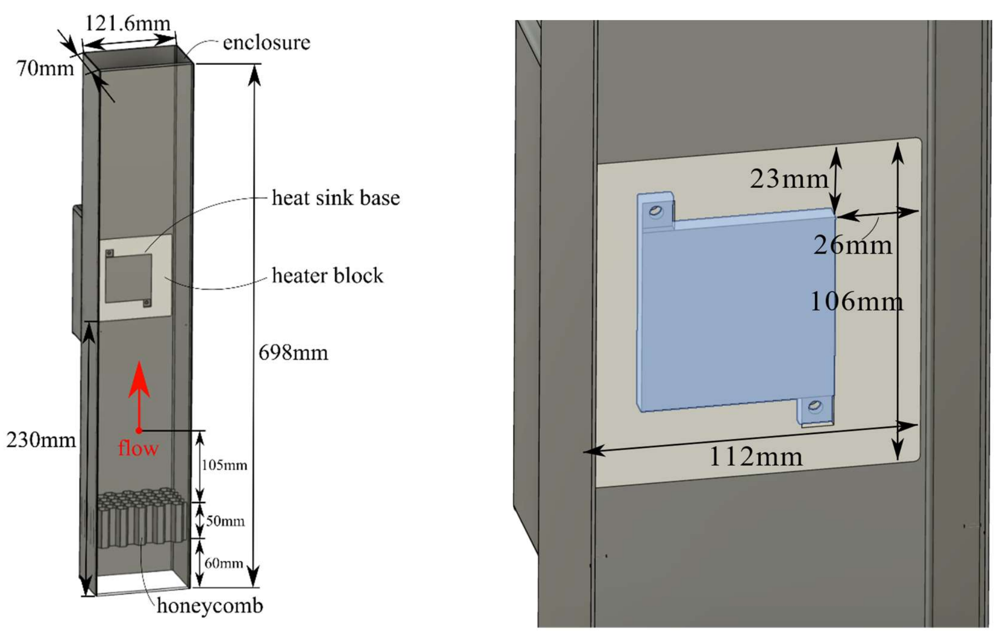
ASME K-16/IEEE EPS Heat Sink Design Competition
– Guidance Document 2024 –

This guidance document provides the details for the 2024 ASME K16 / IEEE EPS Heat Sink Design Competition. The participating student teams will design, analyse, and optimise an additively manufactured heat sink to cool a constant power module subject to forced convection at two air velocities in a vertical enclosure. The teams that are evaluated as having the most effective designs exploiting the design freedom allowed by additive manufacturing, will have the opportunity to have their designs printed at GE and experimentally tested at the University of Southern Denmark. The finalists will be invited to present their work at the 2024 ITherm conference.

Forced Convection Heat Sink in a Vertical Enclosure:

The design conditions are as specified by the experimental setup shown in Figure 1 for forced convection. The setup consists of a vertical rectangular enclosure with an inner area of 121.6 mm by 70mm. The enclosure is 698 mm tall, and the heater block assembly is located 230 mm from the bottom of the enclosure. Near the bottom of the enclosure, which is open, a 50 mm tall block of honeycomb (7mm hole diameter) is located 60 mm into the enclosure. The enclosure is attached to a centrifugal fan with a controllable rotation speed. The velocity of the air is measured at a point in the centre of the channel cross-section at a height of 215 mm from the base of the enclosure. It can be assumed that the inflow is approximately equally distributed and of constant velocity after the honeycomb. The heat sink is attached in the tan highlighted heater block zone approximately 230 mm from the bottom of the chamber. The heater block and heat sink design constraints are detailed on the following pages. The placement of the heat sink baseplate within the chamber is detailed in the left panel of Figure 1. Note that the top of the enclosure is open.



(a) **(b)**

Figure 1: (a) Schematic of the experimental setup including dimensions of the experimental setup. **(b)** Schematic of the placement of the heat sink within the test fixture with the fixed heat sink baseplate highlighted in light blue.

