ABI COOLER SYSTEM PROTOFLIGHT PERFORMANCE

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ABSTRACT

Northrop Grumman has developed and tested the Advanced Baseline Imager (ABI) Pulse Tube Cooler System, a two-stage pulse tube cooler, for space applications. The ABI cooler system incorporates an integral High Efficiency Cryocooler (HEC) pulse tube cooler and a remote coaxial cold head. The two-stage cold head was designed to provide large cooling power at 53K and 183K, simultaneously.

This paper presents the results of data collected on the two protoflight module (PFM-1 and PFM-2) coolers during acceptance testing. Tests conducted on the PFM coolers included applied vibration, survival at non-operational temperature extremes, thermal performance measurements over a range of operational temperatures and temperature stability tests. Designed for a 10-year life, the ABI coolers have the capability to provide 1.9-2.3W of cooling at 53K and between 5.1W and 8.0W of cooling at 183K; while rejecting to 300K with less than 186 W input power to the cooler control electronics. The ABI PFM-1 and PFM-2 coolers provided the cooling at 53K and 183K at input power levels of 162 and 170 W respectively. Both coolers demonstrated short and long term temperature stability of less than 60mKp-p. These protoflight module coolers are the first flight set of coolers delivered to ITT for the ABI program for the NOAA Geosynchronous Operational Environmental Satellite – R Series (GOES R) mission, developed through a NASA contract.

[1] Northrop Grumman Space Technology is part of the ITT Advanced Baseline Imager (ABI) team. ITT leads the team as the prime contractor and has overall responsibility for the program development effort. ABI is a NOAA funded, NASA administered contract.

COOLER SYSTEM DESCRIPTION

The ABI Pulse Tube Cooler System design is a derivative of the HEC cooler that is currently on-orbit on the Japanese Advanced Meteorological Imager (JAMI). Northrop Grumman (formerly TRW), evolved the design from on-orbit pulse tube cooler designs that the company has built and launched over the past decade. No failures have been experienced on any of these coolers on the seven satellite systems launched to date; with some coolers now approaching 11 years of failure-free operation.

The Cooler System consists of a linear pulse tube cold head that is integral to the compressor assembly and a coaxial remote pulse tube cold head; the two cold head design affords a means of cooling a detector array to its operational temperature while remotely cooling optical elements (to reduce effects of radiation on imager performance) and a second detector array.

An ABI Flight Module (FM) is comprised of two Cooler systems or Thermo-Dynamic Units (TDU) and two associated cooler control electronics (CCE) units that provide power and control functions to the TDUs. Multiple FM sets are currently planned for delivery to the Advanced Baseline Imager (ABI) Program. These include the Prototype Module (PTM) that has successfully completed cooler level qualification testing, the Protoflight Module (PFM) earmarked as the first unit for flight as well as additional Flight Modules to be delivered in 2008. In addition to protoflight testing reported herein, integrated system testing will be performed at ITT in Ft. Wayne, IN.

Overall size of the ABI cooler Thermo-Dynamic Unit (TDU), shown in Figure 1, is 370 mm x 350 mm x 130 mm (width x depth x height) with an overall weight of 5.5 Kg. Overall size of the corresponding Cooler Control Electronics (CCE), shown in Figure 2, is 235 mm x 205 mm x 85 mm (width x depth x height) with an overall weight of 3.8 Kg.

