HIRDLS Cooler Subsystem On-Orbit Performance – A Second Year in Space

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ABSTRACT

This paper describes the High Resolution Dynamic Limb Sounder (HIRDLS) Cryocooler Subsystem (CSS) and its on-orbit performance. The HIRDLS instrument was launched on July 15, 2004 as part of the NASA GSFC EOS Aura platform. Ball Aerospace & Technologies Corp. provided the CSS, which included a long-life Stirling cryocooler (cooling at 57 K), cold plumbing to connect the cooler to the Instrument Detector Subsystem, an ambient radiator to reject the cooler power dissipation, and a vacuum enclosure system that enabled bench top ground testing. As of June 8, 2006, the CSS had over 16,000 hours of continuous operation with performance that exceeds requirements. The cryogenic and cooler subsystem has experienced essentially no change in performance which includes no indication of external contamination-related degradation that has been evident on several other cooler spaceflights. This steady performance can be attributed to the multilayer insulation (MLI) based design that will be described in the paper. The HIRDLS mission has had an instrument anomaly where Kapton is blocking the aperture. The undegraded performance provided by the CSS has allowed the development of operational and data processing techniques to alleviate this issue resulting in maintaining 75 to 80% of the science mission.

INTRODUCTION

The Earth Observing System (EOS) is a program dedicated to monitoring the complex interactions that affect the globe, and Aura is one mission in that system. The Aura mission objectives are to determine whether ozone is changing as expected to understand processes that affect global change and to determine the sources of pollution with the four instruments: including HIRDLS, Microwave Limb Sounder (MLS), Ozone Monitoring Instrument (OMI), and Tropospheric Emission Spectrometer (TES). HIRDLS is an infrared limb-scanning radiometer. Its mission focus is small-scale dynamics and transports, notably stratosphere-troposphere exchanges in the tropics and middle latitudes; upper troposphere/lower stratosphere chemistry; trends, changes, and budgets of temperature and 10 chemically and radiatively active gases; and gravity wave sources and distributions above the upper troposphere. The science team consists of the University of Colorado, the National Center for Atmospheric Research (NCAR), and Oxford University. Lockheed Martin Palo Alto was the prime contractor. The HIRDLS instrument has 21 photoconductive Mercury Cadmium Telluride (HgCdTe) detectors, which are cooled to 61 K. The CSS is designed and built by Ball Aerospace. The CSS consists of the cryocooler, cold plumbing, ambient radiator, and vacuum enclosure.

The HIRDLS instrument on the EOS Aura spacecraft was successfully launched on July 15, 2004 aboard a Delta 2 from Vandenberg Air Force Base, California into a 705 km sun synchronous orbit with a

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98° inclination and a 1:45 PM equator crossing time. After the initial instrument checkout, the cryocooler was ramped up to 80% stroke on August 10, 2004. Since that time, the cryocooler has been in continuous operation.

Unrelated to the CSS, the HIRDLS instrument had an on-orbit anomaly that initially resulted in significantly degraded instrument performance and instrument science. The instrument's aperture view is approximately 85% blocked most likely due to a 2-layer Kapton contamination closeout shield that became dislodged during ascent. The HIRDLS team is continuing efforts to refine the obstruction oscillation removal and radiance correction schemes. The team has continued analysis of the pitch maneuver (view to space calibration) data to better characterize the obstruction oscillation and how to correct for it. These studies of the pitch maneuver data provided essential information about how to correct for the radiometric uncertainties caused by the obstruction in the aperture. Results indicate that there are phase and amplitude shifts, orbital and seasonal variations, and scan direction variations in the data. The team is in the process of implementing a correction scheme that removes ~95% of the oscillation. The refined correction scheme will be in place for production data processing in June 2006. These techniques are applicable to all the data taken to date. Without the development of these techniques, the mission might have ended at the end of fiscal year 2005. The mission is now funded for its full 5 years, until 2009. The CSS has provided temperature stability in the mK range, which has been instrumental in the success of the techniques used to mitigate the Kapton blockage issues. These processing techniques with the temperature stability will allow for 75 to 80% of the mission science to be achieved.

CRYOCOOLER SUBSYSTEM DESCRIPTION

Ball Aerospace was responsible for designing and building the CSS. The HIRDLS cryocooler is a single-stage Stirling design with its primary design point at 57 K. The HIRDLS cryocooler is mounted directly to an ambient radiator to reduce integration complexity and to reduce the total mass of the system. The weight-relieved radiator panel provides the necessary waste heat rejection while also acting as the structural mount for the cryocooler. The close proximity between the radiator and the cryocooler eliminates the thermal bus that would otherwise be necessary and that would increase both the mass and the parasitic heat loads. The radiator mounts to the spacecraft through four blade-style flexures to mitigate effects of thermal expansion differences between the spacecraft and the radiator and to reduce the instrument to radiator heat leak path. Figure 1 shows the HIRDLS cryocooler mounted into the radiator. The mass of the CSS, including electronics, is 27 kg. A cryogenic vacuum housing surrounds the cold finger. Before system integration, the cryogenic vacuum housing is capped off to bench tested the system in an ambient environment. During the integration, the vacuum housing was mated to the detector subsystem. A more detailed description of the CSS can be found elsewhere.[1,2] The engineering unit of the CSS was delivered in August 1999 and the flight unit was delivered in November 2000.