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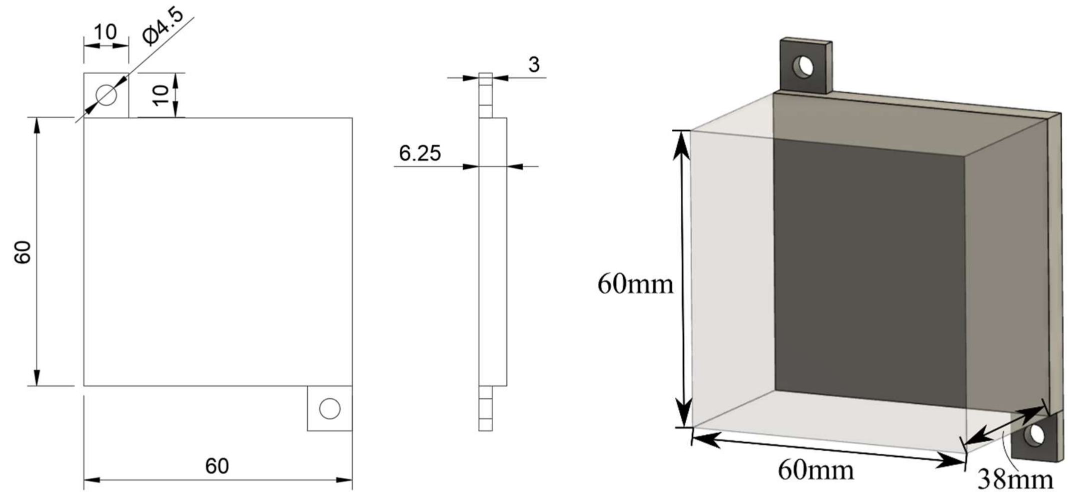
Design Constraints:

Figure 2a shows the dimensions for the fixed heat sink baseplate, which consists of a block of 60mm by 60 mm and 6.25 mm in thickness with two 3mm thick tabs of 10mm by 10mm with 4.5mm diameter holes. Each heat sink design must include this baseplate. Above the baseplate, each team can design their own heat sink. Figure 2b shows the design domain for the heat sink design competition, which is a 38 mm tall block with the same formfactor as the square portion of the baseplate, 60 mm by 60 mm.



