

ELECTRICAL SHORTING OF THERMOCOUPLES IN ATMOSPHERIC ENTRY APPLICATIONS

Cole D. Kazemba¹, J. D. Williams², R.A. Miller², G.T. Swanson¹, and S.J Hughes³

¹ NASA Ames Research Center (cole.d.kazemba@nasa.gov)

² AMA Incorporated at NASA Ames Research Center

³ NASA Langley Research Center

Brief Presenter Biography: Cole Kazemba is an aerospace systems engineer in Entry Systems and Vehicle Development Branch at NASA Ames Research Center. Cole's work focuses on technology development of advanced thermal protection systems for planetary exploration. He has a B.S. in Aerospace Engineering and Mechanics from the University of Minnesota and an M.S. in Aerospace Engineering from the Georgia Institute of Technology.

Introduction: The Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID) will test Hypersonic Inflatable Aerodynamic Decelerator (HIAD) technology. Temperature measurements are taken across the vehicle to address a Level 1 mission requirement regarding performance of the Flexible Thermal Protection System (F-TPS). Temperature measurements are made using dozens of thermocouples (TCs) embedded within the F-TPS at different depths and various locations shown in Figure 1.

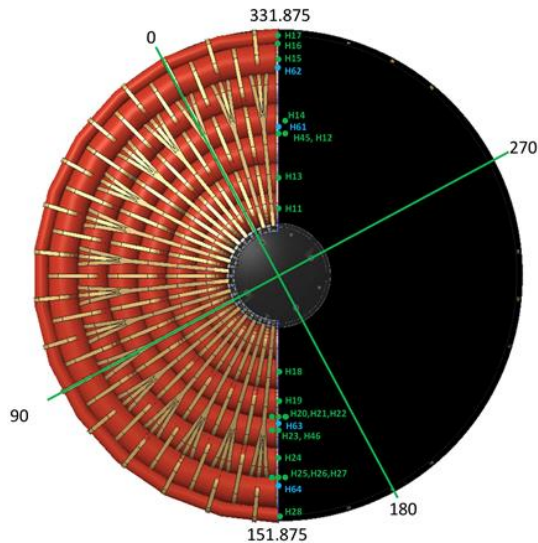


Figure 1: Thermocouple layout on the LOFTID Reentry Vehicle.

The portion of insulated TC wire traveling between the measurement location and the data acquisition system (DAS) will be exposed to thermal gradients and temperatures significantly above the maximum rated temperature of the TC insulation. Several potential error sources may be introduced due to these environmental conditions:

1. Electrical conductivity between the conductive F-TPS materials and the TC wires may create noise in the output signal.
2. Charred wire insulation may lose integrity allowing the two TC leads to directly contact, forming a secondary junction in a new temperature region.
3. Decomposing insulation may chemically react with the Type K TC wire altering its composition and therefore invalidating the calibration.

The discovery of active error sources discussed in this abstract carries implications that must be accounted for in all entry vehicle instrumentation suites.

Uncertainty Characterization: Prior to flight, the uncertainty in the temperature measurements must be characterized and shown to meet the requirements of the LOFTID project. The ASTM Standard [1] describing thermocouple electromotive force (emf) behavior and uncertainties lists a maximum use temperature of 1260°C for Type-K TCs, and therefore it was expected that the TCs would provide reliable measurements up to that temperature. However, the project standard TC configuration employs fiberglass insulation over each individual TC lead as well as a fiberglass overbraid. Though the project has used the thermocouples for many years at significantly higher temperatures, this fiberglass insulation has a manufacturer stated use temperature of 482°C. In an effort to characterize any error attributed to operating the TCs beyond the manufacturer stated use temperature for the insulation, the project executed a series of tests.

Furnace Testing: The first test was conducted using an open-end tube furnace to expose test thermocouples to extreme temperature environments in a flight-like configuration. The test configuration and samples are illustrated in Figure 2. A test TC was run from the DAS though the F-TPS sample and the junction was placed at a known and constant temperature using either a hot plate or ice bath. Once the sample was inserted into the furnace, the temperature response of the test TC was monitored as a function of the internal temperature of the F-TPS (which was measured using monitor TCs covered in a high-temperature ceramic insulation).

As a control, two reference TCs were also run from the DAS to the ice bath. Neither of these reference TCs

passed through the F-TPS sample, but an inside reference TC did pass through the furnace and was therefore exposed to extreme temperatures. The outside reference TC avoided the furnace and ran directly to the ice bath. All TCs were the same length and testing was conducted at three temperatures: 300°C, 700°C, and 1250°C.