Figure 1. HIRDLS cryocooler mounted into radiator.

MLI has been used in the CSS design to minimize radiation heat transfer as opposed to the use of bare or uncovered low emissivity surfaces. Compared to a low emissivity surface design, the CSS MLI design results in improved performance (measured ε* of 0.015 even with tight clearances less than 0.25 in.) and inherent robustness against external contamination. Essentially, MLI is robust to external contamination migration into the layers, especially the innermost cryogenic layers. MLI inherently contains water contamination that is difficult to remove, but this effect is already accounted for in the measured performance as opposed to developing with time on-orbit. Previous cryocooler space systems that have suffered from degraded performance due to contamination all had design areas that relied on no or very few layers of MLI. These systems were susceptible to significantly increased loads as the low emissivity surface emittance increased.

CRYOCOOLER PRE LAUNCH HISTORY

Two separate anomalies in the cryocooler occurred late in spacecraft level testing. The first in August 2003 was a failed counterbalance mechanism, and the second in November 2003 was a failed communication due to an electrical short. The investigation of the first anomaly was extensive leading to a 4- to 5-month launch delay. The counterbalance anomaly was observed after spacecraft sine, acoustic, and shock testing. The corrective action was to disable the counterbalance drive circuitry and short the motor wires, which results in a slightly increased force to the HIRDLS instrument of approximately 4.4 N (1 lbf) that was determined to have undetectable impact on the HIRDLS instrument, the spacecraft, or other instruments. Because the cryocooler was not removed from the instrument, the root cause was not definitively identified. However, the probable cause was overstroking by the instrument of the displacer for 3 months prior to spacecraft testing. The counterbalance design on the HIRDLS cryocooler was susceptible to overstroke because it only had a soft stop in one direction. The current Ball Aerospace generation of cryocoolers had designed out the counterbalance overstroke susceptibility for other reasons long before the anomaly on HIRDLS occurred. The second anomaly was resolved quickly with minimal schedule impact to the program. The short was caused by a test point located at frame contact and is not associated with the cryocooler technology. Neither of these anomalies has affected on-orbit performance of the CSS.

HIRDLS CSS ON-ORBIT PERFORMANCE

The HIRDLS cryocooler has been operating since initial ramp up on August 10, 2004. On-orbit data are collected each day; Figures 2 through 4 are points taken at midnight GMT every day. Figure 2 details the displacer cold tip temperature and the detector temperature. The detector temperatures have varied less than ±2.8 mK for nearly 2 years. Figure 3 details the CSS heat rejection temperatures including the compressor, displacer, and radiator. Finally, Figure 4 shows the cryocooler stroke as a function of time. Cryocooler stroke is an indication of how hard the cryocooler has to work to meet the detector temperature requirement. As the stroke increases, the input power required for constant detector temperature also

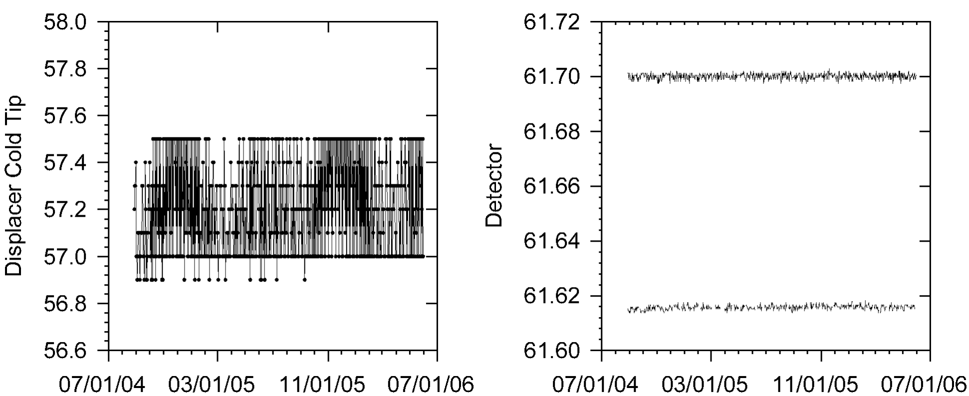

Figure 2. On-orbit displacer cold tip and detector temperatures (K). Note that the detector temperature is within a ±2.8 mK range.

