THERMAL CHARACTERIZATION OF SUPERCONDUCTING SOLID STATE HEAT PIPES

Ramona O. Cummings
Marshall Space Flight Center, Thermal Analysis and Control Branch, Spacecraft Thermal Team

Dr. James B. Blackmon and Sean F. Entrekin
University of Alabama – Huntsville, Propulsion Research Center, Mechanical Engineering Dept

ABSTRACT

NASA and academia have been investigating new technology heat pipes, utilizing annular solids without wicking sinter or working liquid, but with choice of at least two internal conductivity enhancers. Referred to as "Supertubes", these solid state heat pipes display super conducting characteristics once temperature threshold is reached. To mature the technology by showing predictability, analyses were used as an integral part of the test and development. In addition, the analyses provided gradient information at locations between the limited number of test sensors, and at close proximity to the heat source. The paper will show non-proprietary portions of thermal tests and analyses conducted on Supertubes for NASA.

INTRODUCTION

NASA's Technology Maturation Program (TMP) provided seed money for several technologies, including those for thermal management of heat dissipation from candidate high concentration solar photovoltaic cell arrays, high-voltage power delivery systems, and other high temperature spacecraft components. One of the technologies under evaluation at the Marshall Space Flight Center (MSFC) and the University of Alabama – Huntsville (UAH) Propulsion Research Center (PRC), received additional, low level funding by TMP. That candidate technology utilized patented (**Reference 1**), solid state, superconducting tubes, called Supertubes, to direct heat to an optimally placed advanced space radiator (ASR). This paper presents overview of methodology and results of the UAH PRC Supertube work that was funded by NASA TMP, excluding proprietary features. Detailed procedures and additional results are in the UAH PRC final report (**Reference 2**.)

SUBSET OF PHASE I TESTING AND ANALYSIS

Phase I tests were exploratory, and utilized existing hardware, as fully detailed by the UAH PRC authors in **Reference 2**. Initial testing, done under thermal vacuum (T/V) conditions, was not repeated due to cost. Instead, the remainder of the testing to date has been conducted under thermal ambient (T/A) conditions, with results falling conservatively within the T/V performance data. An overview of non-proprietary subset of Phase I T/A testing follows:

Several small Supertubes, including two 17” long, 5/16” OD (see **Figure 1**)
Identically sized deoxidized copper rods for comparison
As-received surface properties; end-of-life (EOL) emissivities assumed
Thermal instrumentation limited to four K-type thermocouples per test
Heat guns, heated/boiling water (**Figure 2**), or band heater used as heat sources

Figure 1: 17” Supertube

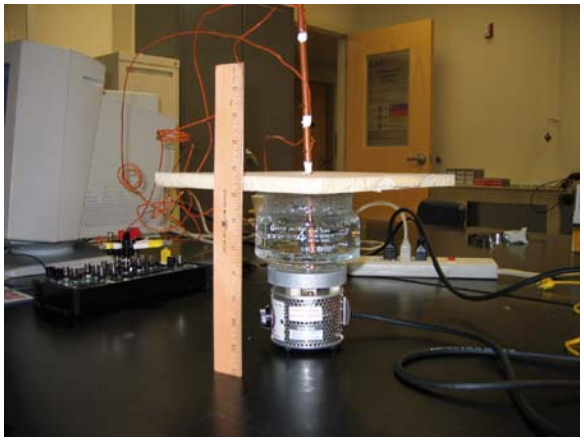

Figure 2: Setup for Boiling Water test of 17” Supertube

The data for the early boiling water test on a 17” Supertube, **Figure 3**, shows how the Supertube is able to draw heat along its length notably better than a regular copper rod.

