Design and Analysis of Battery Thermal Management Systems

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Outline

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- **Summary and Conclusions**
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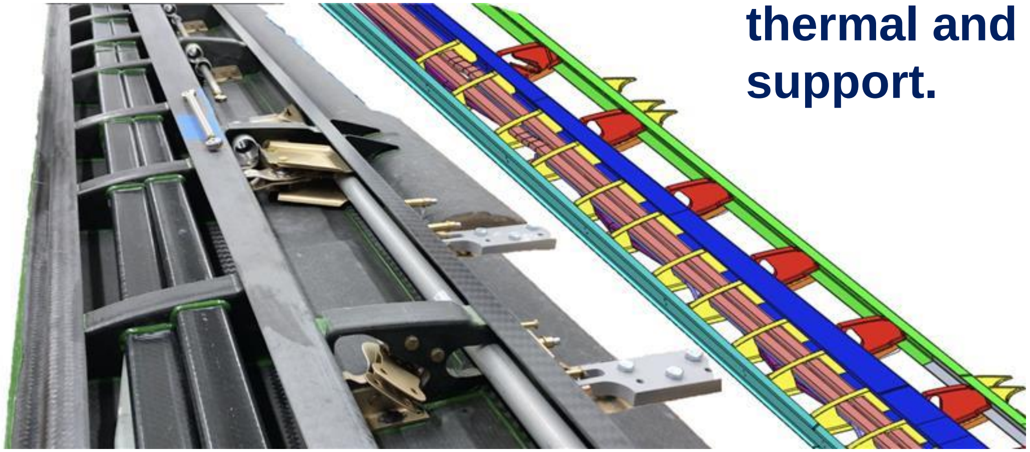
- **Acknowledgments**

Introduction

- Proper Thermal Management can <u>increase</u> operational safety, efficiency, and overall battery life.
- Battery packs are to be used in electric airplane X-57 and other electric aircraft.
- These packs are intended to be put into the wings.

Requirements:

- 3D Printable
- Specific Gravimetric Energy Density
- Built of two or more materials:
    - Low density polymer to keep weight down.
    - High conductivity material such as metal or ceramic for thermal and structural support.



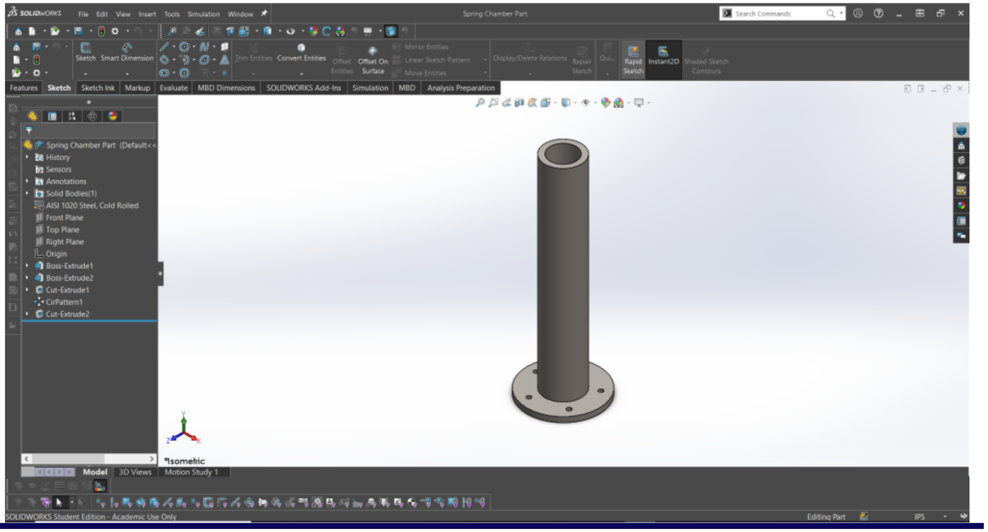
Picture credit to Jeffery Chin

Materials and Methods

- **Materials:**
  - **6063-O Aluminum**
    - **2700 kg/m³**
    - **201 W/m-K**
  - **TC Poly E ins Ice 9 Flex**
    - **1550 kg/m³**
    - **2.5 W/m-K through plane**
    - **8 W/m-K in plane.**

- **The final packs must have 12 to 16, 18650 batteries.**
- **The pack designs should minimize material volume and mass.**

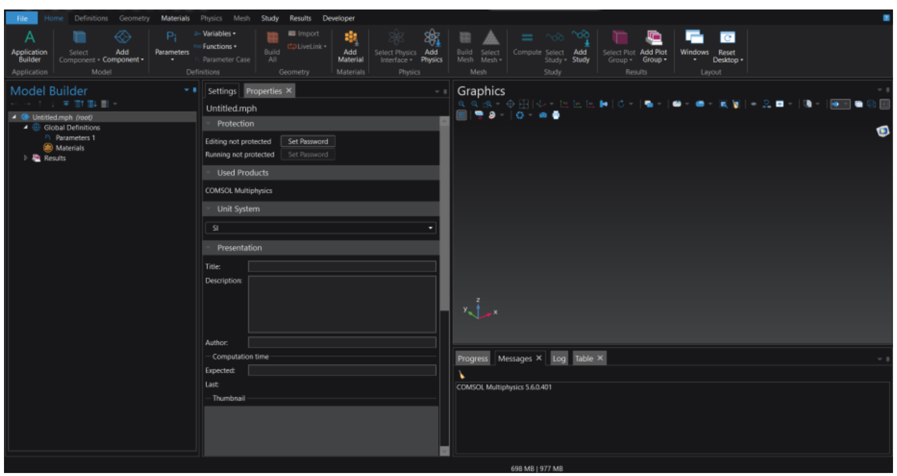
SolidWorks software was used for battery pack design



Thermal Modeling Using COMSOL

Simulation variables set at a constant for all tests:

