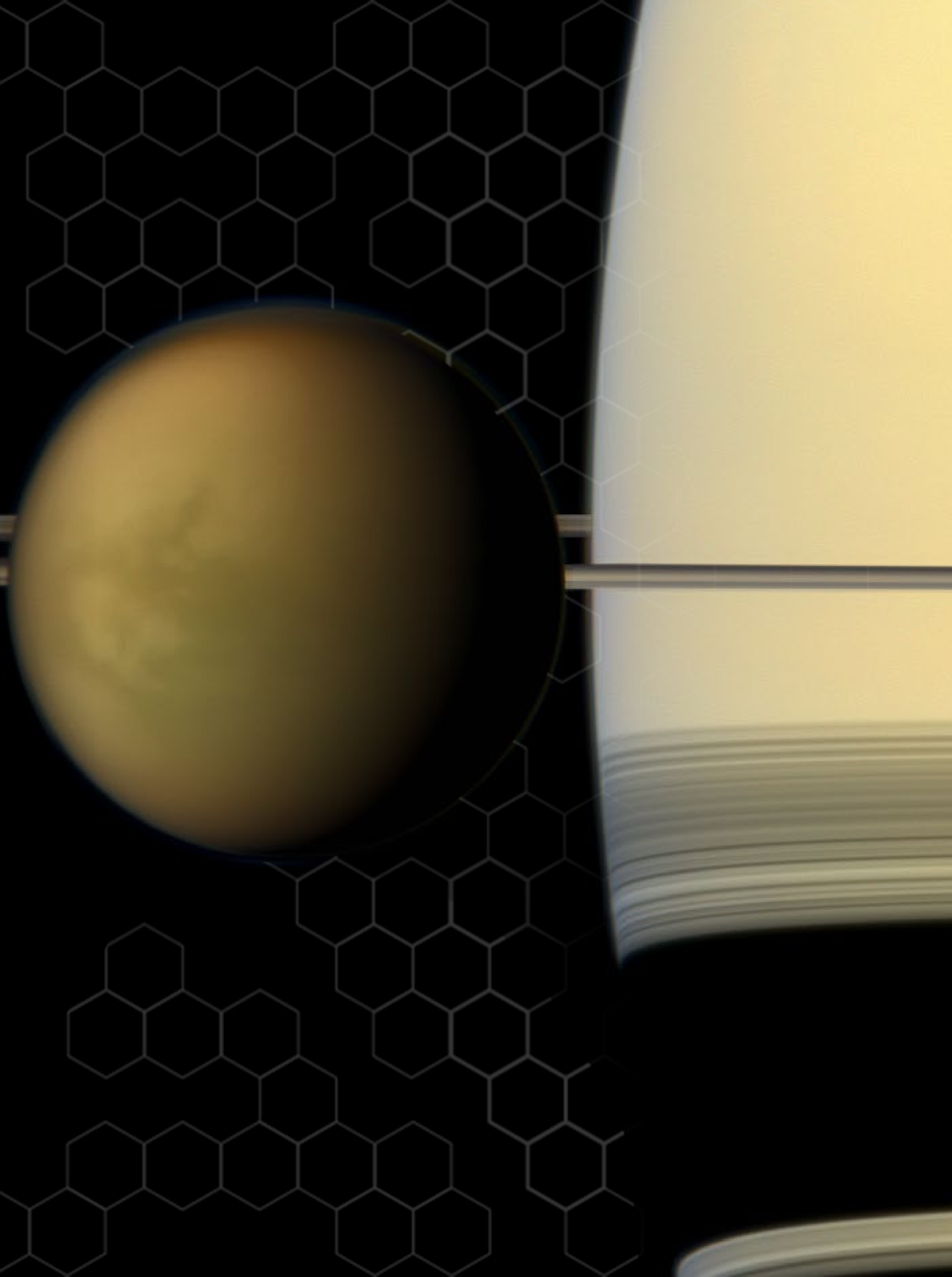
DRAGONFLY

A relocatable lander to explore Titan's prebiotic chemistry and habitability



Study of the thermal physical properties of insulating materials in a Titan environment

