

## **Gravity Friendly Heat Pipes with Low Freezing Temperature:** *Additive Manufactured Heat Pipe Technology*

### **PROJECT OVERVIEW**

*Additive Manufacturing (AM) is a unique fabrication method that enables complex and flexible geometry designs for a wide range of components, including two-phase thermal management components like heat pipes. This project focuses on titanium-ammonia heat pipes used for future space electronic payloads like satellites and comparing their performance against conventionally manufactured heat pipes with screen mesh capillary wicks. AM increases the ability to integrate components into chassis elements, directly cool electronics components, and improve the functionality against gravity which eases ground testing. Both AM and screen mesh wick structures offer enhanced evaporator heat flux versus aluminum-ammonia, grooved wick heat pipes, enabling direct thermal management of electronics components.*

*Prospective telecommunications satellite payloads are expected to release a step-increase in power dissipation, requiring innovative thermal management techniques. Ammonia heat pipes are heavily deployed at platform level within radiator panels, as surface mounted heat pipes and as thermal links. However, system designers cannot integrate them into electronics chassis for direct micro-electronic cooling due to the low evaporator heat flux limit of extruded axially grooved capillary wicks, low maximum operating temperature, and inability to function against gravity on ground test. Novel gravity-friendly heat pipes offer a means of direct thermal management of future payloads.*

*This project identified, developed, and completed acceptance testing on a new heat pipe technology that extends the functional temperature range of ammonia working fluid heat pipes. It also helped overcome challenges during ground-testing of non-gravity friendly heat pipe by implementing new wick structures that enable functionality against gravity. The project investigated novel working fluid and wall materials combinations (Figure 3), investigated enhanced screen-mesh capillary wick structures, and developed a first generation of additive manufactured heat pipes. The goal of these new AM heat pipes is to enable integration of the chassis structure and enable direct thermal management of microprocessors.*

### **BOYD'S CURRENT USE OF ADDITIVE MANUFACTURING**

Additive Manufacturing, or 3D Printing, is a fabrication method that's gaining popularity as 3D printers advance to accommodate a wider range of materials and definition. The Additive Manufacturing Team at Aavid, Thermal Division of Boyd Corporation is composed of experienced engineers in both thermal and additive design. Our team leverages advanced process knowledge to design and print functional parts that other companies cannot.



Figure 1 – Additive Manufacturing Prototype of Aavid, Thermal Division of Boyd Logo

Additive Manufacturing enables faster lead times by eliminating the need for fixtures and limiting setup time that accompanies more traditional metal fabrication processes. 3D Printed parts combine what would be multiple manufacturing processes for a complex product into a single print, reducing lead times from months to days. Since we use real time monitoring of ongoing prints, we identify manufacturing risks and potential defects sooner, allowing you to better maintain supply chain schedules.

### TECHNOLOGY EVALUATION PHASE

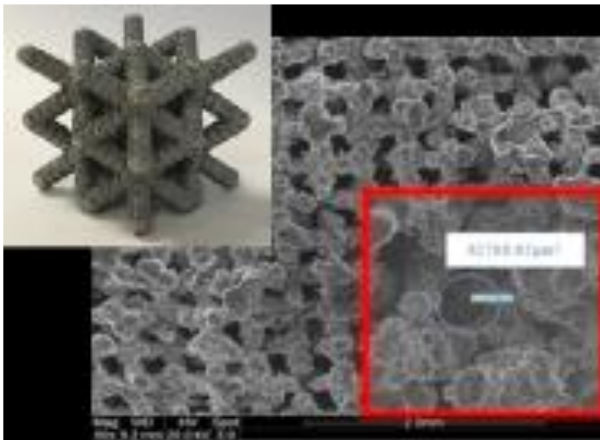


Figure 2 - Additive Manufacturing Lattice Cell Representation and SEM Image of Microscale AM Heat Pipe Wick Structure

Boyd's Additive Manufacturing team assessed and identified trade-offs of candidate heat pipe technologies for this project. Our engineers selected a range of potential technologies to manufacture test samples for evaluation. The team analyzed promising technologies for future development including a method that enables high-temperature operation of copper-methanol heat pipes and a new working fluid that potentially enables very high operating temperatures but still meets the low freezing point and equivalent thermal performance of ammonia. The team also examined various screen mesh wicked heat pipe configurations with copper, aluminum, and stainless steel vessels, which enables increased evaporator heat flux compared to aluminum grooved wick heat pipes.