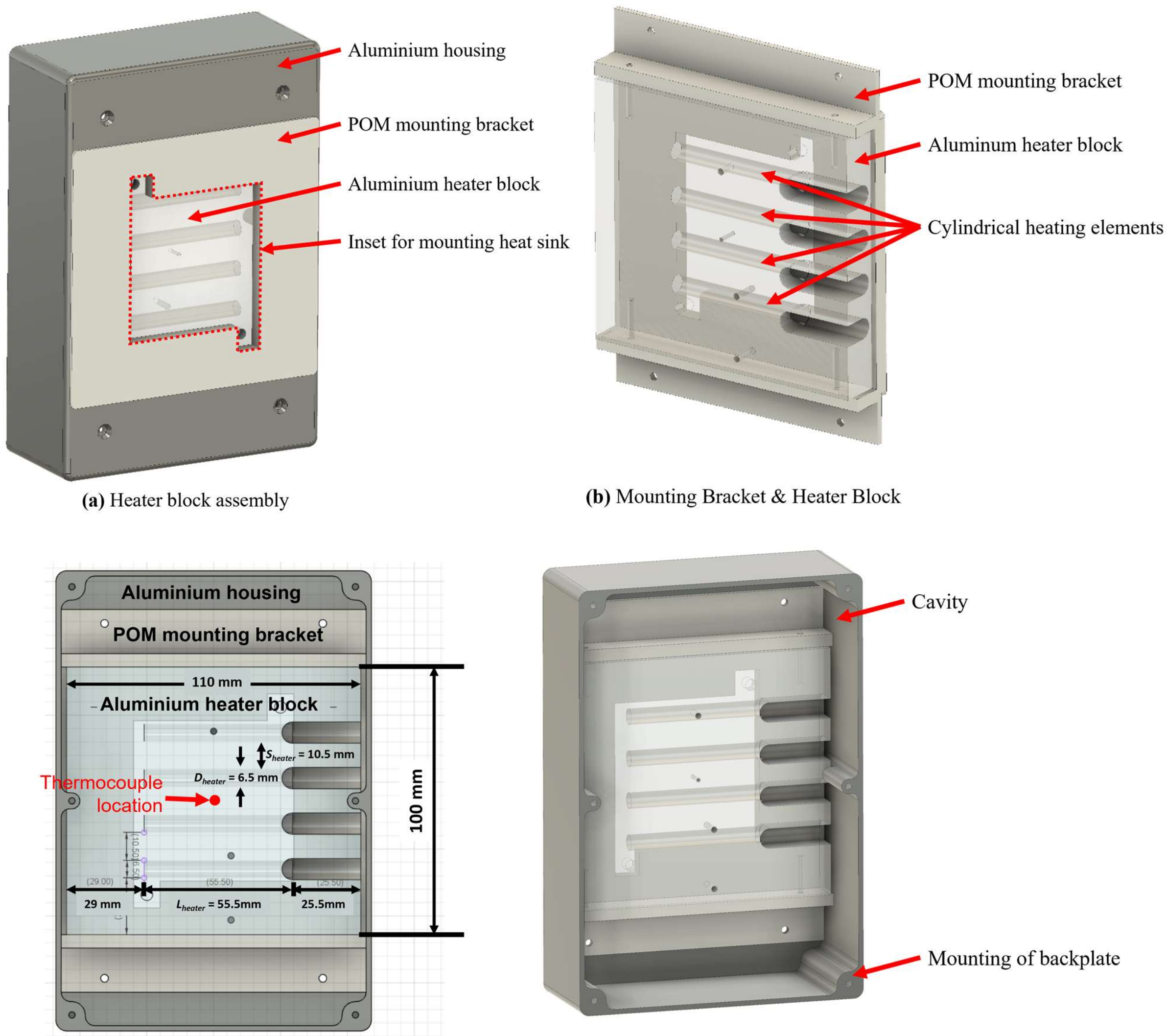
(a) **(b)**

Figure 2: Dimensions of (a) the fixed baseplate and (b) the design domain for the heat sink.

Heater Block Configuration:

Figure 3 (on the following page) details the heater block assembly and heat sink mounting plate. The assembly consists of a housing, mounting bracket, and heater block. The aluminium heater block is mounted to a bracket fabricated from polyoxymethylene (POM) with a cut-out for the heat sink baseplate. The heat sink is mounted such that the top of the baseplate will sit flush with the surrounding POM surface and the inner wall of the vertical enclosure. The heat sink will be attached using the thermal interface material documented in Table 1. After the heater block assembly is mounted inside the housing, the housing is stuffed with insulating mineral wool and sealed with a backplate as illustrated in Figure 3d.

The heater block itself consists of an aluminium plate of dimensions 110 mm by 100 mm and 15mm in thickness. Four cylindrical resistance heaters (6.5 mm diameter and 55.5 mm long) are placed inside holes drilled into the aluminium block. The base of the heat sink is aligned on top of the four cylindrical heaters as shown in Figure 3b and c. The designs will be evaluated at a tentative total power input of 3W, which may be adjusted during experiments to keep within the thermal limits 8f the setup. A K-type thermocouple is mounted in the centre of the heater block, shown by the red dot in Figure 3c.



(a) Heater block assembly

(b) Mounting Bracket & Heater Block

(c) Back view with dimensions

(d) Cavity to be stuffed with rockwool

Figure 3: (a) Overview of the heater block assembly including the aluminium enclosure, POM mounting bracket, and aluminium heater block. The inset/cut-out for mounting the heat sink is outlined with a dashed red line. **(b)** Detail of the POM mounting bracket and aluminium heater block illustrating the placement of the 4 heaters. **(c)** Back view of the heater block assembly with dimensions of the cylindrical heaters (diameter D_{heater}, length L_{heater}, and spacing S_{heater}) and their placement. The temperature measurement location is at the centre of the heat sink base area is in indicated with a red dot. **(d)** Back view of the heater block assembly illustrating the cavity to be stuffed with insulating mineral wool and the mounting points for the backplate.

