An Empirical Study of Oscillating Heat Pipe

Heat Rejection Radiators for Next Generation Space Platforms

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# Abstract

Sophisticated thermal control technologies with high heat flux acquisition and high operating temperature capabilities are sought after for next generation spacecraft platforms. With the proliferation of solid-state power amplifiers (SSPA) and other high energy-dense electronics onboard spacecraft, the need to acquire heat at relatively high concentrations and efficiently spread it over large areas for dissipation is becoming increasingly critical. Compared to conventional Si, GaN and SiC based electronics allow for higher operating temperatures therefore higher radiation rejection capacity. However, existing heat pipe radiator solutions often have a maximum of 360K or less, thereby limiting the value of these high-performance materials. Opportunities outside of electronics call for even higher temperature radiator systems that many heat pipe radiators cannot support, such as future large-scale, fission power generation modules that will necessitate the advancement of high temperature radiators in the 400-575 K range. A novel set of radiator technologies have been under development to support these objectives around increasing power densities and higher temperature heat rejection requirements using the Oscillating Heat Pipe (OHP) technology embedded in light-weight envelope materials. This combination has proven to push the boundaries of what the current state-of-the-art thermal radiator technologies can provide in terms of power dissipation per unit mass [kW/kg], or specific power. The OHP radiator is also capable of achieving very low mass per unit area [kg/m2], or areal density, and very high thermal conductance [W/K]. Multiple OHP form factors, microchannel architectures and working fluids have been empirically demonstrated in ways that can close the gap between future needs and current capabilities of the status quo passive heat pipe radiators. A thorough review of those demonstrations are presented herein, with a roadmap outlining present qualification efforts underway for various spaceborne platforms.

Novel designs are shown to achieve highly isothermal, large area heat rejection, with temperature differences typically on the order of 2-5K or even less, depending on the configuration. With this high degree of temperature uniformity and low temperature rise back to the heat source interface, radiators can be designed smaller and more lightweight than they could using conventional designs. In the operating temperature range suitable for electronics, conductance has been demonstrated between 150 – 400 W/K for 0.25 and 0.50 m2 area panels, with only 2 mm or less overall thickness. In the higher temperature applications like surface fission power reactors, new classes of working fluids are in development. Radiators have been designed to reach specific power of greater than 1 kW/kg and an areal density less than 1 kg/m2 (two-sided rejection, 375 K surface) while retaining the same high degree of isothermality as what current heat pipe radiators offer. The experimental prototypes were able to reach a thermal conductance of greater than 100 W/K while operating at powers greater than 1 kW.

These empirical results have been correlated back to numerical models for thermal conductance modeling, and to first-principles models for predicting the limits of operation, both which are to be used in future design work. The OHP radiators have been demonstrated to have a broad useful operating temperature range with respect to the various limiting mechanisms first identified by Drolen et al. The OHP radiators are seemingly unaffected by the documented Swept Length Limit, often associated with large-area heat input regions. This is especially advantageous for electronics applications where the payload is often a rectangular interface with a contact area of greater than 200 cm2. The OHP radiator has been shown to handle relatively high heat concentrations on the order of 10 W/cm2 and greater, which reduces the need for massive heat spreading capability within the electronics enclosures themselves.

Qualification efforts have been completed for the low-areal density electronics payload cooling radiator devices, which are especially well suited for small satellite applications. Qualification testing completed includes thermal-vacuum, random vibration, mechanical shock, thermal shock, temperature cycling and accelerated aging. Similar extensive testing campaigns are starting now, to qualify the higher temperature OHP radiators for fission power applications. This thermal radiator technology has also found applications in electric aircraft, where the same panels can be used as thermally active panels in the vehicle’s outer mold line (OML). Wind tunnel demonstrations have been completed in support of the High-Efficiency Electrified Aircraft Thermal Research (HEATheR), which showed the OHP panels’ ability to handle even higher heat loads commensurate to the more effective air-cooled heat rejection boundary. Advancements continue through sustained research to further reduce the areal density through advanced manufacturing development, and the useful operating temperatures expanded through novel working fluid selection.