### ADDITIVE MANUFACTURED HEAT PIPE DEVELOPMENT

The University of Liverpool pioneered the development of laser powder bed fusion (LPBF) technology, where 2D solid patterns are laser melted in sequential layers of metal powder to form complex 3D geometry. The major challenge facing this method was producing sufficiently small wick pore sizes to enable capillary pumping against gravity. This development focused on miniaturization of lattice cell structures and laboratory characterization of the capillary structures. At the project onset, the minimum lattice cell size produced by additive manufacturing was too large to enable capillary pumping against gravity. The collaborative additive manufacturing team achieved reduced cell sizes by leveraging custom software to program and complete multiple build trials with customized laser parameters defined to each build sample.



Figure 3 - AM Laser Parameter Trial and Optimized Parameter Build Plates Comparison

These optimized laser parameters enabled these engineers to build a series of test pieces across a range of miniaturized cell sizes. The team utilized novel visualization techniques and test methods to measure pore size, lift height, porosity, and permeability of the samples. With this detailed information, we were able to select two preferred candidate wick structures which were subsequently used to build and test functional titanium-ammonia heat pipes.

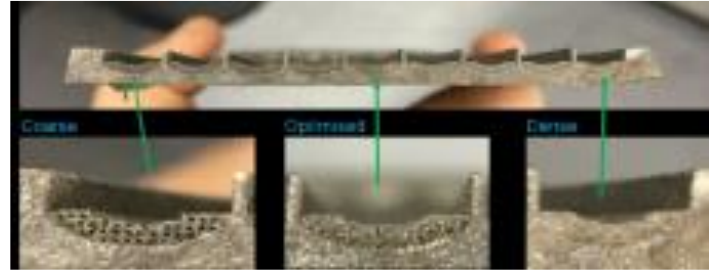


Figure 4 - AM Test Piece with Various Lattice Wick Pore Size

## SCREEN MESH WICKED HEAT PIPE DEVELOPMENT

Aavid has spent the last few decades designing and manufacturing copper heat pipes with screen mesh wick structures. Screen mesh wick structures offer an increased evaporator surface heat flux over grooved wick structure that enables direct contact to the microelectronics. Typically, the pore size of screen mesh wicks is large, which enables a large mass flow rate of condensate leading to high power transport. As the large pore size limits functionality against gravity, our additive manufacturing team selected a new stainless steel screen mesh material with fine pore size for investigation. The heat pipe envelope was also fabricated from stainless steel to prevent galvanic corrosion. To adequately compare this design against the additive manufactured heat pipes, the team utilized ammonia as the working fluid.

## HEAT PIPE TEST PIECES & QUALIFICATION TESTING

For direct comparison, both screen mesh and AM heat pipe test assemblies consisted of a circular tube envelope heat pipes and joined to evaporator and condenser blocks with space-qualified thermal epoxy. The heat pipes constructed with additive manufacturing did not leverage the full advantage of 3D design flexibility, but did consist of integrated end caps, fill tubes, and wick structure. As seen in *Figure 5*, the team has since fabricated more complex vapor chamber. Both individual heat pipes and the heat pipe assemblies underwent acceptance and qualification testing in accordance with a test plan derived from the ESA SOW. Both assemblies demonstrated 30 W of required heat transport in space conditions (zero-gravity / adverse tilt) during direct thermal management performance tests of a 40 mm x 40 mm microprocessor. While the functionality against gravity was limited, the screen mesh heat pipes increased evaporator surface heat flux over current axially grooved heat pipes which would allow direct microprocessors cooling. The additive manufactured heat pipe assemblies could function up to an angle of -20° against gravity as opposed to -0.3° for the screen mesh wicked heat pipes. In addition to standard ammonia heat pipe acceptance tests (e.g. helium leak test, proof pressure at temperature test, ageing, NCG tests, etc.), individual heat pipes and heat pipe assemblies successfully completed freeze-thaw testing and vibration testing that simulate launch conditions, without degrading heat pipe functionality.