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Experimental setup details:

Component	Type	Operating condition
Vertical enclosure	Armfield HT19	Forced convection
Data acquisition and control box	Armfield HT10XC	Connected to laptop via USB
Heating block	Armfield HT19 Generic aluminium	Estimated thermal conductivity of 170 W/(m·K). Single K-type thermocouple mounted in hole using glue.
Heaters (x4)	Cylindrical resistance heaters, 24 V up to 50 W (each)	Total power set to 3W
Thermal interface material	RS Pro 794-3973	Graphite, 10 W/(m·K), 0.16 mm thickness
Insulating mineral wool	Generic Rockwool	Thermal conductivity of approximately 0.035 W/(m·K)
Fan	Centrifugal fan (part of Armfield HT19)	Measured channel velocity of 1 m/s and 5 m/s

Table 1: Details of the experimental setup.

CAD models:

CAD models of the heater block assembly, heat sink baseplate, and vertical enclosure can be found at: https://github.com/sdu-multiphysics/heatsinkdesigncompetition/tree/main/2024

Additive Manufacturing Details:

The heat sinks will be additively manufactured in **316L stainless steel** using binder jet technology. Conventionally manufactured 316L has a thermal conductivity of around 14-16 W/(m·K). The porosity of the additively manufactured parts is generally below 2%. Other manufacturing constraints including minimum feature sizes and tolerances will be posted to the competition website.

Furthermore, semi-finalists will be invited to a teleconference with GE Additive to ensure their designs meet manufacturing constraints. It is anticipated that some modifications to designs will be needed during the period of Feb 18 – Feb 25 2024.

Submission:

Exact submission details will be published on the ITherm website and also circulated to registered student teams. The final submission should include ***all*** of the following:

- White paper in PDF format
- A simulation file – may be in any common simulation format (e.g. Comsol, Ansys, etc.)
- Heat sink geometry in STEP format
- Heat sink geometry in STL format

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Design Objectives and Scoring:

Key Competition Dates:

- White Paper & Design Model: Due Feb 4 2024
- Semifinalist Design Revisions: Approx. Feb 18 – Feb 25 2024
- Printing & Testing: Approx. Feb 25 – Apr 30 2024
- Finalist Announcements: Approx. Apr 30 2024
- Finalist Presentations at ITherm 2024: May 28 – May 31 2024

Pre-register your team at https://forms.gle/ydCQ1MnG9tqfFf8NA for updated information throughout the design period.

The competition consists of 3 phases:

1) **Design & White Paper:** During the first phase of the competition, student teams design and analyse their heat sinks, summarizing the process and results in a white paper. The white papers are evaluated by a panel of experts and the designs are further evaluated by standardised simulations run by the competition organisers after submission. A template for the white paper is available at: https://github.com/sdu-multiphysics/heatsinkdesigncompetition/tree/main/2024
2) **Revisions, Fabrication, & Experimental Evaluation:** The top designs from the white paper phase will be fabricated by GE and tested at SDU. It is anticipated that teams may need to make some modifications to designs during the period of Feb 18 – Feb 25 2024 to meet manufacturing constraints. The top experimentally performing designs among these semi-finalists will be invited to present as finalists at *ITherm 2024*.
3) **Final Presentation:** After the designs are evaluated experimentally, the invited finalist teams will need to prepare a presentation for *ITherm 2024* describing their design and analysis process, the experimental results compared to the models, etc. Finalists will be notified approximately on Apr 30 2024 and have approximately 1 month to prepare for the final competition. One member of the team will present at the conference, and a panel of experts will judge the presentations.

The objectives for **the white paper** are provided in the list below:

(a) Highest Figure of Merit (FOM) for the vertical enclosure under forced convection at two flowrates as evaluated by standardised simulations run by the competition organisers
(b) Demonstrate effective use of thermal analysis and modelling
(c) Effective use of additive manufacturing in the design
(d) Well written, formatted, and clear white paper

The assigned scoring metrics for the white paper are shown in Table 2:

Metric	Assigned point value
Predicted FOM*	25
Analysis and modelling	25
Effective use of AM	35
Writing style and formatting	15

Table 2: Scoring metrics for the white paper (* = as determined by organisers).

The design objectives for **the final competition** are provided in the list below:

(a) Highest experimentally determined FOM
(b) Effective use of additive manufacturing
(c) Presentation skills

Overall scoring will be assessed according to the scoring metrics in Table 3:

Metric	Assigned point value
Experimental FOM	40
Effective use of AM	35
Presentation Quality	15

Table 3: Scoring metrics for the final competition.

Note that designs which fail to adhere to the additive manufacturing requirements as laid out by GE may be penalised or disqualified from the competition.