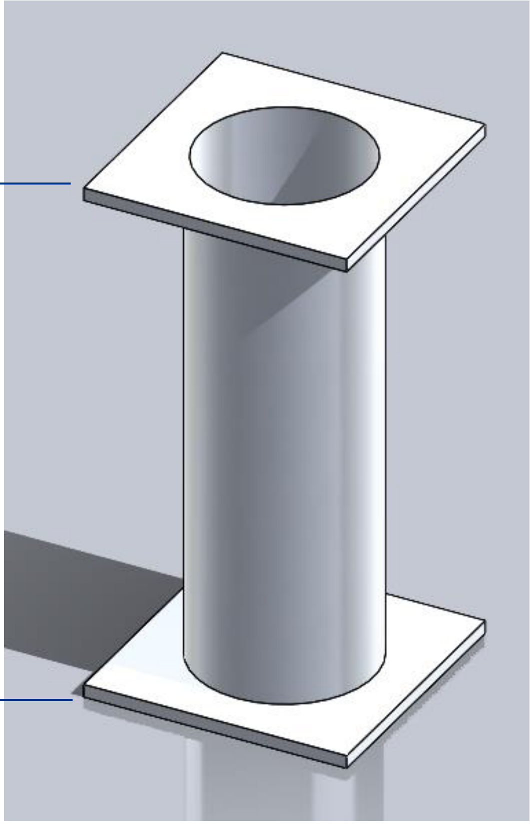
- Heat flux = 1161.4 W/m^2
- T_{in} = 319.7 K
- V_{in} = 15 m/s



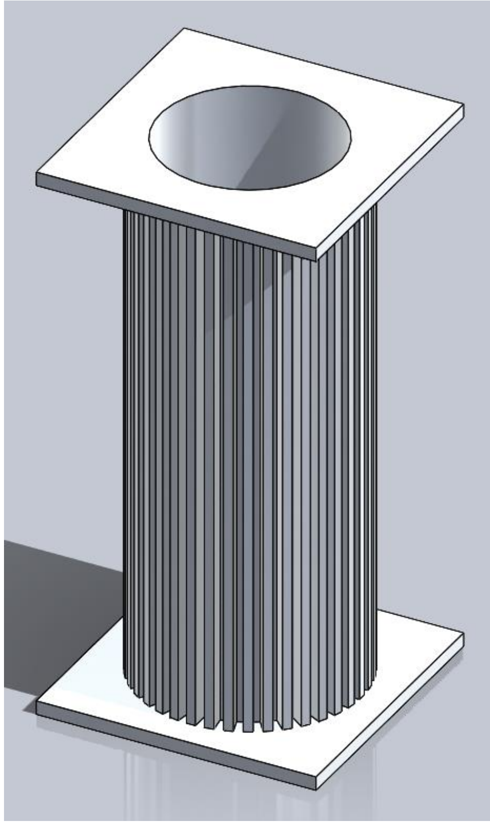
- All temperature plots were from time dependent studies with 100 sec intervals out to 1000 sec.
- All recorded data was taken from the 1000 sec-time plot.
- The "Heat Transfer in Solids and Fluids" module was utilized for all COMSOL computations.

Battery Sheath Testing, 1/3

65 mm



Change in Temperature: 1.59 °C

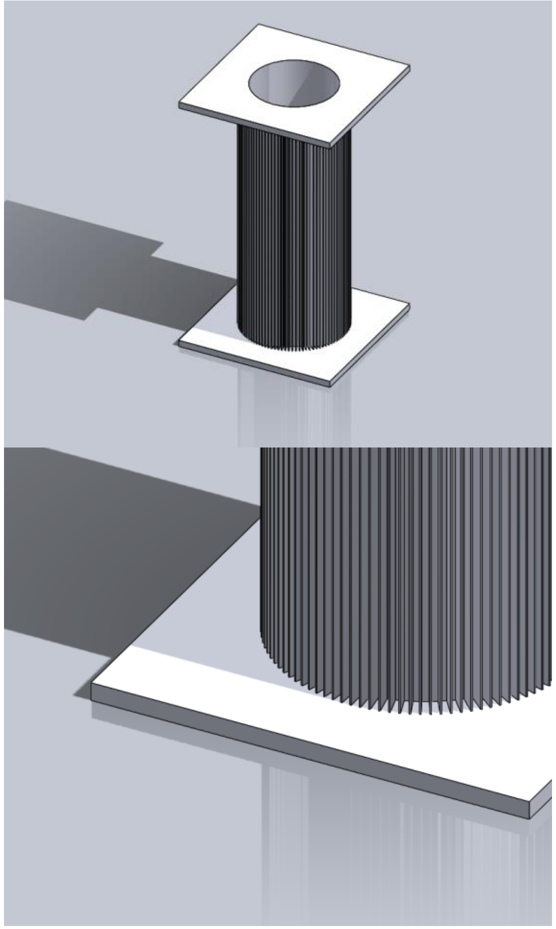


Change in Temperature: 0.90 °C

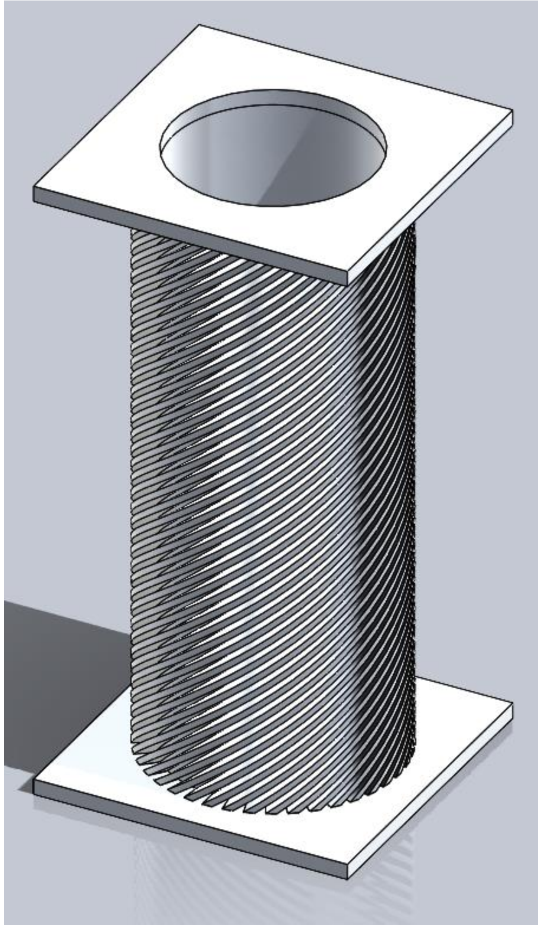
- **Sheaths aid in reducing linear temperature gradient from inlet to outlet.**
- **Adding fins to sheaths further reduces temperature gradient.**
- **All the modeled sheaths are 65 mm tall.**

Cooling Method: Air
Materials: 6063-O Aluminum
Mass Left: 16.465 g
Mass Right: 29.121 g