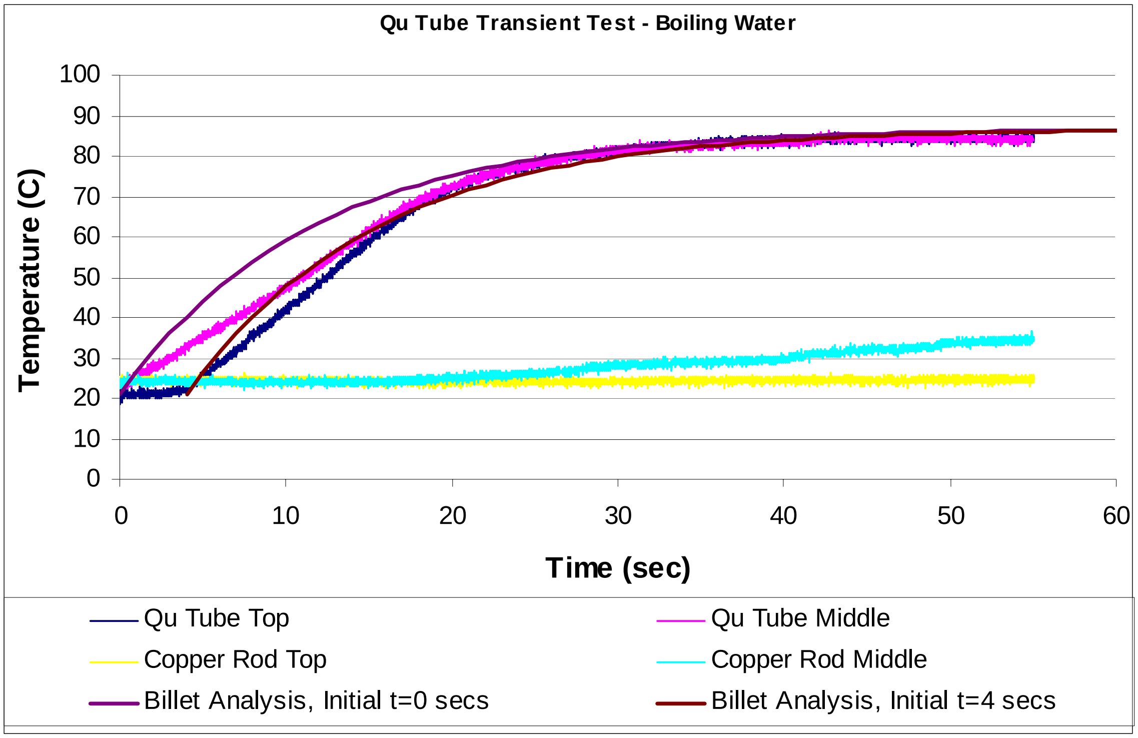

Figure 3: Data and Billet Analysis for Boiling Water Test, 17" Supertubes

The billet analysis referred to in **Figure 3** assumes an infinite thermal conductivity, and so is the ideal or best possible case. As shown, the Supertube performed almost equal to the assumed perfect conductor. And while it took less than 40 seconds for even the far end of the 17" Supertube to heat to approximately 88 C, the identically sized copper rod lagged considerably. In addition, these 60 seconds show the beginning of how temperatures on the copper rod will striate, whereas all of the Supertube has isothermalized. This isothermalization, and at temperatures higher than what the copper rod can achieve, are key to the higher heat rejection that Supertubes can provide.

Factors were then applied analytically to copper conductivity to determine lower bound of superconductivity seen in the Supertube. As shown in **Figure 4**, the factor is a minimum of 10,000.