Figure of Merit (FOM):

Designs will be ranked based on a mass-based figure of merit (FOM). This should be calculated according to the following definition:

$$FOM = \frac{1}{m_{hs}(R_1 + R_5)}$$

where R_1 is the measured thermal resistance at 1 m/s, R_3 is the measured thermal resistance at 5 m/s, and m_{hs} is the mass of the heat sink in kilograms (including the fixed baseplate). The measured thermal resistance at flow rate j is defined as:

$$R_j = \frac{T_{meas} - T_{amb}}{Q_{meas}}$$

where T_{meas} is the measured temperature in the center of the heater block, T_{amb} is the ambient temperature, and Q_{meas} is the measured thermal power input.

Effective Use of additive manufacturing:

A subjective assessment will be made of the overall design aesthetics and use of the incredible design freedom provided by additive manufacturing compared to conventional manufacturing. Creativity is rewarded in this category along with the formation of structures that would otherwise not be possible to manufacture as illustrated in Figure 5.

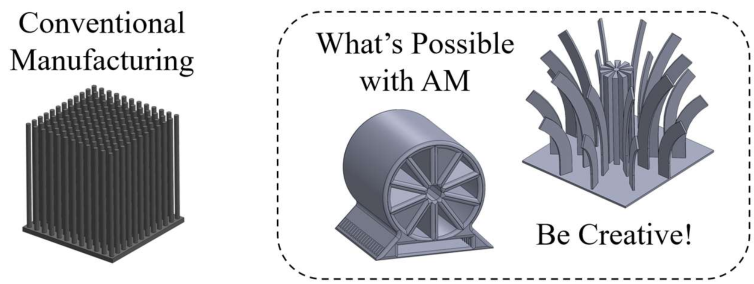
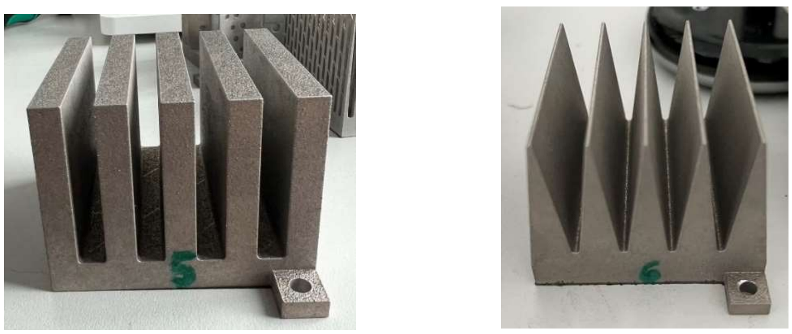


Figure 5: Illustration of conventional versus additive manufacturing design freedom.

Reference Experimental Data:

Reference experimental data is given for two straight fin heat sinks to help teams calibrate their models. Although this year, the heat sinks will be fabricated in stainless steel for the competition, last year, two heat sinks were additively manufactured in **aluminium** [with an approximate thermal conductivity of 110 W/(m·K)] and tested in the forced convection configuration.

The first has fins of constant thickness, whereas the other has tapered fins wider at the bottom. The CAD geometries are available in the competition GitHub repository: https://github.com/sdu-multiphysics/heatsinkdesigncompetition. The fins are oriented in the direction of the flow. The heater block assembly is the exact same with the same measurement point as shown in Figure 6. The experimental data for the reference geometries are given in Table 4.



(a) **(b)**

Figure 6: Reference heat sink geometries with fins of **(a)** constant thickness and **(b)** tapered thickness.

	Constant thickness		**Tapered thickness**	
Mass	0.2868 kg		0.2706 kg	
Velocity	1.0 m/s	5.0 m/s	1.0 m/s	5.0 m/s
Power	18.20 W	18.27 W	17.50 W	17.9 W
$\boldsymbol{T_{amb}}$	31.1 °C	27.4 °C	30.9 °C	27.6 °C
$\boldsymbol{T_{base}}$	53.4 °C	39.3°C	55.2 °C	40.7 °C
R	1.23 K/W	0.65 K/W	1.39 K/W	0.73 K/W
FOM	0.03097		0.02905	

Table 4: Experimental data for reference geometries.