Battery Sheath Testing, 2/3



Change in
Temperature:
0.88 °C



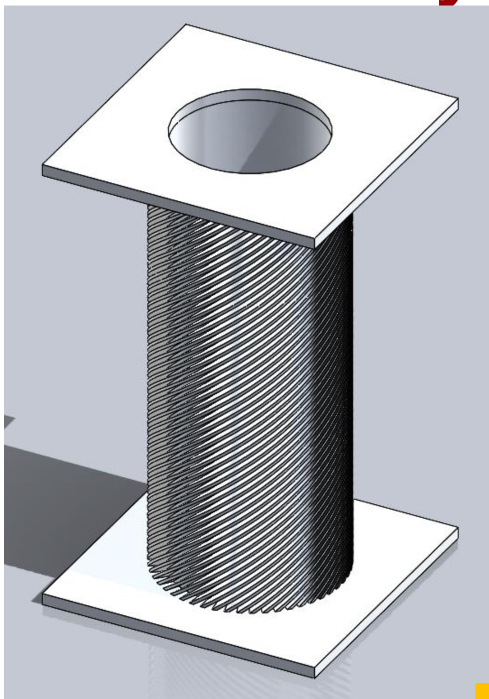
Change in
Temperature:
0.44 °C

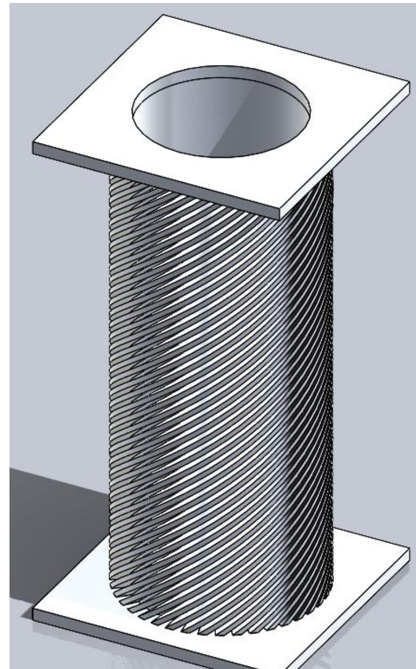
- Increasing the number of fins and decreasing thickness is not very effective for straight fins
- Wrapping fins helically around the sheath can significantly decrease temperature gradient

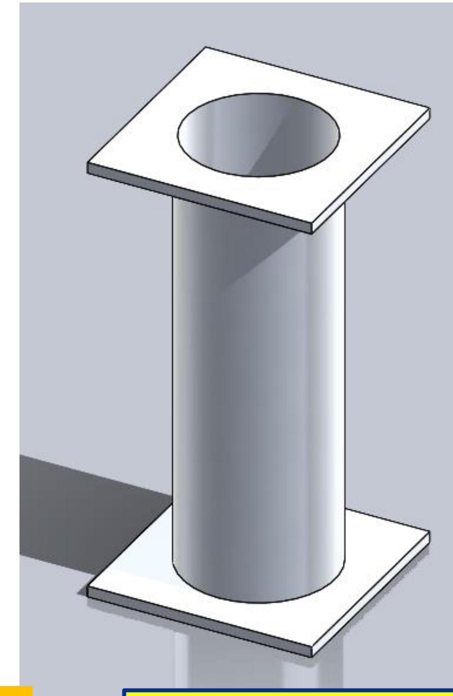
Cooling Method: Air
Materials: 6063-O Aluminum
Mass Left: 20.276 g
Mass Right: 29.166 g