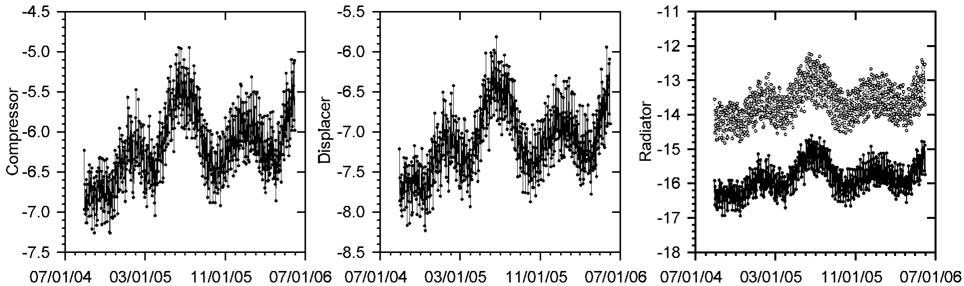

Figure 3. On-orbit rejection temperatures (°C).

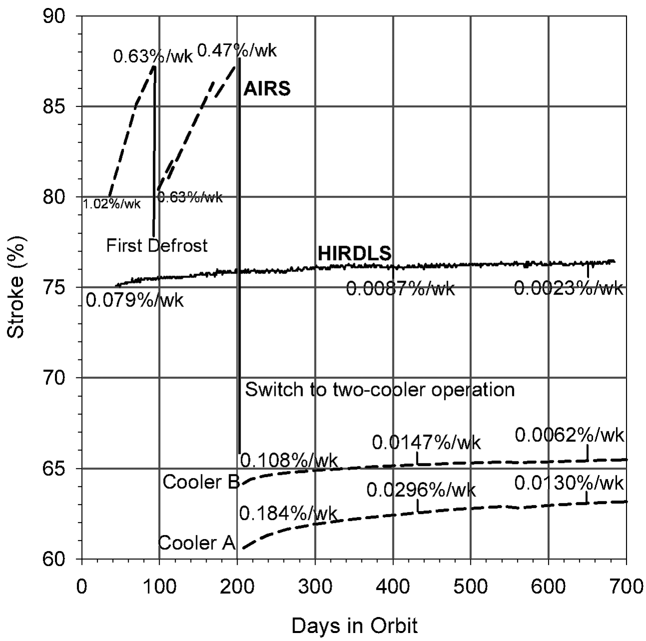

Figure 4. On-orbit cryocooler stroke performance for HIRDLS (solid lines) and AIRS (dashed lines).[3,4]

increases. Figure 4 shows a slight increase in stroke over time to keep constant detector temperature. This load increase is due to contamination on the cryogenic surfaces changing the surface emissivity and therefore increasing the loads. In general, cryocooler stroke would be allowed to rise to approximately 90% before decontamination operational modes would be used to remove condensation on the cryogenic surfaces. Alternatively, input power limitations might drive a decontamination cycle before the 90% level is reached. Preflight operational plans for the HIRDLS instrument called for decontamination cycles every few weeks during the first year of operation. Such a decontamination cycle has not been required during the first year of cryocooler operation because the stroke has increased less than 2% from 75.0 to 76.5%. This extremely small level of contamination is unprecedented in cryocooler operational data released into the public domain.

By comparison, two recent flight cryocoolers on Atmospheric Infrared Sounder (AIRS) and TES have experienced significant performance degradation.[3,4,5] The AIRS instrument is on the EOS Aqua spacecraft, which is in 705-km sun synchronous orbit with a 1:30 PM equator crossing time. AIRS employs redundant pulse tube cryocoolers to cool its infrared focal plane to 58 K; its cryogenic system design is discussed in a previous paper.[3] During the initial operation, the AIRS cryocooler stroke was increasing at the rate of 1.02% per week. After an initial decontamination cycle, this rate was reduced to 0.63% per week, and a second abbreviated decontamination cycle was attempted on Day 168 with a final stroke change of 0.47% per week. Eventually, the AIRS operational team decided to turn on the redundant cooler to reduce the number of required deicing operations. Figure 4 compares the AIRS and HIRDLS cryocooler stroke performance for the first 2 years. The TES instrument is on the EOS Aura spacecraft with HIRDLS; its cryogenic system design is discussed elsewhere.[5] TES employs two pulse tube cryocoolers to cool four focal planes in two separate housings to 65 K. During the first 12 days of cryocooler operation, the cooler stroke increased at a rate of 0.467% due to ice buildup on the exposed cold detectors and other cold surfaces. This ice caused a reduction in the IR transmissivity; decontamination cycles were initiated when IR transmission losses rose to 60%. During the first year of operation, the TES instrument completed nine decontamination cycles. These decontamination cycles were required to meet the IR transmission loss limit, not because the cryocoolers did not have the required capacity or because of an input power limit. Figure 5 shows the on-orbit comparison of the stroke performance on HIRDLS and TES for the first year in orbit. Only Cooler A is shown for TES for clarity; Cooler B exhibited the same performance except that its initial stroke level was 50.5% rather than 42.7%. While decontamination cycles were not required because of cooler capacity or input power issues, it seems likely that such decontamination cycles would have been required eventually given the high rate of stroke increase. Finally, Figure 6 compares the stroke rate of change for all three instruments: AIRS; HIRDLS; and TES. From this figure, the HIRDLS rate of change started and has remained significantly below those of AIRS and TES over the same time periods. Because of this remarkable performance, HIRDLS has not required a single decontamination cycle for its entire mission unlike both AIRS and TES.

