ASCENT Project 056

Turbine Cooling through Additive Manufacturing

The Pennsylvania State University

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Cost Share Partner: Pratt and Whitney

Objective:

Cooling of turbine hot section components is necessary for durability but contributes to increased fuel burn. This study investigates novel cooling designs enabled by additive manufacturing (AM), which are tested in a full-scale rotating turbine facility.

Project Benefits:

Advanced microchannel cooling technology could lead to lower cooling flow requirements, where even a 5% reduction in needed cooling air would decrease specific fuel consumption of the aircraft by >1%. This will also be the first public comparison of cast vs AM blades at relevant rotating conditions.

Research Approach:

Cast turbine blades from a prior FAA CLEEN II program are scanned using CT technology, replicated using additive manufacturing (AM), and tested in a rotating turbine facility at PSU, to generate a direct comparison between cast and AM blades. In parallel, a large number of novel microchannel design concepts are tested in a stationary linear cascade at Penn State. Finally, best designs will be integrated into the rotating turbine blades and tested to determine quantitative reductions in cooling flow with advanced microchannel technology.

Major Accomplishments (to date):

The cast turbine blades were CT scanned and a model for AM was developed. A stationary turbine blade cascade design for rapid vetting of novel microchannel designs is nearly complete. Two vendors have been selected for AM fabrication of the turbine blades.

Future Work / Schedule:

The first set of additively manufactured turbine blades will be fabricated in summer and tested in fall; novel microchannel designs will be vetted in the stationary cascade in summer.

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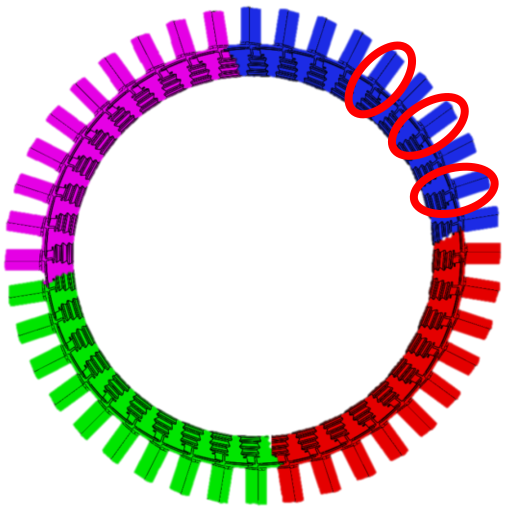
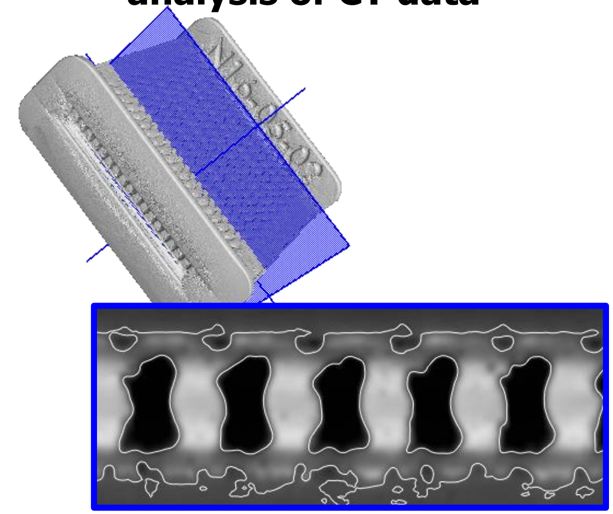
Cast turbine airfoils from a prior FAA program were scanned using X-ray CT