July 9-13, 2023 CEC/ICMC Honolulu, HI

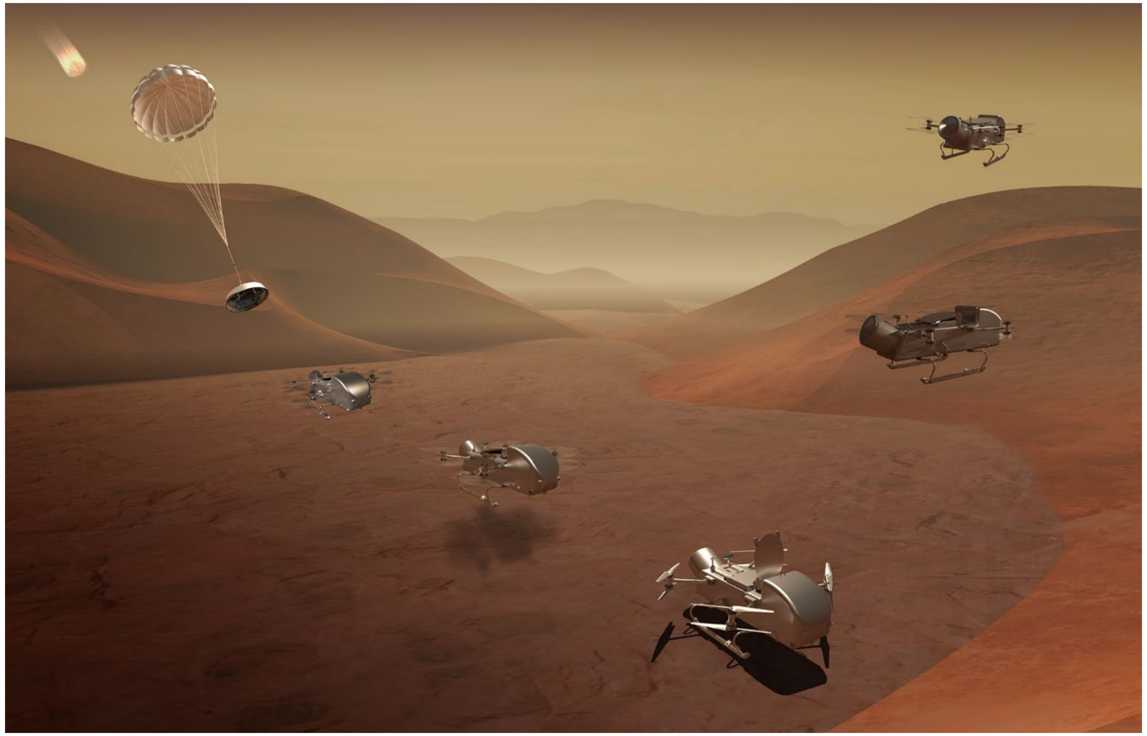
Richard Ottens, Peter Barfknecht, Kelly Burch, Steven Cale, Brian Comber, Matthew Francom, Hak Seung Lee, Paul Rueger

Outline

- What is Dragonfly?
- What is DraMS?
- Why the need for insulators?
- Requirements for the Cold Zone
- Insulation Options
- Conductivity Rig
- Results
- Conclusions
- DraMS Cryo Team

What is Dragonfly

- Dragonfly is a rotorcraft that will explore the chemistry of the surface of Saturn's Moon Titan.
- It will take advantage of the unique conditions of Titan's dense atmosphere (1.5 atm) and low gravity (1.4 m/s^2) to allow Dragonfly to fly from site to site.
- Dragonfly will be looking for prebiotic compounds on the surface, as well as studying the composition of the surface and atmosphere


John Hopkins APL

What is DraMS

- Dragonfly Mass Spectrometer (DraMS) is a linear ion trap mass spectrometer consisting of two modes
  - Laser Desorption Mass Spectrometry: to measure the composition of surface samples targeting large organic molecules [1]
  - Gas Chromatography Mass Spectrometry: to separate and identify prebiotic molecules by volatilization. [1]
- DraMS is split into two thermal sections
  - Warm Instrument Zone (~Room Temp)
  - Cold Sample Zone (~150K, Titan temp ~94K)