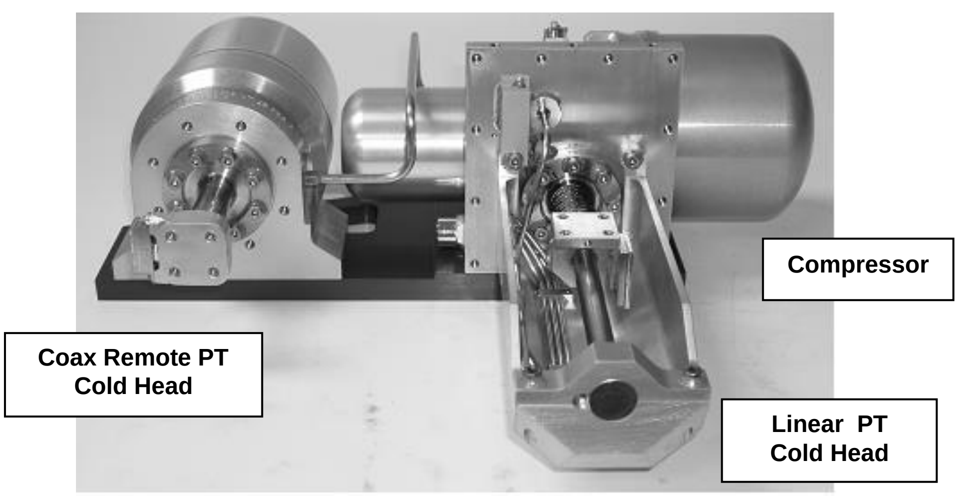


Figure 1. ABI PFM TDU

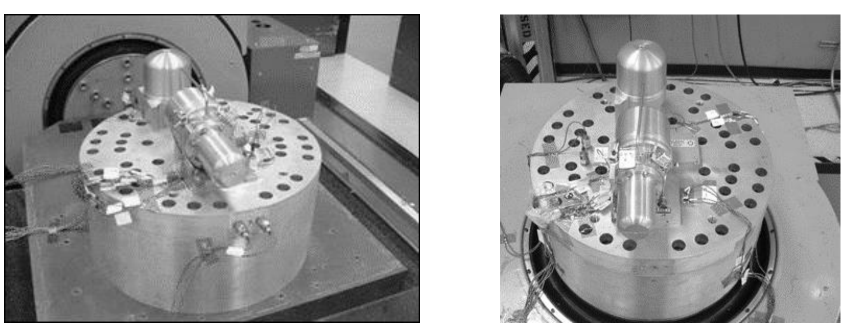
Figure 2. ABI PFM CCE

TEST SETUP DESCRIPTION – LAUNCH VIBRATION TESTING

Launch vibration testing of the two ABI PFM coolers was performed in the Launch Vibration Test Facility at NGST. Each TDU was tested individually 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 TDU 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 two test configurations are included as Figure 3. Each CCE was individually tested to three axis excitation in the same test facility.

TEST SETUP DESCRIPTION – THERMODYNAMIC PERFORMANCE

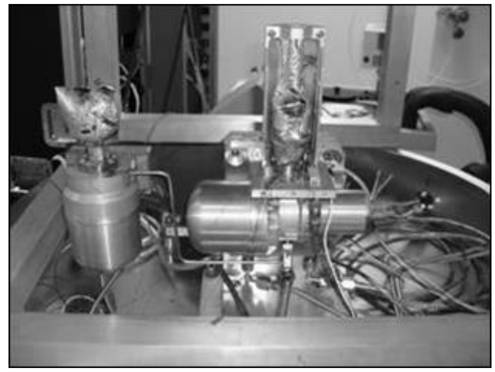
Testing of the two ABI PFM coolers (PFM-1 and PFM-2) was performed in the cryocooler Flight Integration and Test Laboratory at NGST. Thermodynamic performance tests were performed with each cooler mounted in a vacuum enclosure; the vacuum enclosure is designed to support a full range of thermal-vacuum operational conditions. During performance testing the cooler under test is integrated to temperature controlled heat sinks that interface with the compressor/linear pulse tube cold head assembly as well as the remote pulse tube cold head assembly. Fluid passing through the two heat sinks is temperature controlled to maintain the cooler thermal interfaces at desired set-points throughout the thermodynamic performance test. The associated Cooler Control Electronics provided power and control inputs to each of the PFM coolers throughout the test. Pictures of the test facility and the test setup are included as Figure 4.