Battery Sheath Testing, 3/3

ΔT~0.80 °C







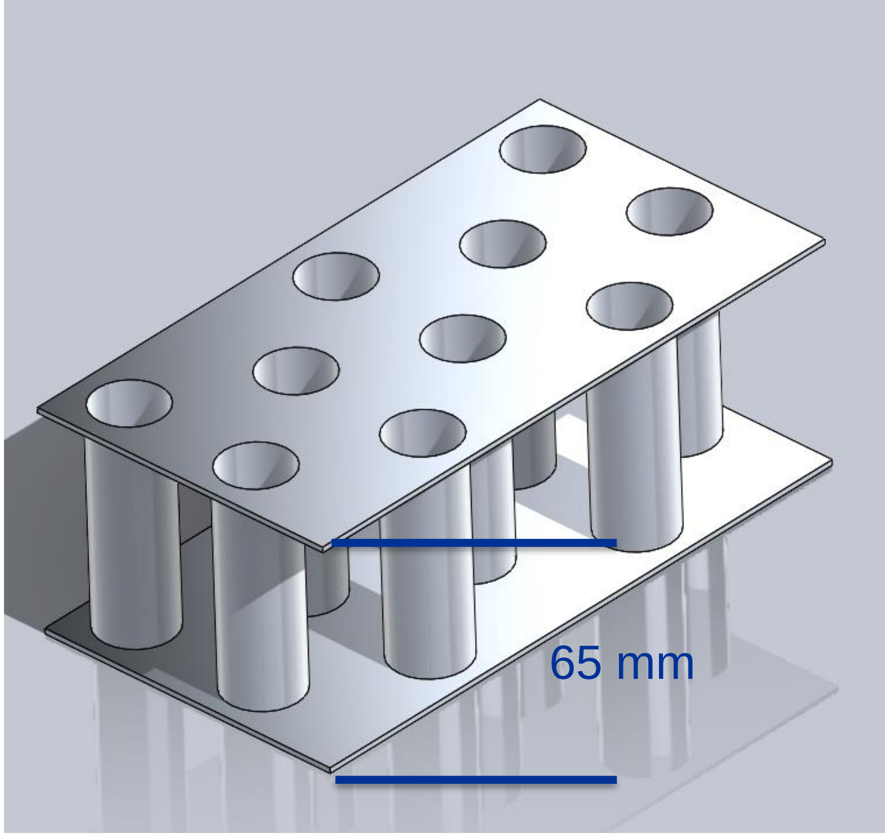
Lowest Temperature Gradient
ΔT=0.44 °C

Lowest Weight
ΔT=1.59 °C

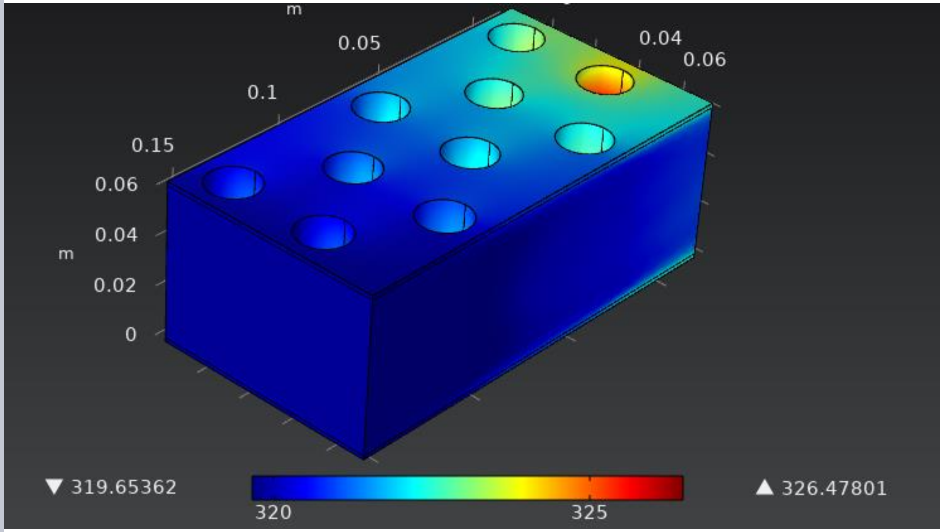
- **Reducing the fin thickness while increasing number of fins is not effective for spirally wrapped fins either.**
- **The best sheath for weight is with no fins, however the best sheath for temperature gradient is thicker spirally wrapped fins.**

Cooling Method: Air
Materials: 6063-O Aluminum
Mass Left: 26.399 g
Mass Middle: 29.166 g
Mass Right: 16.465 g

Air Flow Test and Modeling



COMSOL Thermal Results

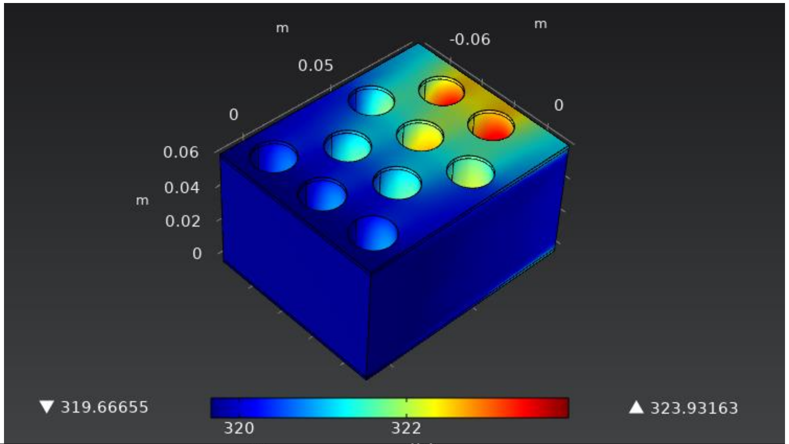


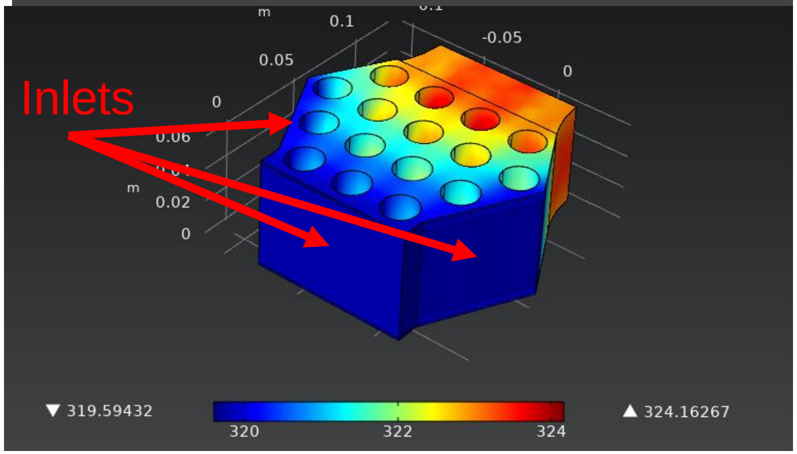
The bottom bar indicates the maximum and minimum pack temperatures.

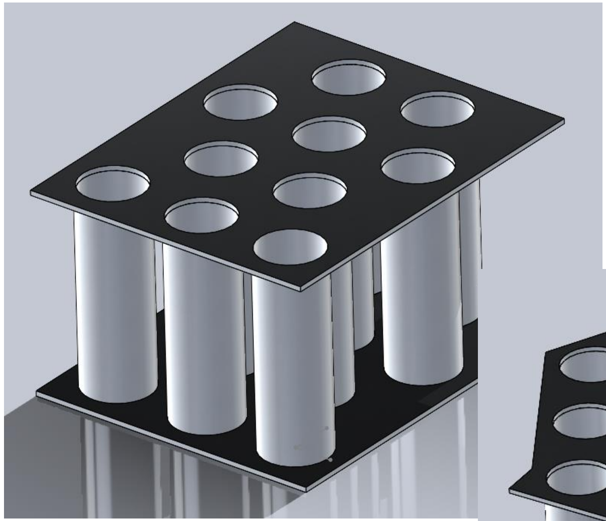
- **The battery pack is 65 mm tall**
- **The sheaths were kept as simple cylindrical to save computation power.**

Cooling Method: Air
Materials: 6063-O Aluminum
Total Pack Mass: 0.177 kg
ΔT=6.82 °C