"Rainbow wheel" indicating blades with different cooling technologies



X-ray CT scanning facility on PSU campus

Example nominal-actual analysis of CT data



Models were generated from the CT and will be printed at two vendors

https://jpt.spe.org/additive-manufacturing-makes-waves-industry

Novel cooling designs are being implemented into a test airfoil

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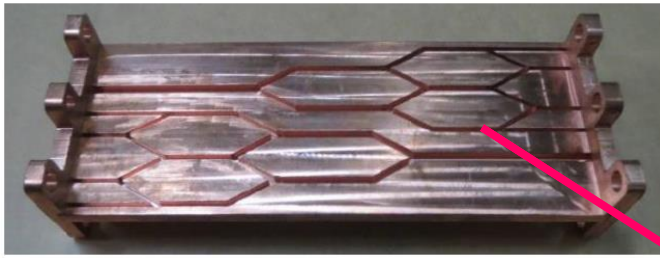
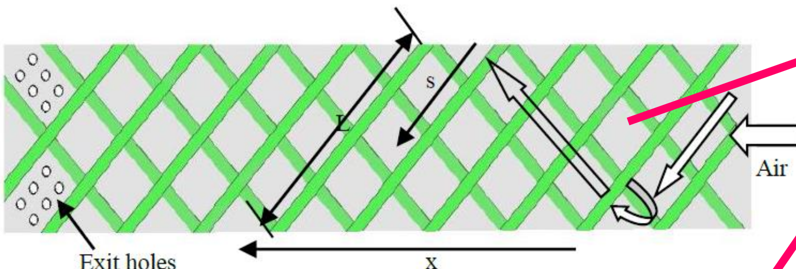
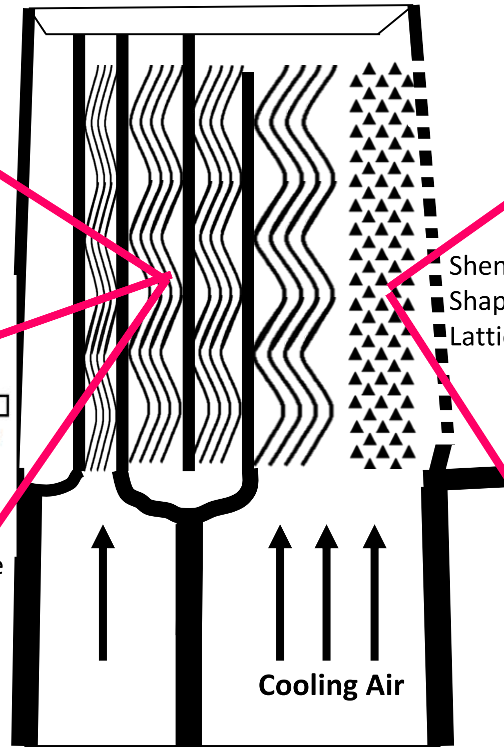
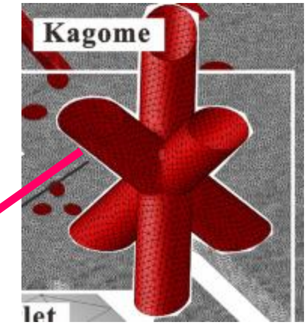


Shui et al., “Investigation of Heat Transfer and Flow Characteristics in Fractal Tree-like Microchannel with Steam Cooling,” 2017, Proc. ASME Turbo Expo.

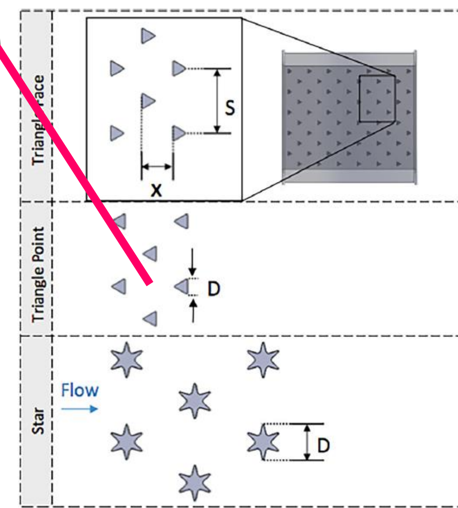


Saha, et al., “Heat Transfer Enhancement and Thermal Performance of Lattice Structures for Internal Cooling of Airfoil Trailing Edges,” 2013, J. Therm. Sci. Eng. Appl..

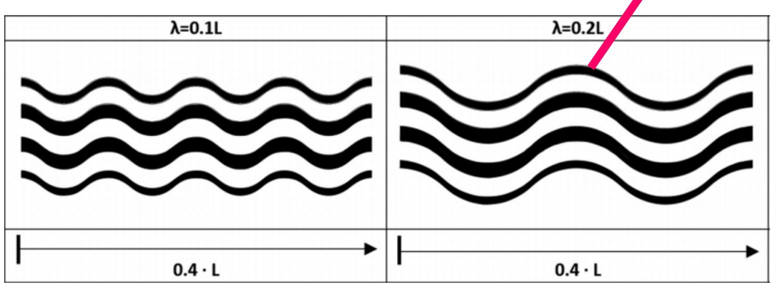




Shen et al., “Heat Transfer Enhancement of Wedge-Shaped Channels by Replacing Pin Fins with Kagome Lattice Structures,” 2019, Int. J. Heat Mass Transf.