On slider plate (X-, Y- axes) Atop table (Z- axis)

FIGURE 3. Vibration test setup

Cryocooler Integration & Test Lab



ABI PFM in Vacuum Chamber

Figure 4. Test Laboratory and Setup

TEST DESCRIPTION AND RESULTS – LAUNCH VIBRATION TESTS

Each TDU and CCE was subjected to protoflight launch vibration levels, i.e., power spectral density equal to qualification levels applied for a duration of one (1) minute per axis. G_{RMS} levels for the TDU were 8.93 g_{RMS} over a frequency band of 20-2000 Hz in the X-axis; 7.62 g_{RMS} in the Y-axis; 9.80 g_{RMS} in the Z-axis. G_{RMS} levels for the CCE were 14.14 g_{RMS} over a frequency band of 20-2000 Hz for all axes. The difference in applied launch vibration levels between the TDU and CCE are associated with the difference in physical location on the ultimate spacecraft platform.

Performance measurements on each of the TDUs and CCEs indicated no change in performance after exposure to these protoflight qualification levels of launch vibration.

TEST DESCRIPTION AND RESULTS – THERMODYNAMIC PERFORMANCE

COOLER SYSTEM SURVIVAL AND OPERATIONAL TEMPERATURE

The ABI cooler system has the capability to survive non-operational temperature extremes of 243K to 333K for the TDU and 243K to 323K for the CCE. The cooler system must also operate without degradation after exposure to operational temperature extremes of 258K to 318K for the TDU and 258K to 328K for the CCE. To verify this capability each PFM integrated cooler assembly (TDU and CCE) was subjected to the thermal vacuum test cycle depicted in Figure 5; testing was performed in the vacuum test chamber shown previously in Figure 4. Initial testing verifies the cooler system integrity after completion of vibration testing; testing after exposure to the non-operational (NOP) survival cycle verifies the cooler system survivability; final performance testing after the operational (OP) cycle verifies the cooler system operation without degradation. No change in performance was observed for either PFM cooler system during or after exposure to the thermal-vacuum test profile shown.

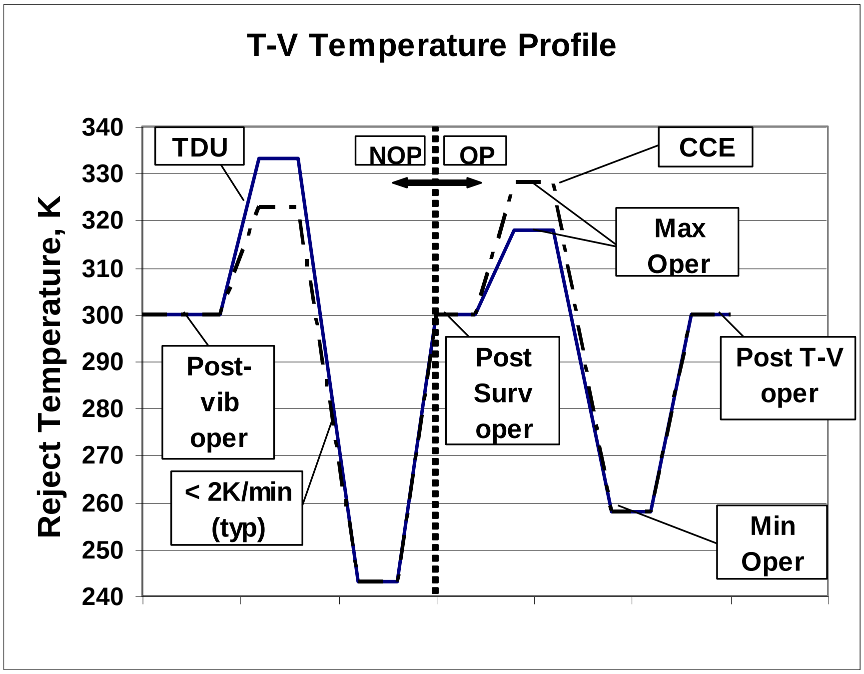


Figure 5. Thermal-Vacuum Test Profile

THERMODYNAMIC PERFORMANCE

The ABI cooler system has the capability to operate at an input power of ≤ 186 W for with a heat load of 1.9 - 2.3 W @ ≤ 53K for the linear cold head and a heat load between 5.1 W and 8.0 W @ ≤ 183 K for the remote cold head; cooler reject temperature is defined to be 300K. The test results, taken during the thermal-vacuum test profile, show a CCE input power of 162W for the specified condition for cooler unit PFM-1; test results for cooler unit PFM-2 show a CCE input power of 170W for the specified condition. These data correspond to performance margins of 14% and 11% respectively. Figure 6 shows the cooler load lines at load and no-load conditions for the two PFM coolers under test. For unit PFM-1, the slope for the linear cold head was 136 mW/K and the remote cold head was 49 mW/K. For unit PFM-2, the slope for the linear cold head was 137 mW/K and the remote cold head was 53 mW/K.