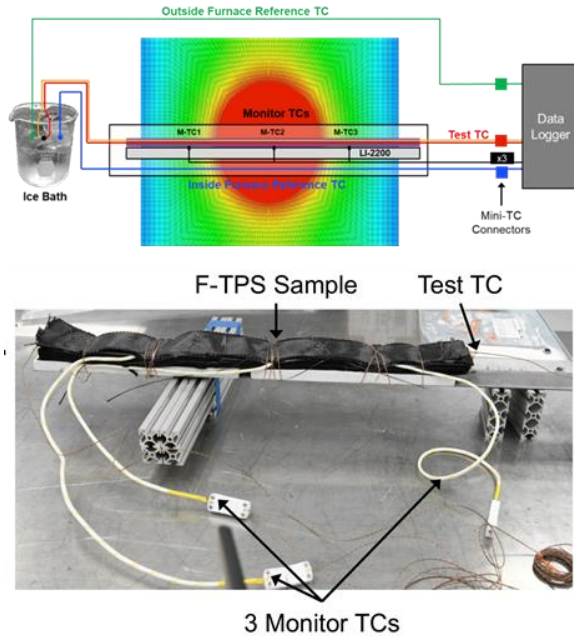


Figure 2: Furnace test configuration (above) and test sample (below)

The furnace tests revealed that, under certain conditions, the thermocouple leads in the test TC could form an electrical short that directly affected the temperature measurement. Data from the inside and outside reference TCs did not exhibit this behavior (see Figure 3). Several iterations of furnace tests as well as supplementary testing using TGA revealed two mechanisms by which this shorting can occur.

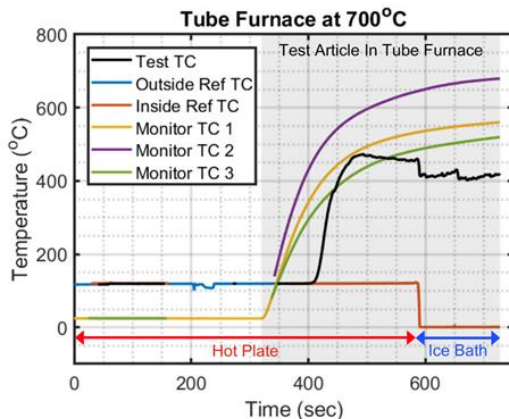


Figure 3: Test result at 700°C showing deviations in the test TC measurements

Shorting Mechanisms: One mechanism for TC shorting, and the resulting measurement error, originates with the silicone-based binder material that coats the fiberglass insulation. This binder is added to aid in manufacturing and to prevent fraying of the braided insulation due to handling. The environment within the F-TPS during exposure to high heating environments is oxygen-deprived because the decomposition products consume the available oxygen at a high rate. Under these conditions, the silicone binder leaves behind a carbonaceous char as it decomposes at ~200°C. This char is electrically conductive and provides an electrical path between the two thermocouple leads. Thermal gravimetric analysis (TGA) testing in air and argon confirmed this mechanism.

In response to the discovery of this first shorting mechanism, additional tube furnace tests were conducted on TCs which had their binder removed through a heat-cleaning process in air. These tests showed that despite the removal of the silicone binder, shorting still occurred in a similar manner. Post-test inspection of the TCs revealed that both the outer and inner fiberglass insulation was black in color and electrically conductive. With silicone removed as a source, it was determined that the decomposition products of the F-TPS were penetrating and depositing on the fiberglass and creating the same failure mode.

After testing various insulation materials in the furnace, the only configuration robust against the shorting phenomenon was a TC wrapped with mica. The mica survives test temperatures while providing an electrically insulating and impermeable barrier to the decomposition products.

Arcjet Testing: In order to understand the TC shorting issues in a more flight-relevant environment, arcjet testing was conducted at Boeing's LCAT facility. These tests can achieve more representative heating rates, but also provide gas chemistry conditions which are much more similar to flight compared to the static, sea-level air of the furnace. This is significant because the reaction rates of the F-TPS relative to the delivery rate of oxygen at the surface and in-depth will affect the amount of F-TPS decomposition products which will deposit on the TC insulation.

Heat cleaned TCs as well as custom made TCs wrapped with mica and covered with fiberglass or ceramic braid were tested according to the configuration shown in Figure 4 which mimics the tube furnace setup. Each TC type was accessed for suitability in flight. Test results have not been fully analyzed, but initial conclusions show that the mechanisms discovered in furnace testing exist in the arcjet environment. The near-surface

TCs appear to perform better in the arcjet than in furnace testing, pointing to a higher relative oxygen content.

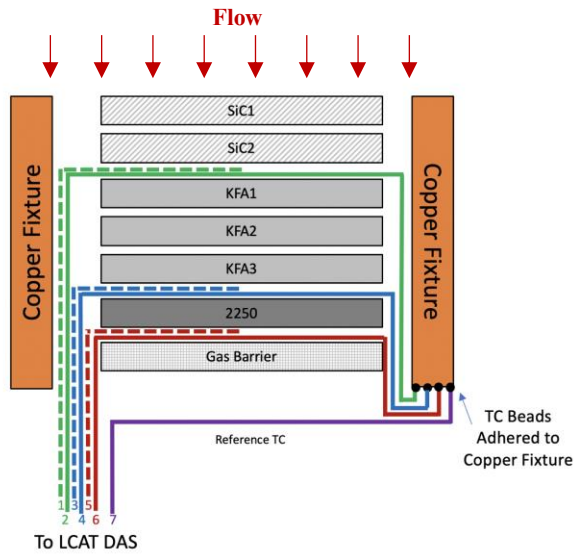


Figure 4: Arcjet test configuraiton

Conclusions: The TC shorting mechanisms discovered under the LOFTID project have significant implications for the mission, but the lessons learned also point to careful considerations which must be accounted for in all entry vehicle instrumentation suites. Some of these considerations will be addressed. Further discussion of the arcjet testing and the project's path forward to implementing a flight solution will be provided in the final presentation.

References:

[1] ASTM E230, Standard Specification for Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples