Department of
MECHANICAL ENGINEERING
THE UNIVERSITY OF UTAH

ASME/IEEE HEAT SINK CHALLENGE

Josh Brodbeck, Nate Brown, Zane Frey, Eric Montenegro, Oliver Proctor
Advisor: Dr. Sameer Rao

INTRODUCTION

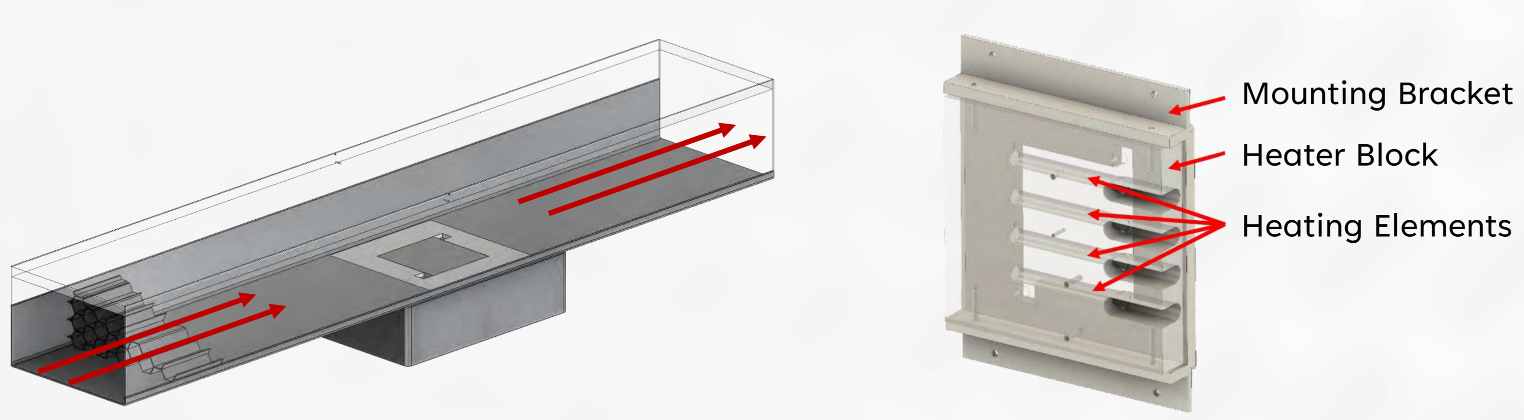
As electronics become increasingly power intensive, so too do their cooling requirements. With the advent of metal additive manufacturing (AM) technologies, 3D printing metal parts through processes such as laser powder bed fusion (LPBF) or binder jet allow for unique and intricate geometries that can enhance cooling to avoid thermal performance decline.

PROBLEM STATEMENT

- Design a heat sink design for the 2023-2024 ASME/IEEE Heat Sink Challenge that...
  - Utilizes GE Additive's binder jet AM technologies
  - Meets the specifications defined below
  - Maximizes cost-normalized performance, defined by the Figure of Merit (FOM) equation:

$$FOM = \frac{1}{m_{HS}(R_1 + R_5)}, \quad R_i = \frac{T_{meas} - T_{amb}}{Q_{in}}$$

	Metric	Value	Unit
Material Specifications	Input Power	3	W
	Material	316L Steel	-
	Thermal Conductivity	15	W/m-K
	Build Volume	60 x 60 x 38	mm
Printing Specifications	Min. Feature Size	0.4	mm
	Feature Height/Width	12.5	-
	Overhangs (unsupported)	45	deg



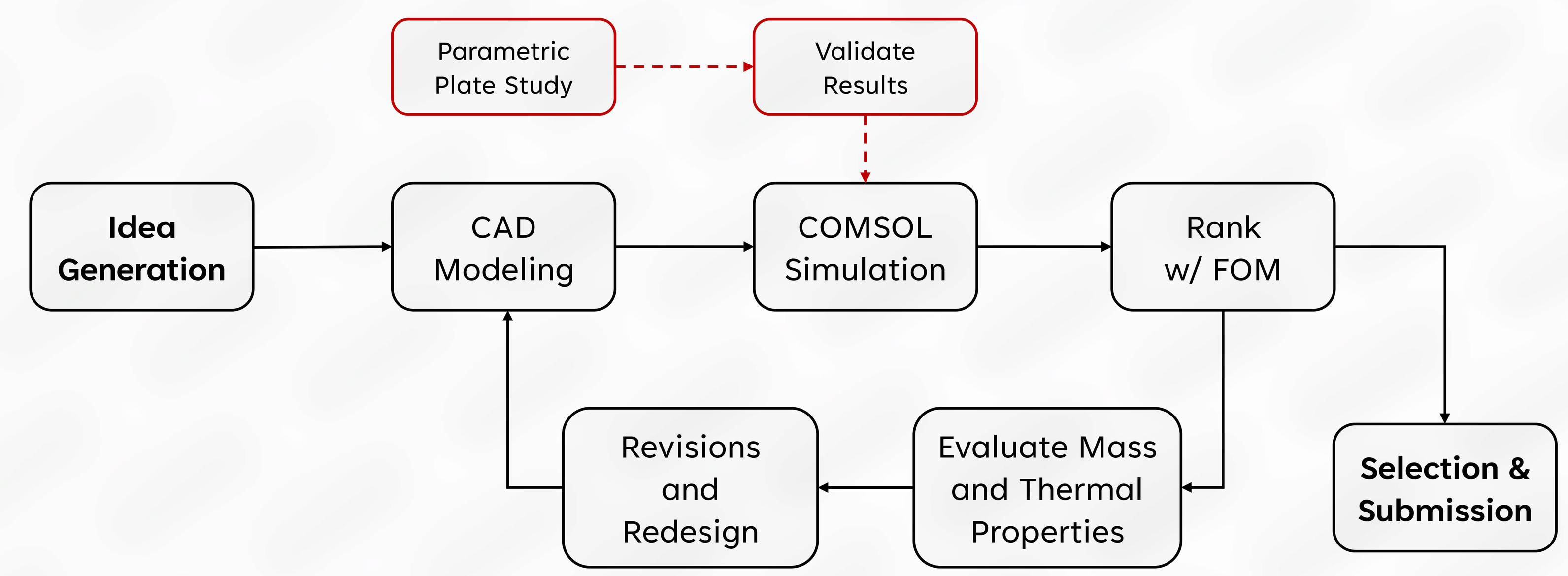
Forced-air test apparatus and heating element assembly for competition testing

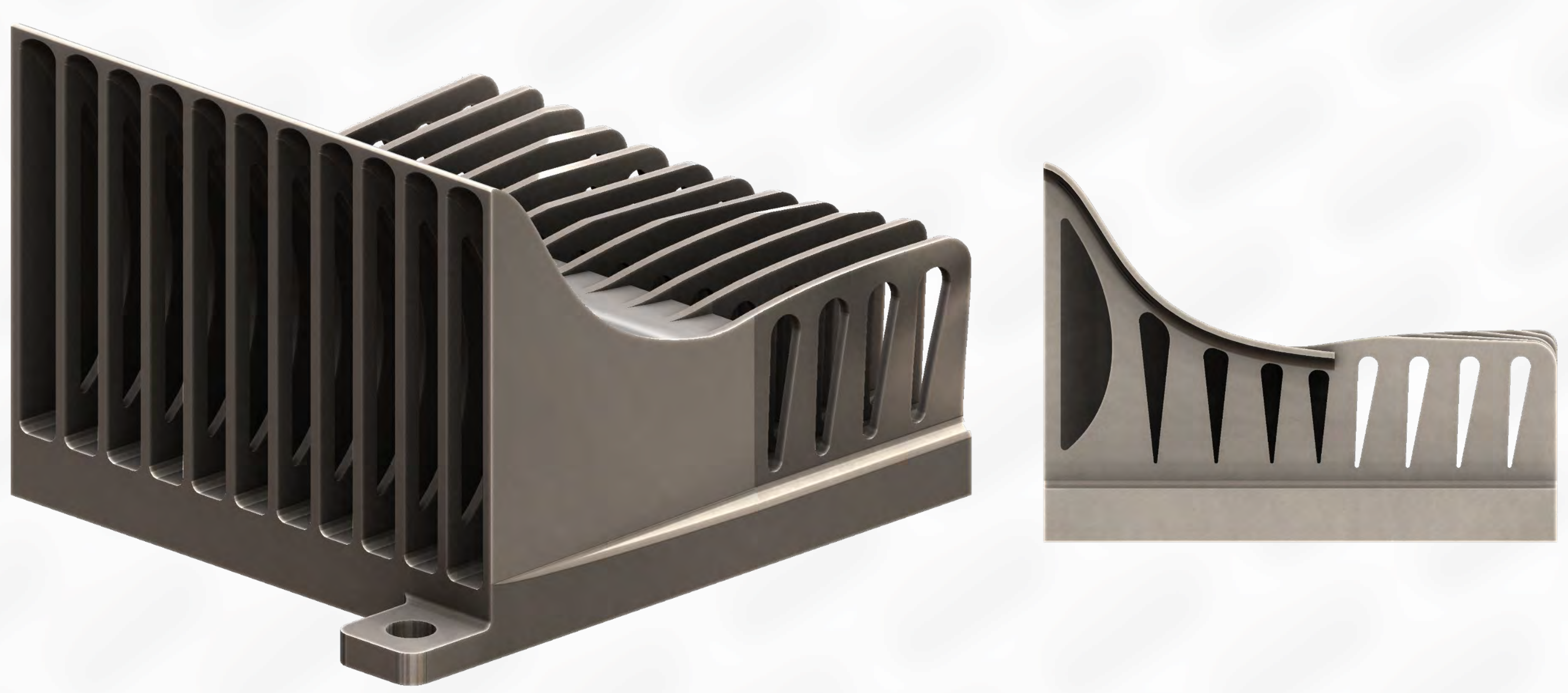
HEAT TRANSFER

- Typical heat sinks...
  - Increase convective heat transfer by increasing convective surface area, A_s
  - Are made from copper or aluminum (200-400 W/m-K)
- Thermal limitations of 316L Stainless Steel:
  - Low thermal conductivity (14 W/m-K) limits feature height
- Design increases convective heat transfer coefficient, h

$$q_{\text{conv}} = hA_s(T - T_\infty), \quad q_{\text{cond}} = -kA_c\frac{dT}{dx}$$

DESIGN PROCESS

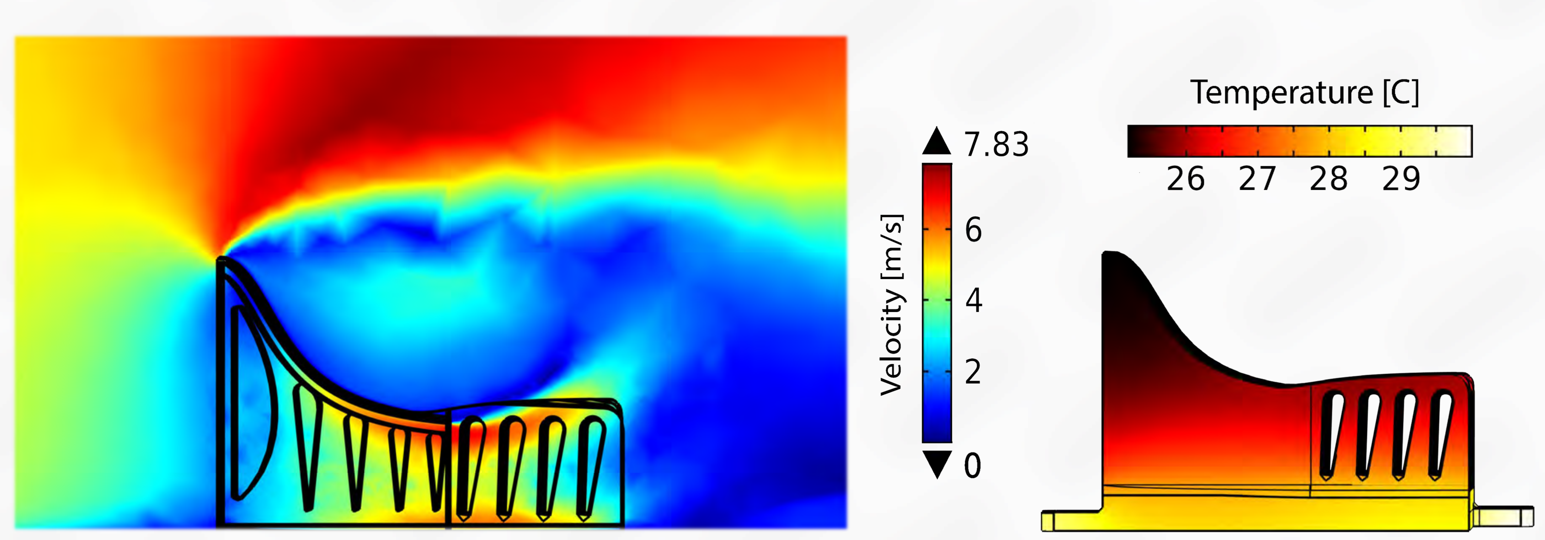




The final "Venturi Plates" SolidWorks model submitted to GE Additive for printing. Left: isometric view of heat sink, Right: profile section view of heat sink

DESIGN DESCRIPTION

The final "Venturi Plates" design capitalizes on the Venturi effect, accelerating intake air towards the heated base to enhance local convective heat transfer near the base plate. To prevent pressure buildup, the enclosure terminates near the midpoint of the heat sink. Plate dimensions and thicknesses were determined via a parametric thermal performance study. Mass is reduced with internal cutouts and slots, which also facilitate vertical conduction near the base plate. Finally, curved and filleted edges facilitate 3D printing.



CFD Simulations results for Venturi Plates. Left: velocity slice through heat sink, Right: Temperature profile of heat sink

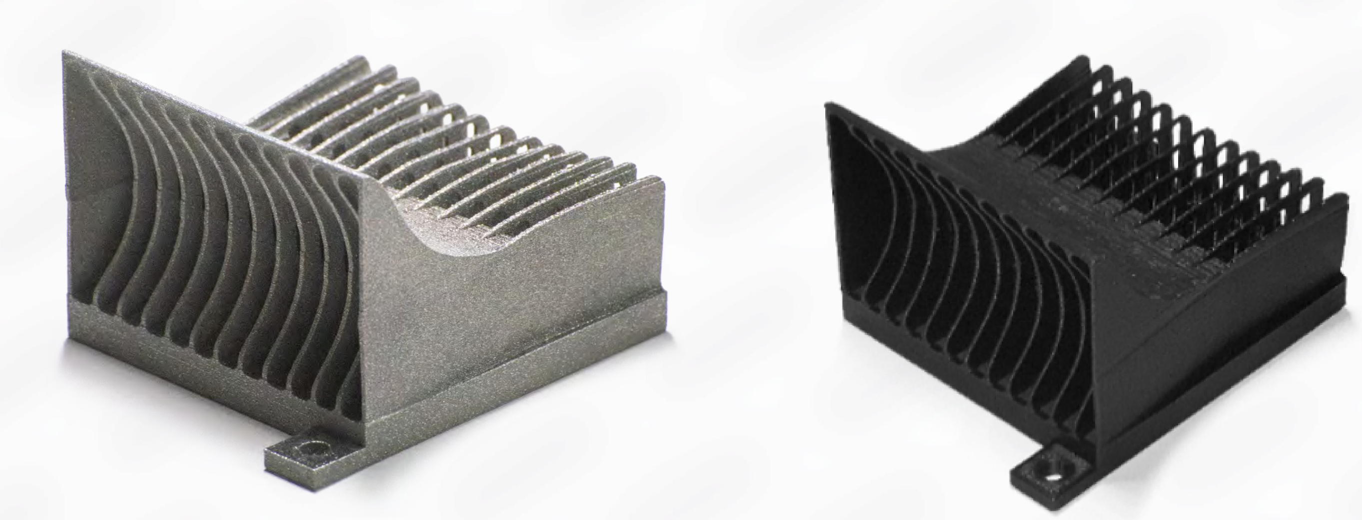
CFD TESTING/ANALYSIS

- Thermal performance simulated in COMSOL Multiphysics
  - Conduction, convection, and radiation modeled
  - Turbulent flow modeled with Length-Velocity (L-VEL) Model
- Results were validated using IEEE provided data
  - 7.4% error in probe temperature (30% is typical for CFD)
- Final GE Model performed 4.3% better than benchmark (FOM)
  - 4.2% lower performance than ideal Venturi Plates model
  - Venturi effect produced airflow up to 38% higher than freestream

	Venturi Plates	GE Model	Benchmark
Input Power [W]	3	3	3
Ambient Temp. [°C]	25	25	25
Temp. @ 1 m/s [°C]	31.8	31.9	33.0
Temp. @ 5 m/s [°C]	28.5	28.4	29.3
Mass [g]	287.5	300.0	262.2
Figure of Merit [W/kg·C]	**1.0131**	**0.9709**	**0.9302**

ADDITIVE MANUFACTURING

The final design contains elements which would be difficult to reproduce with conventional manufacturing. A metal prototype was produced in the U of U's Metal 3D Printing Lab using laser powder bed fusion. The final design will be printed by GE using a binder jet process, a two-step process in which powdered metal is bonded with an adhesive and then annealed to fuse the powder into a solid part.



Physical prototypes of semifinal designs. Left: laser powder bed fusion metal print, Right: plastic 3D printed prototype

CONCLUSION

- Selected as semifinalists (amongst 7 teams)
  - Modifications to made to model for GE binder jet process
  - GE printing and experimental testing ongoing
- If selected as finalists (top 3 teams):
  - Present design at 2024 ITherm Conference (May 28-31) in Denver, CO