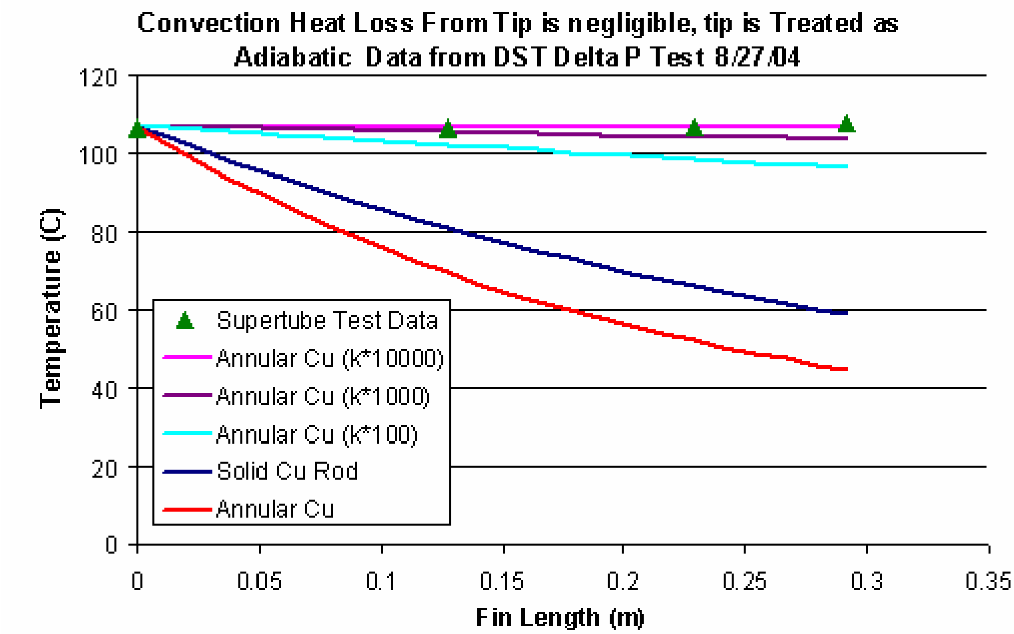

Figure 4: Data for 17" Supertube and Analytical Multiples for Copper Conductivity

SUBSET OF PHASE II TESTING AND ANALYSIS

The initial testing pinpointed the need for longer Supertubes, more sensitive instrumentation, higher fidelity controllers, and joint and repair optimizations. Due to project cutbacks, only the longer units and more thermocouples were able to be procured for the next set of testing, which started in late 2005. All preliminary information is in **Reference 2**; however, since considerably more testing needs to be done on the longer Supertubes, much of the information on their performance will be the subject of a later report. As an overview, non-proprietary subset of Phase II testing, all T/A, included the following:

Nine 10' long, by 5/16" OD Supertubes (see **Figure 5**)

Identically sized deoxidized copper rod for comparison

As-received surface properties; EOL emissivities again assumed

Thermal instrumentation currently limited to five K-type thermocouples per test

Band heater used as heat source (see **Figure 6**)