Primary Pack Concept Selection







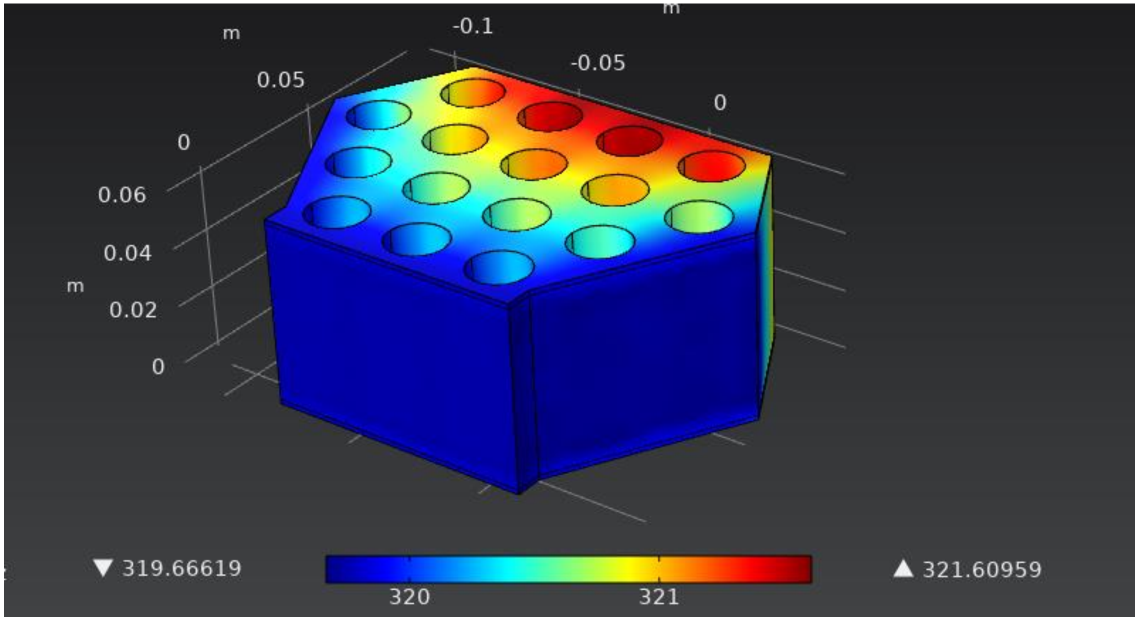
Simple Box Pack Structure Option

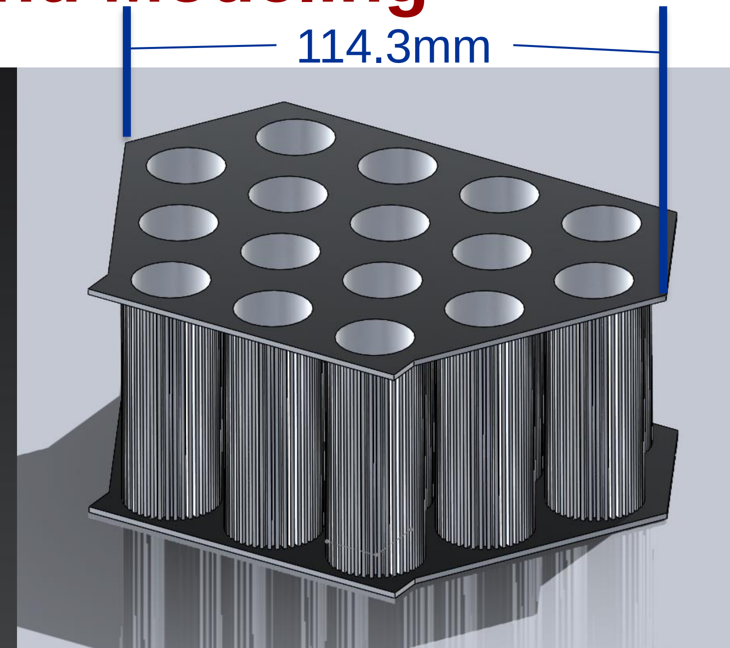
New multi-inlet pack structure option.

- **Side air injection can more efficiently add batteries to packs.**
- **Simple cubic pack design was derivative of previous work.**
- **Both battery packs are 65 mm tall.**

Cooling Method: Air
Materials: 6063-O Aluminum
Mass Top: 0.132 kg
Mass Bottom: 0.186 kg
ΔT Top=4.27 °C
ΔT Bottom=4.57 °C

Sheath Pack Testing and Modeling

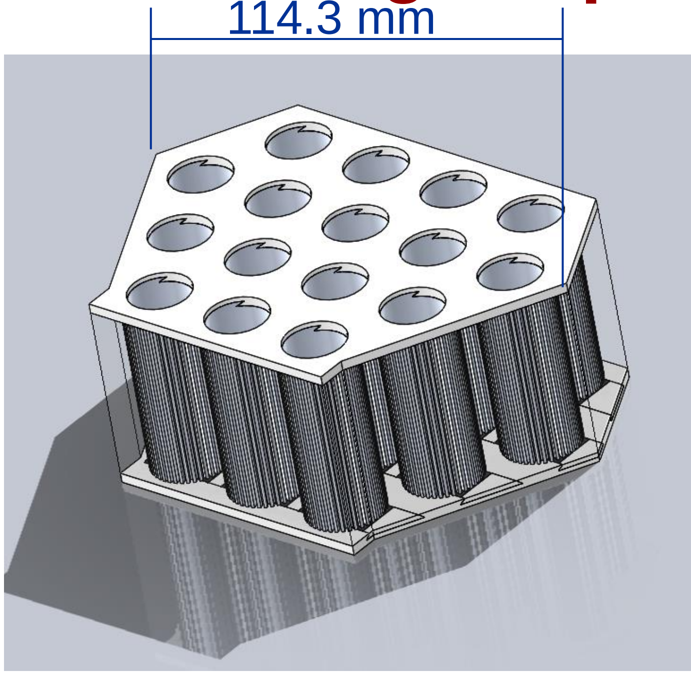


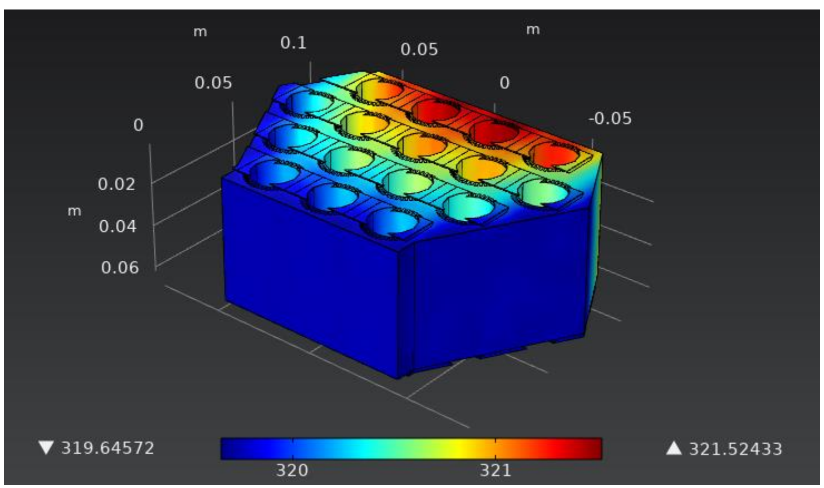


- **Adding fins to a pack design can significantly reduce the temperature gradient across the pack and should be researched further.**
- **The battery pack is 114.3 mm wide.**

