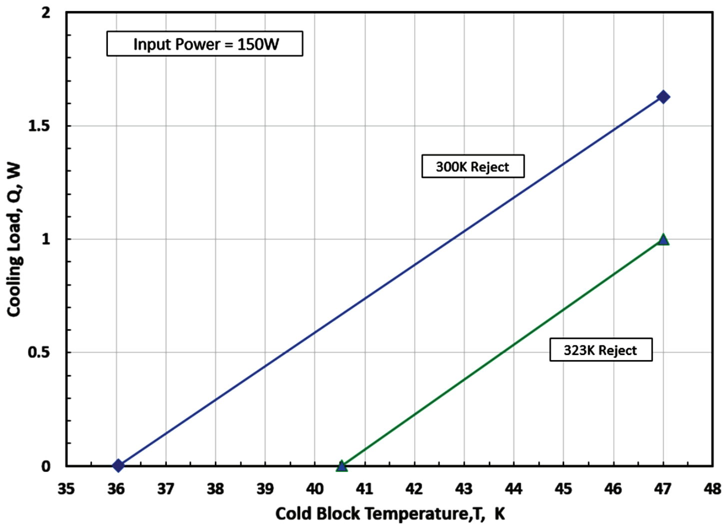

Figure 15. Effect of reject temperature on MinicoolerPlus performance

head was designed to provide 1.5 W of cooling at 47 K with an input power of 150 W. Figure 14 shows the load line of the MinicoolerPlus up to 80 K. The measured data compare well to the predicted performance. Figure 15 plots the load line as function of the reject temperature. The main effect of the reject temperature is to shift the no load temperature from 36 K to 40.5 K.

SUMMARY

The HEC Coaxial Cryocooler developed by Northrop Grumman Aerospace Systems has successfully verified cooler system operation in a flight environment. Survivability and operability performance have been demonstrated through applied launch vibration and thermal-vacuum test profiles. Thermodynamic performance has been characterized and temperature control stability performance is achieved. This development demonstrates the strong foundation and the adaptability of the NGAS heritage HEC toward different space and tactical configurations.

NGAS has also demonstrated to the ability to provide 1.5W of cooling at 47K with an input power of 150W in a scaled HEC package, which it calls the MinicoolerPlus.

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