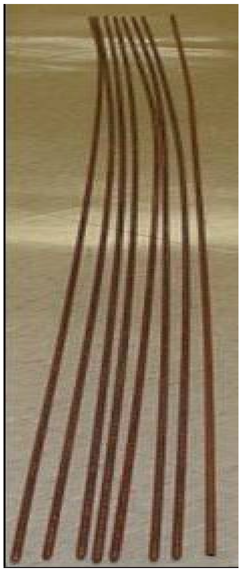

Figure 5: 10’ Supertubes

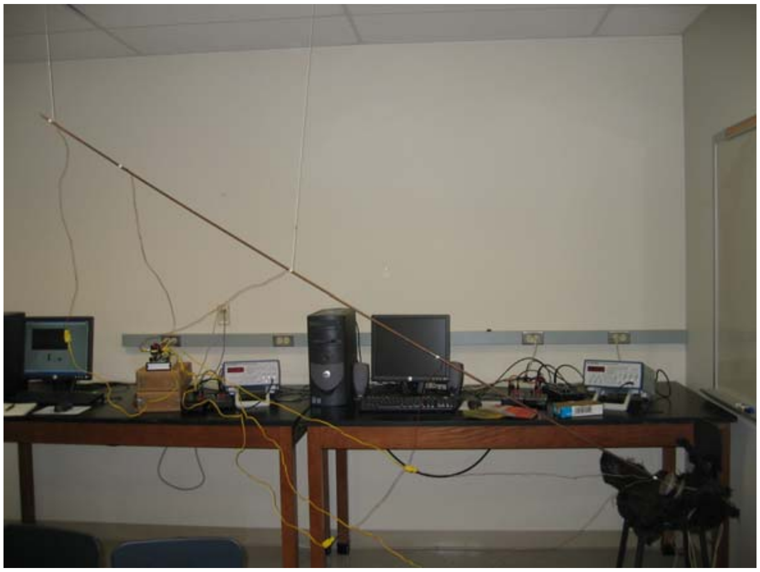

Figure 6: Setup for band heater testing of 10’ Supertubes

As the band heater was ramped up to 210 C, the 10’ Supertube performed as shown in **Figure 7**, where the Supertube at each of the five axial locations listed was essentially at the same temperature (isothermalized).

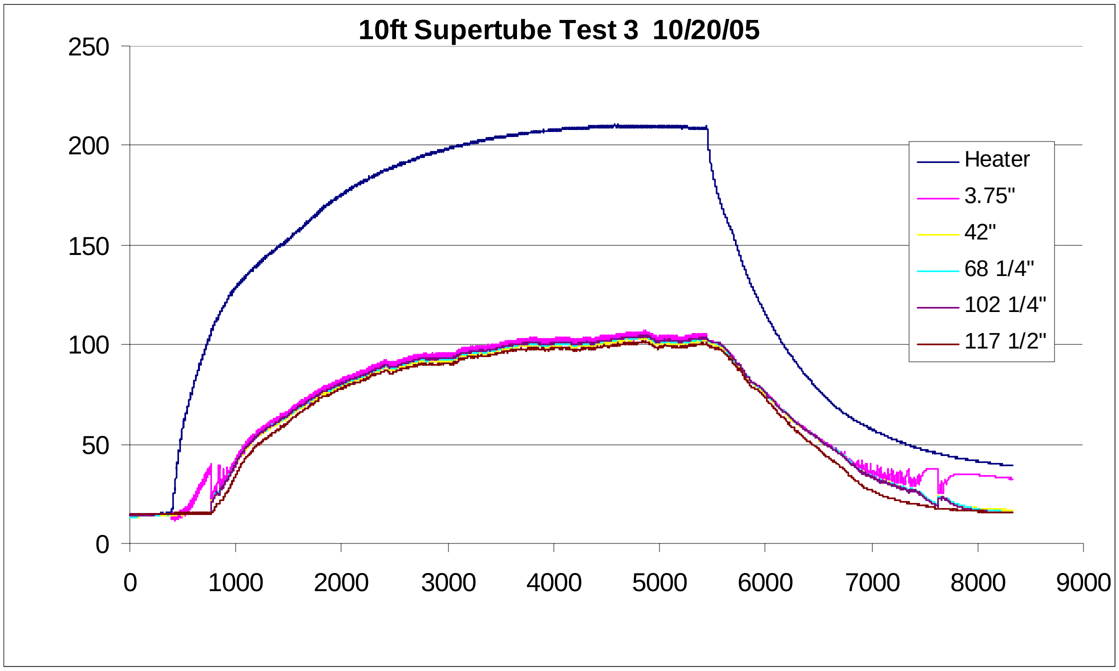

Figure 7: Data from band heater testing of 10’ Supertubes

A test was then performed on identically sized copper rod. Again the band heater was ramped up, this time to approximately 275 C, the band heater temperature needed to get the copper rod sensor nearest it at about the same temperature it was in the 10' Supertube band heater test. The copper rod performed as shown in **Figure 8**, where temperature plateaus were reached at each of the five axial locations listed.