Cooling Method: Air
Materials: 6063-O Aluminum
Mass: 0.393 kg
ΔT=1.94 °C

Design Improvements Testing 1/2

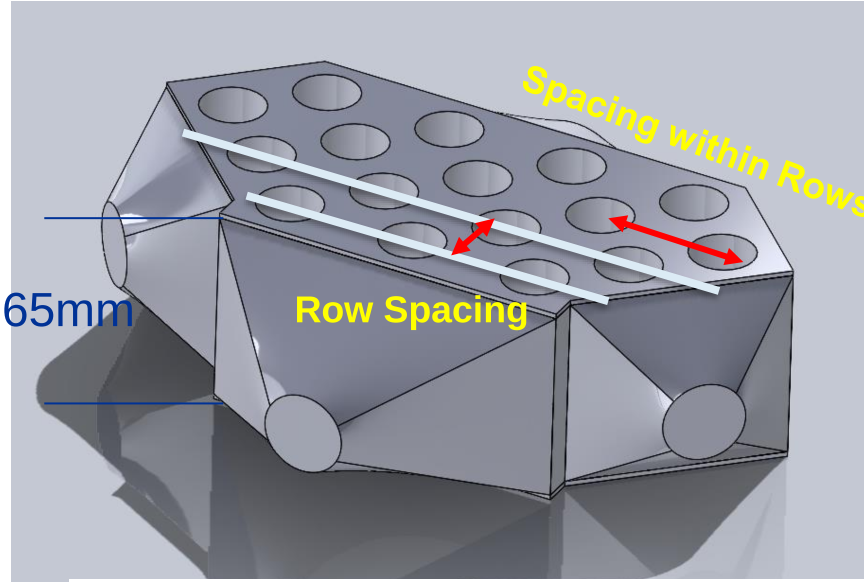


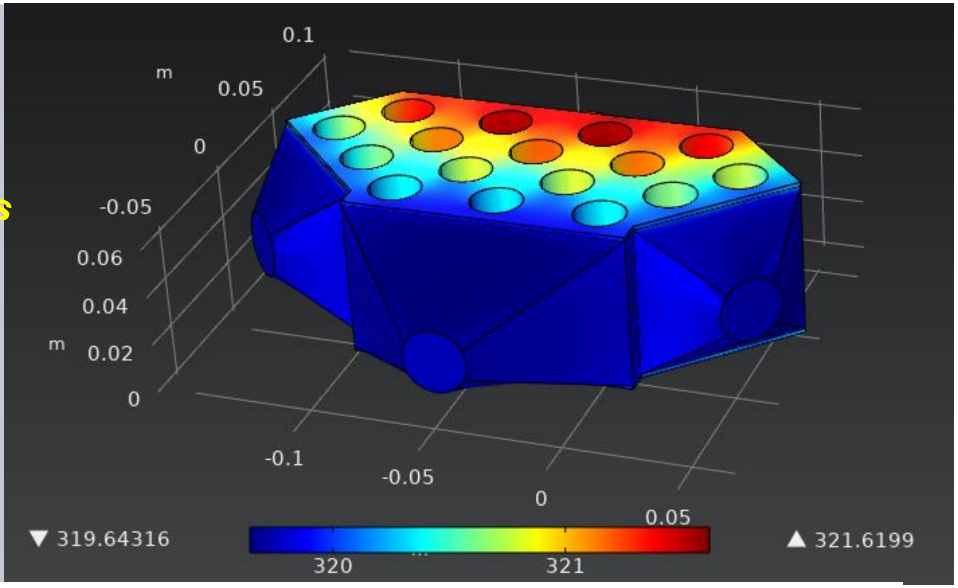


- **Replacing top and bottom plates can significantly reduce weight.**
- **This design has more parts however it will increase electrical safety.**
- **Replacing top and bottom plates does not significantly impact temperature gradient.**

Cooling Method: Air
Materials: 6063-O Aluminum, TC Poly E ins Ice 9 Flex
Mass: 0.298 kg
ΔT=1.88 °C

Design Improvements Testing 2/2





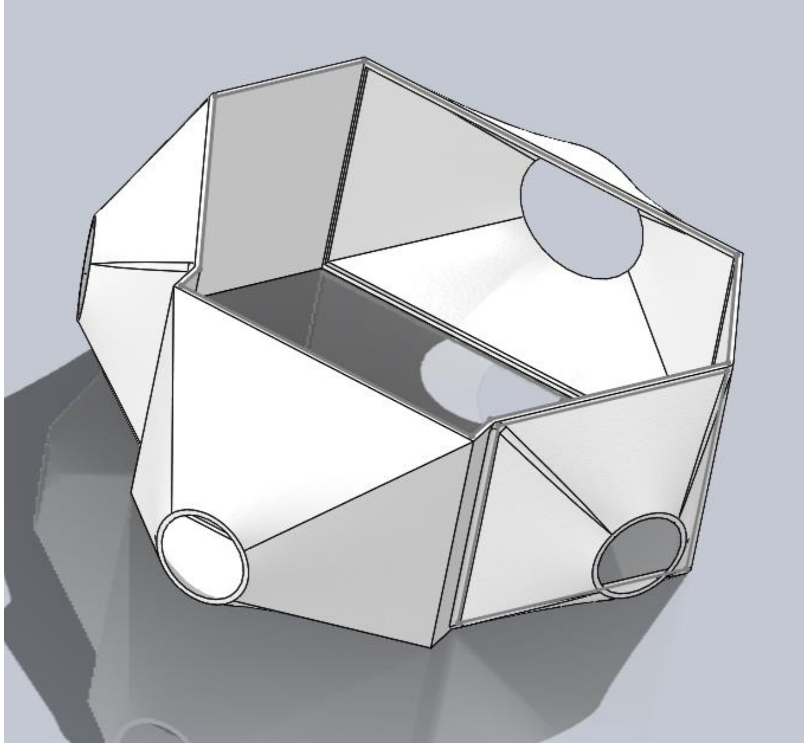
Battery Spacing in Row (mm)	Row Spacing (mm)	Resulting ΔT_{Pack} (°C)
30.48	27.94	2.49981
35.56	27.94	2.1202
30.48	30.48	2.30634
35.56	30.48	2.11439
35.56	25.4	2.12636
35.56	22.86	2.17957
40.64	20.32	1.97674

- **Spacing in rows has a big effect on the pack temperature gradient.**
- **An Increase in Spacing Increases Mass**