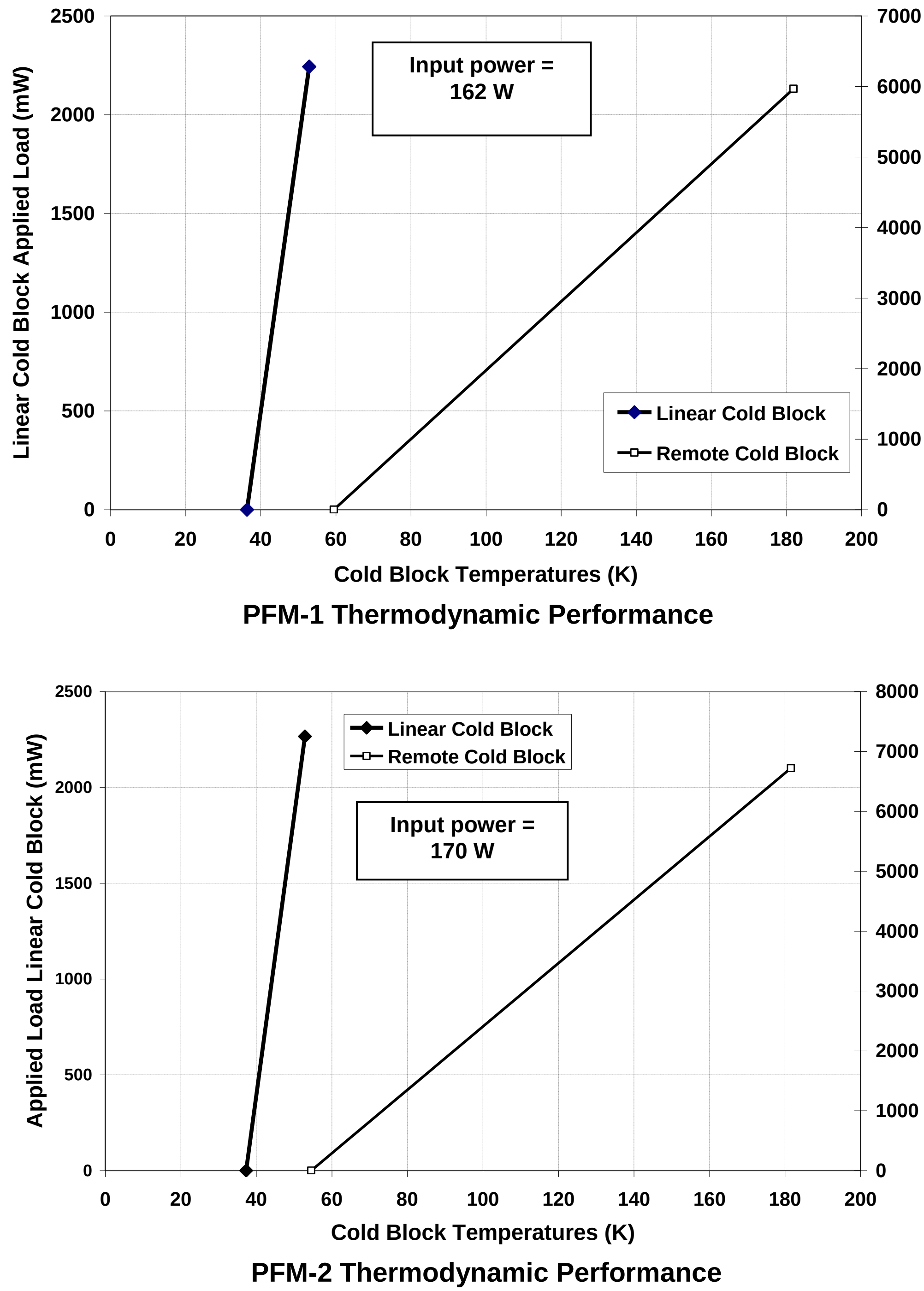


Figure 6. ABI PFM Cooler Load Lines

TEMPERATURE STABILTY PERFORMANCE

The ABI cooler has the capability to provide short term stability temperature control within 100 mK peak-to-peak and long term stability within ± 500 mK. Temperature control stability data was measured over a four (4) hour period in which the reject temperature was varied from 260K to 298K at a rate of ~ 0.16 K/min. Both PFM cooler systems demonstrated identical short and long term stability within 60 mK peak-to-peak throughout this test. Test data from PFM-1, included as Figure 7, verifying this capability.

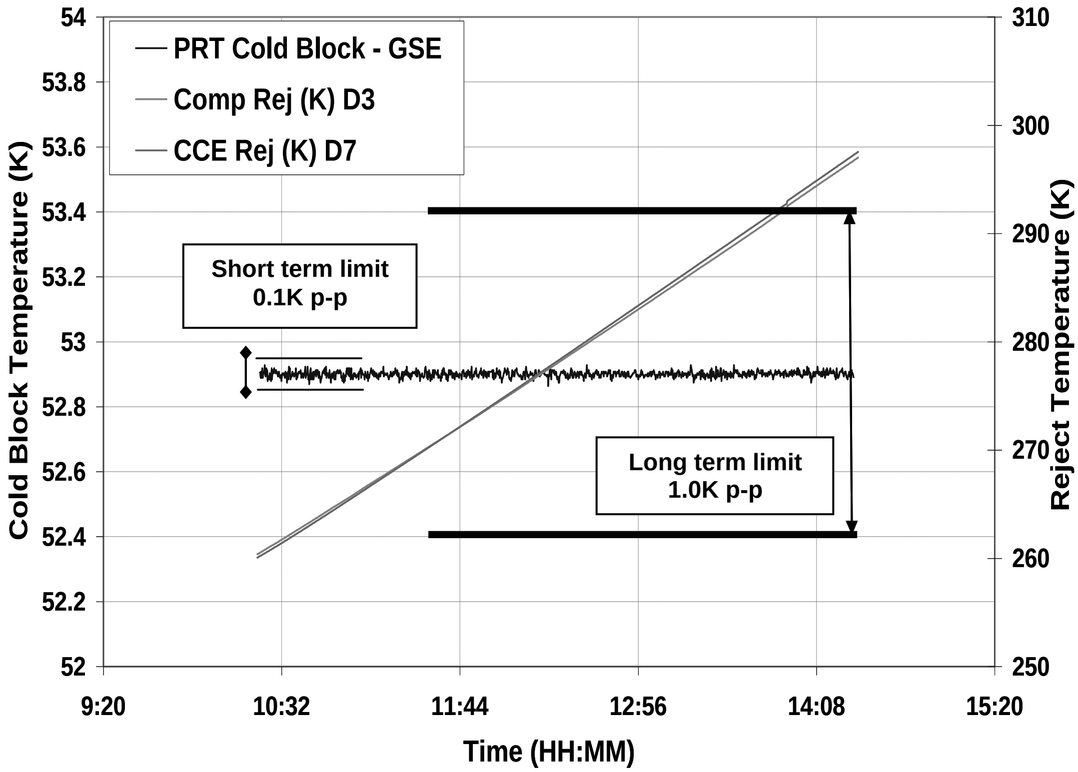


Figure 7. Temperature Control Stability, PFM-1

SUMMARY

The ABI protoflight module coolers developed by Northrop Grumman have successfully verified cooler system operation. Survivability and operability performance have been demonstrated through applied launch vibration and thermal-vacuum test profiles. Thermodynamic performance has been validated with demonstrated performance margin of 11 to 14%; temperature control stability performance is handily met.

These coolers have been delivered to ITT for system level integration and further verification of higher level system performance. Remaining flight modules are planned for completion of acceptance testing and delivery in CY 2008.