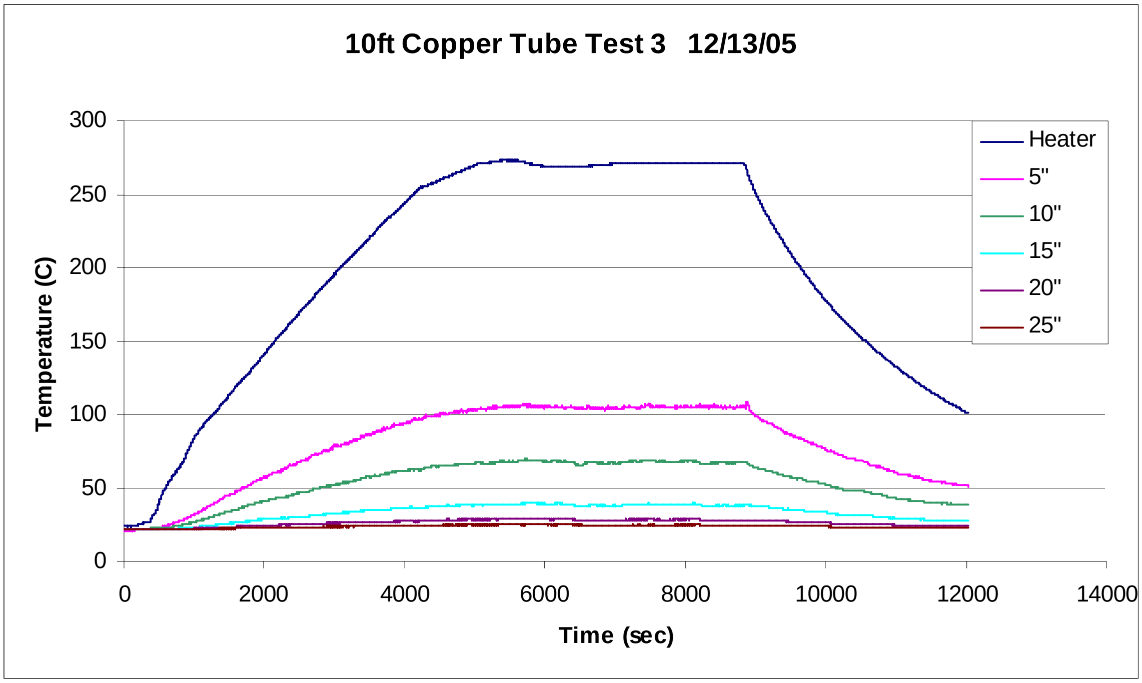

Figure 8: Data from band heater testing of 10' Copper Rod

Again, the isothermalized response of the Supertube (**Figure 7**) shows how they can be utilized to effectively conduct heat away from a high heat source. The gradient response of the copper rod (**Figure 8**) shows it is ineffective for that function. Indeed, even the first section of the copper rod cannot conduct as much heat, and each section thereafter conducts even less.

Factors were then applied analytically to copper conductivity to determine lower bound of the superconductivity seen in the Supertube. As shown in **Figure 9**, the factor is 30,000 minimum.