Cooling Method: Air
Materials: 6063-O Aluminum
Mass of shown pack: 0.558 kg

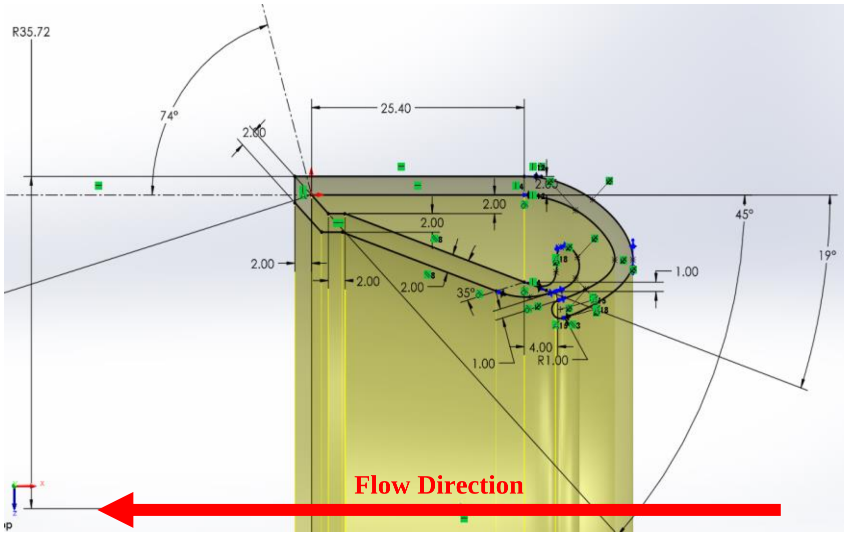
Exterior Casing Design

- **Making the pack casing out of PMC's will reduce overall decrease in Specific Gravimetric Energy Density**
- **More research should be done to decrease the number of air inlets by rerouting air within the pack to conserve space.**
- **Research into highly conductive PMC's and composites can increase the viability of the heavier options that are more effective.**

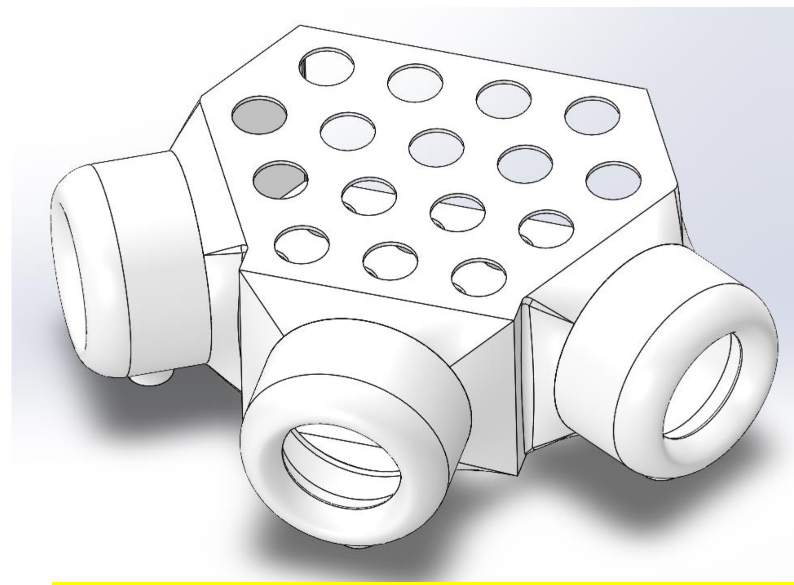


Cooling Method: Air
Materials: TC Poly E ins Ice 9 Flex
Mass: 0.0952 kg

Bladeless Fans



- Provides a solution that is lightweight, fire retardant and easy to implement.

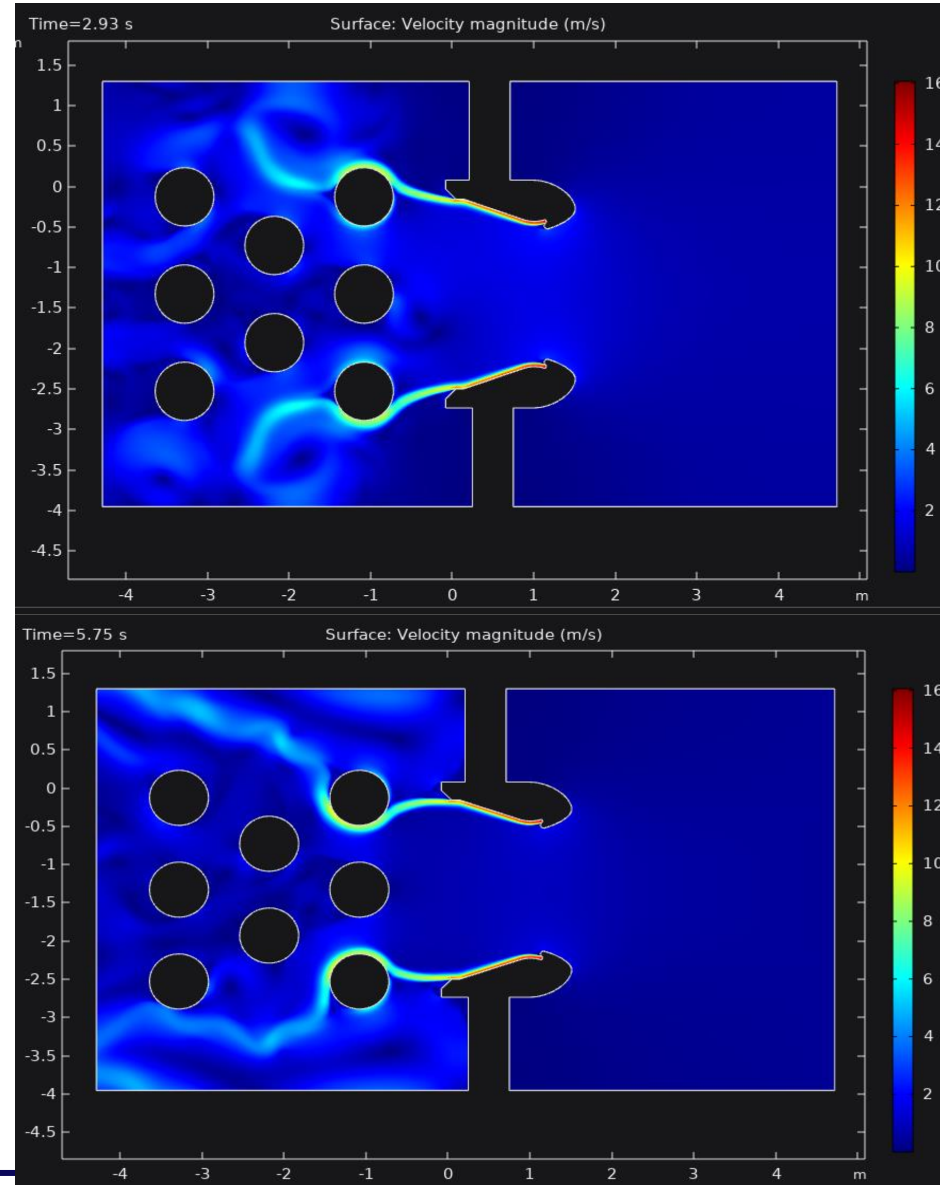


- Utilize the Coandă effect and air entrainment to magnify the input air flow by 1500%.
- Bladeless fans allow for the entire pack to be additively manufactured as one piece.
- Can be manufactured in separate pieces if easier.