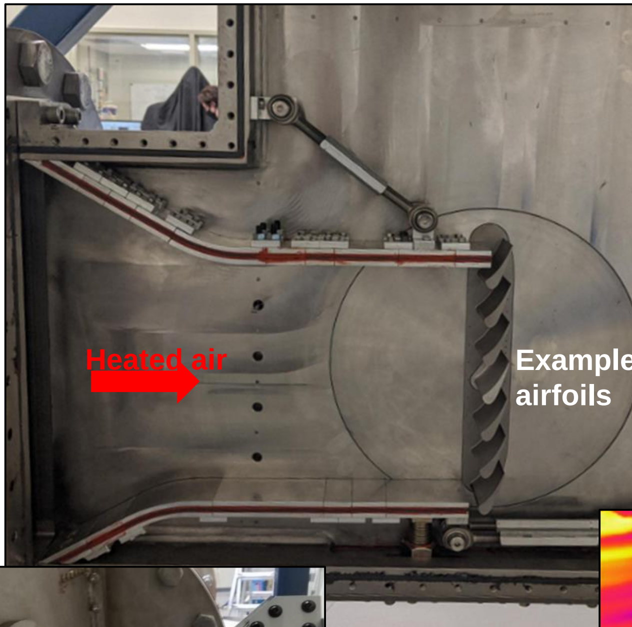
Ferster, et al. “Effects of Geometry, Spacing, and Number of Pin Fins in Additively Manufactured Microchannel Pin Fin Arrays”, 2020, J. Turbomachinery.



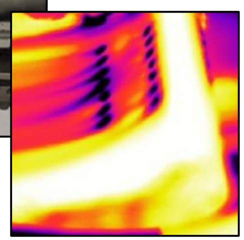
Kirsch and Thole, “Heat Transfer and Pressure Loss Measurements in Additively Manufactured Wavy Microchannels”, 2017, J. Turbomachinery.

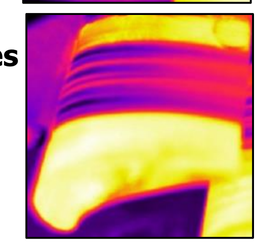
Multiple novel designs will be tested before implementing in a rotating blade

High Speed Stationary Cascade



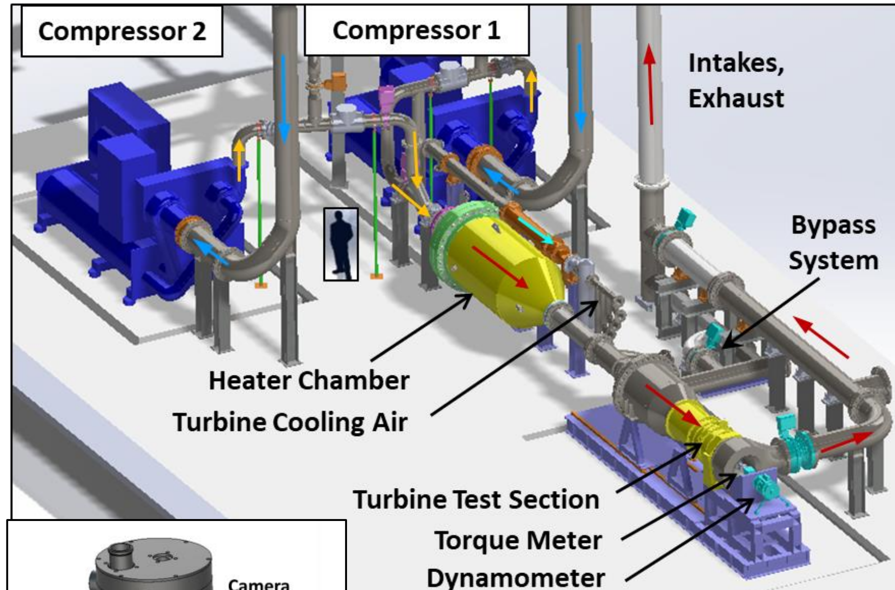
IR camera with 360° views of <u>stationary</u> blades

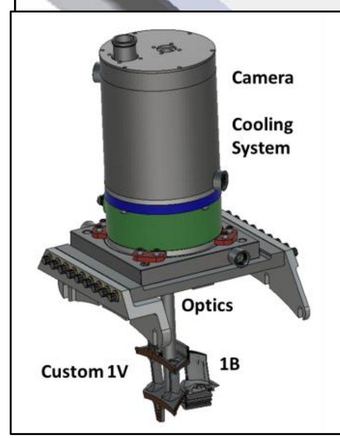




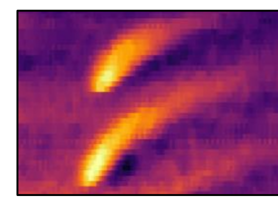
Zuccarello, et al., "A Steady Transonic Linear Cascade for True Scale Cooling Measurements", 2020, Proceedings of the ASME Turbo Expo.

Rotating Turbine Facility





IR camera images to view <u>rotating</u> blades



Knisely, et al. "Acquisition and Processing Considerations for Infrared Images of Rotating Turbine Blades", 2021, J. Turbomachinery