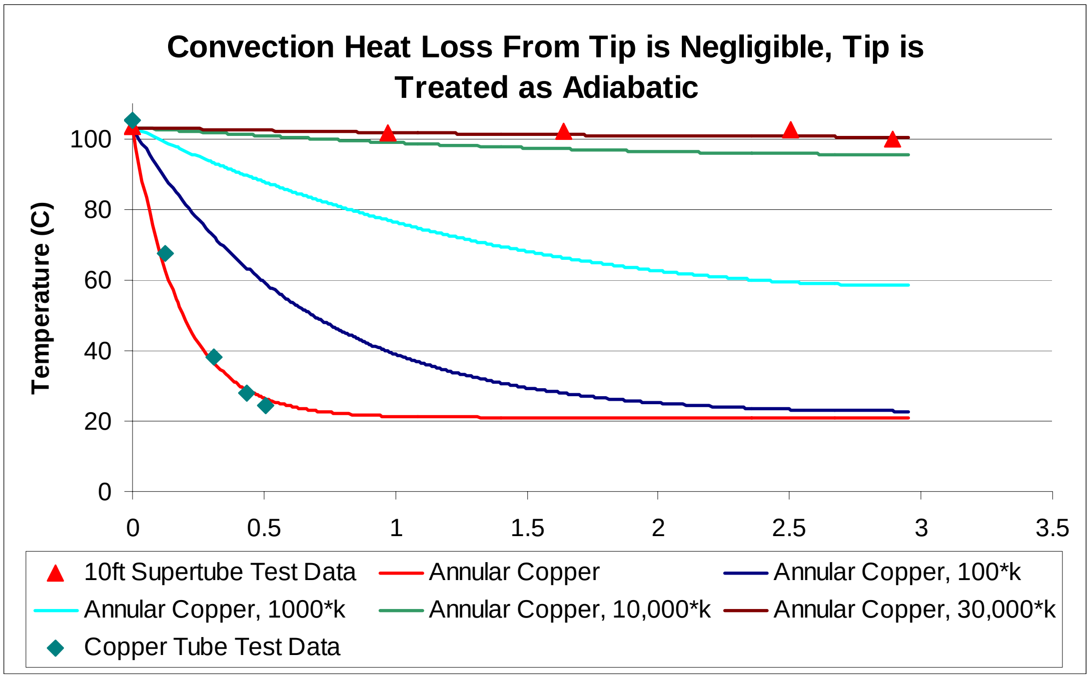

Figure 9: Data for 10' Supertube and Analytical Multiples for Copper Conductivity

CONNECTION OPTIONS FOR SUPERTUBES

The high conductivity of Supertubes allows quick isothermalization of individual units. However, unless units can be joined by process that continues the superconductivity pathway, the ASR would have to be close to the high heat source. That location could have a less than optimal viewing environment and potentially high parasitic heat. In addition, thermally efficient joints would draw the heat more efficiently across the interface, helping conduct more heat to the ASR, where it can be efficiently radiated. Several options are discussed in **Reference 2**, all of which result in some to complete loss of continuous superconductivity. None of the joining concepts were funded for testing under the previous work agreements due to money and priority constraints.

FUTURE WORK

If further funded, the authors recommend that higher fidelity sensors (thermistors), as well as high fidelity controllers be obtained, and that joint studies and repair optimizations be conducted. In addition, test segments and analysis to target two additional areas should be added. First, test segments should be conducted to ascertain if the rate of heat application could also be key to activation of the superconductivity, and if so to quantify those flux rates. Second, additional test segments should be conducted under T/V conditions, to further assess Supertube T/V performance. In the added test segments, sufficiently long, repeated observations would be required to determine and verify the flux and vacuum thermal parameters.

CONCLUSIONS

For temperatures from activation up to the melting point of their carrier metal, Supertubes provide excellent heat transport characteristics. In addition, Supertubes with their small diameter, annular, solid-state configurations result in lower mass than conventional heat pipes and pose no fluid handling concerns. Although both are susceptible to meteorite damage, the lower mass and complexity of Supertubes make redundancy more viable for them than for the conventional heat pipe systems. Once the superconductivity threshold is reached, the Supertubes' axial conductance is much larger than the external radiative heat transfer. Therefore, degradation of the surface properties is negligible for thermal performance, making Supertube use attractive for dust laden environments. In addition, thermal parameters that characterize the Supertubes' ground performance have been correlated to repeated, long term observations, and provide step in verification of extrapolations for on-orbit thermal performance.

REFERENCES

1. Qu, Yuzhi, "Superconducting Heat Transfer Medium", Patent No. 6,132,823 dated October 17, 2000.

2. Blackmon, Dr. James B. and Entrekin, Sean, "Advanced Space Radiator for High Concentration Solar Photovoltaic Array Thermal Control and Modular Reconfigurable High Energy Project Final Report", May 8, 2006.

NOMENCLATURE, ACRONYMS, AND ABBREVIATIONS

ASR Advanced Space Radiator
EOL end-of-life
MSFC Marshall Space Flight Center
OD outer diameter
PRC Propulsion Research Center
T/A Thermal Ambient
T/V Thermal Vacuum
UAH University of Alabama – Huntsville