Cooling Method: Air
Materials: TC Poly E ins Ice 9 Flex
Mass: 0.245 kg
Energy Density 207.25 Wh/kg

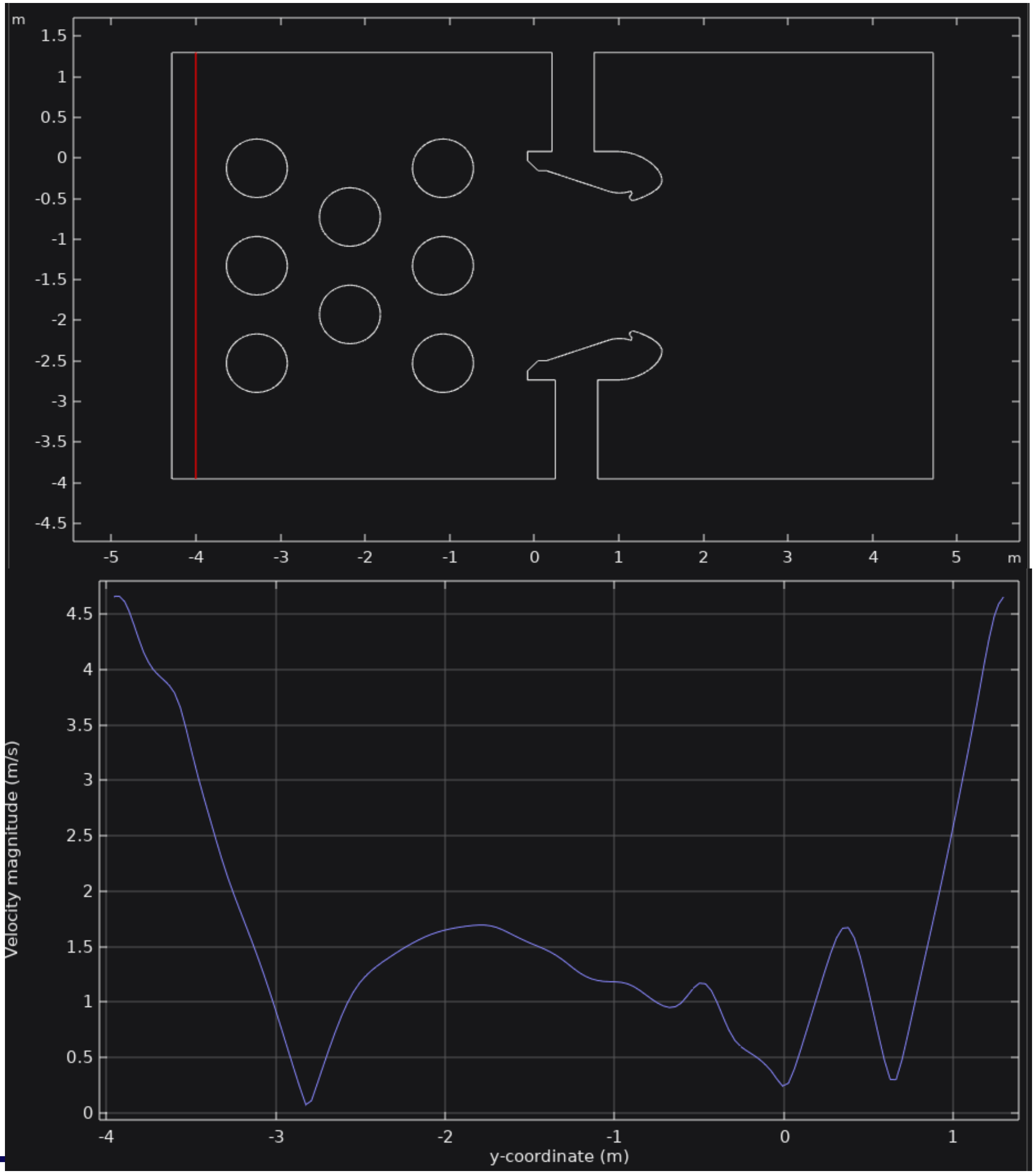
Bladeless Fan Proof

- 2-D cross-section of the bladeless fan with batteries placed in front to test flow characteristics.
- Flow appears turbulent as expected.
- Flow jets create a fluidic oscillator that has a period of roughly 5.85 seconds.



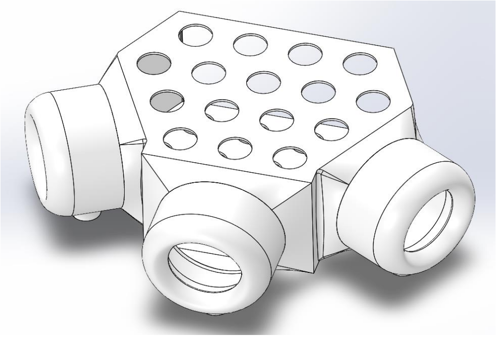
Flow Results

- From the cut line, the average velocity was found.
- From this data the air temperature required to cool the batteries was found to be roughly 15 to 20 degrees Celsius.



Conclusions

- Bladeless fans show signs that they can cool battery packs without the use of high conductivity metals.
- Implementing fluidic oscillators makes it possible to eliminate dead zones behind batteries.
- Future work should strive to obtain a model that also describes the thermal qualities.



- Fin sheath design is effective at decreasing the ΔT across each battery and therefore across the battery pack. However, it also adds additional weight thus driving down the energy density.
- The dovetail sheath attachment design is an effective way to drop pack weight and increase the energy density while also increasing the replaceability of each part.
- Future work should focus on evaluation of new materials and advanced manufacturing technologies to address design challenges.

Acknowledgments

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