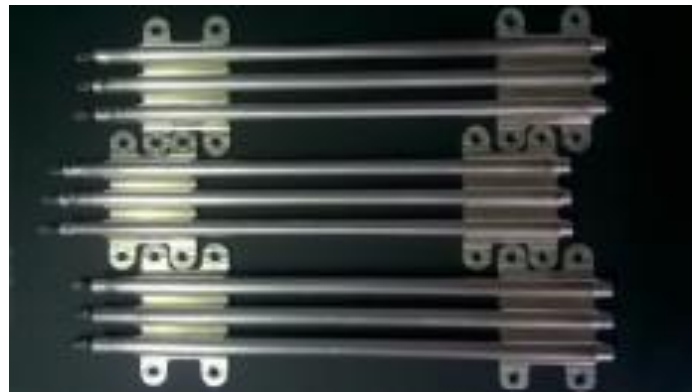


Figure 5 - Stainless Steel 316L Screen Mesh, Ammonia Heat Pipe Epoxy Bonded Aluminum Evaporator & Condenser Flanges

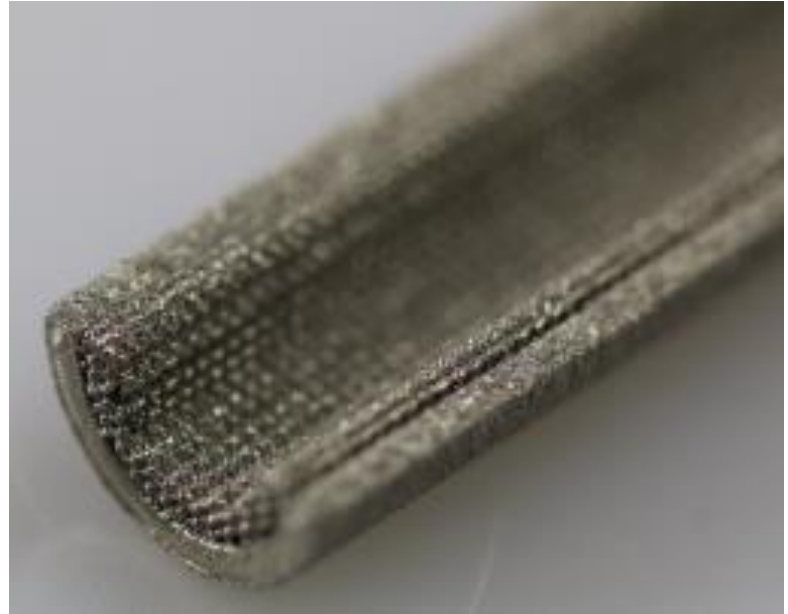
### ADDITIVE MANUFACTURED HEAT PIPE FUTURE

The Boyd Team has now patented the first generation of additive manufactured titanium-ammonia heat pipe technology. Benchmark testing against alternative stainless-steel screen-mesh wicked ammonia heat pipes demonstrates enhanced performance of AM heat pipes. This technology achieved NASA's Technology Readiness Level 4 (TRL 4), meaning it has been validated within a laboratory environment. Now, additive manufacture titanium-ammonia heat pipes are ready to transition into the TRL demonstration phase for full qualification in a space flight program. To initiate the demonstration phase, our team manufactured AM titanium vapor chamber test pieces with a more complex mechanical design. This preliminary vapor chamber test piece utilizes the AM wick laser parameters defined in this project and demonstrates full functionality against gravity (100 mm lift height).

Boyd Corporation is interested in discussing potential applications beyond spaceflight to continue the development of additive manufactured two-phase cooling technologies.



*Figure 6 - Future Integrated AM Heat Pipe Vapor Chamber Proof-of-Concept*



*Figure 7 - State-of-the-Art Additive Manufactured Titanium Heat Pipe Test Piece with Integrated AM Lattice Wick*

To receive more information regarding Boyd Additive Manufacturing or Heat Pipes, please visit our [Additive Manufacturing page online.](#)

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