HIRDLS ON-ORBIT PERFORMANCE SUMMARY

The HIRDLS CSS has performed exceptionally well since the cryocooler was turned on August 10, 2004. The prelaunch anomalies experienced by the cryocooler in late 2003 have not reoccurred. During the 2 years of operation, the cryocooler stroke has increased by only 1.5%, which is unprecedented in the open literature. Because the CSS has not experienced any performance degradation, instrument operations have not been interrupted with deicing cycles unlike AIRS and TES, both of whom have required multiple deicing cycles. Detector temperature stability provided by the CSS has been a significant factor in the success of the data processing techniques used by the HIRDLS instrument team to mitigate the effects of the Kapton blockage.

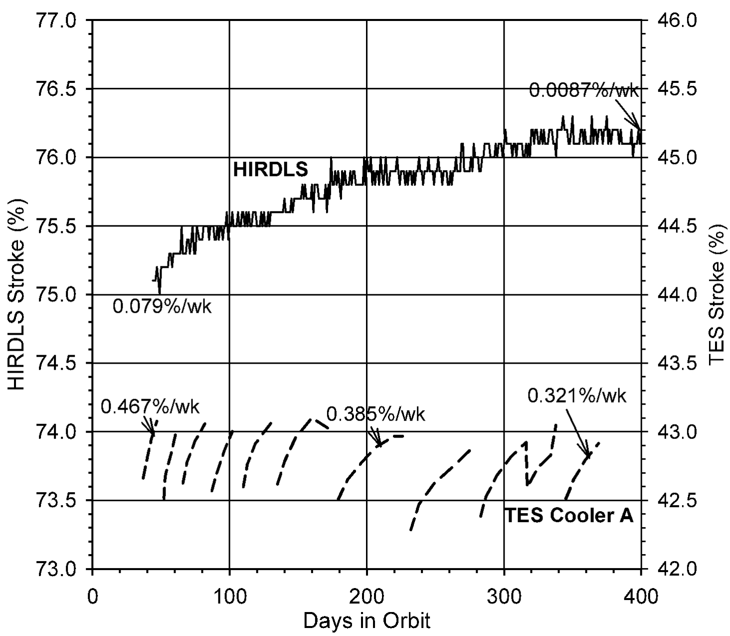

Figure 5. On-orbit cryocooler stroke performance for HIRDLS (solid lines) and TES (dashed lines) during the first year of operation.[5]

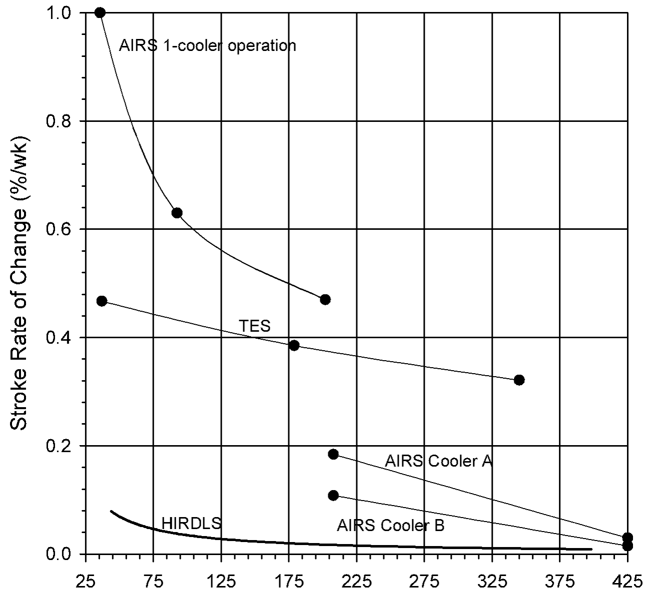

Figure 6. Comparison of stroke rate change per week for Year 1 operations on AIRS, HIRDLS, and TES[3,5]

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