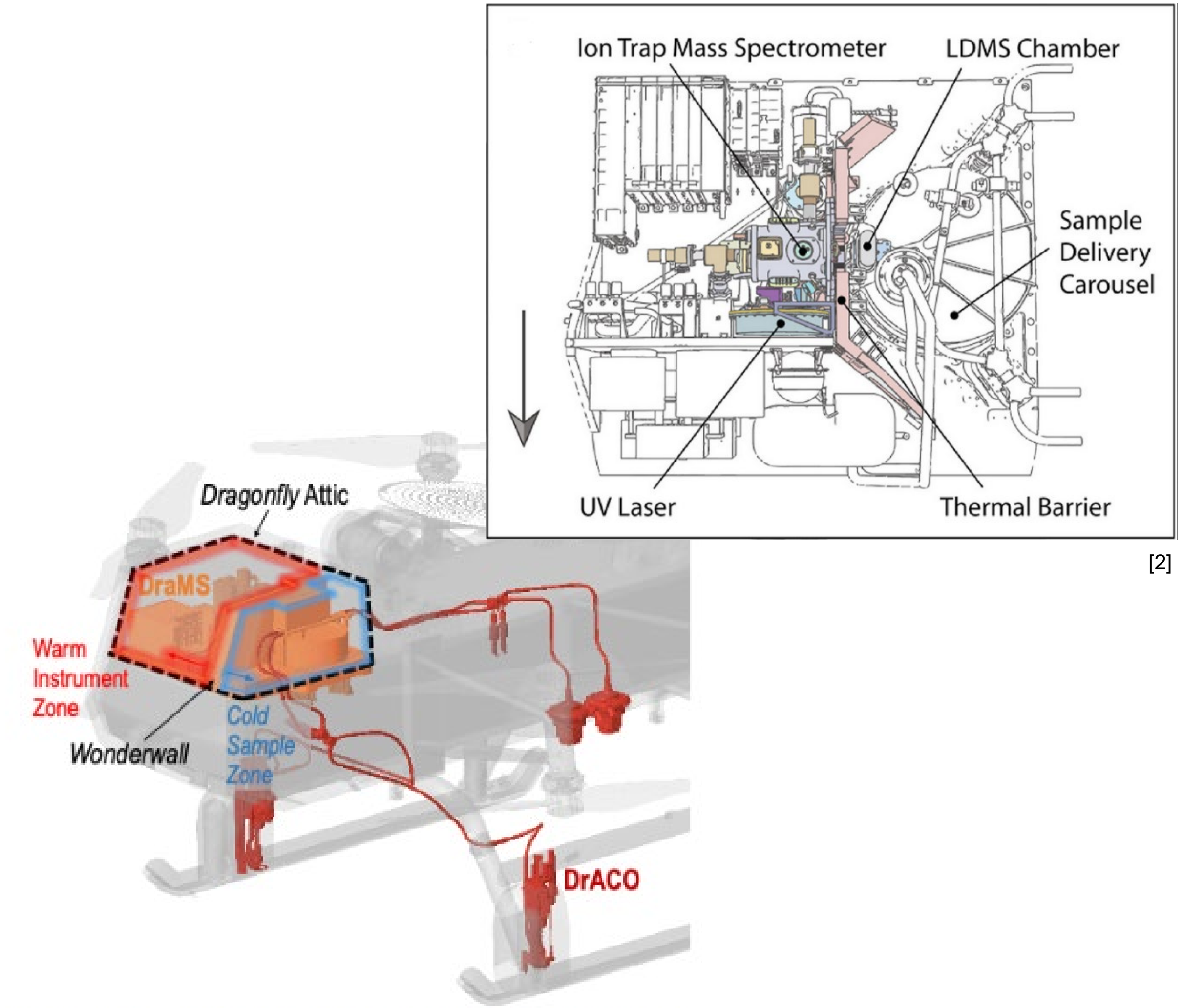
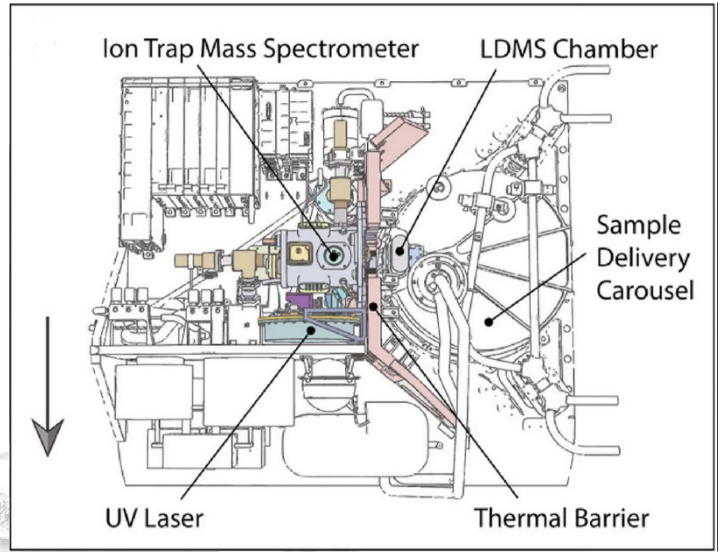


Figure 1. The *Dragonfly* "Attic" Cold Zone and Warm Zone. [1]

Why the Need for Insulators

- The majority of Dragonfly's interior
  - Held at around room temperature
  - Semi-hermetic to the Titan atmosphere
- Dragonfly has a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) to supply <u>limited</u> electrical power and heat.
- Temperature differentials of ~150K only a few inches
- As a result, Dragonfly needs to be well insulated and standard cryogenic insulations (MLI, vacuum jackets) will not work due to convection and mass restrictions.

John Hopkins APL



[2]

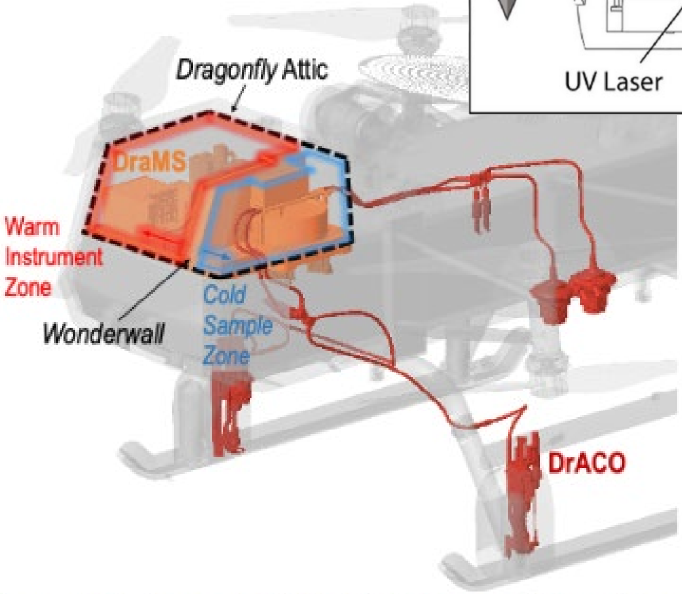
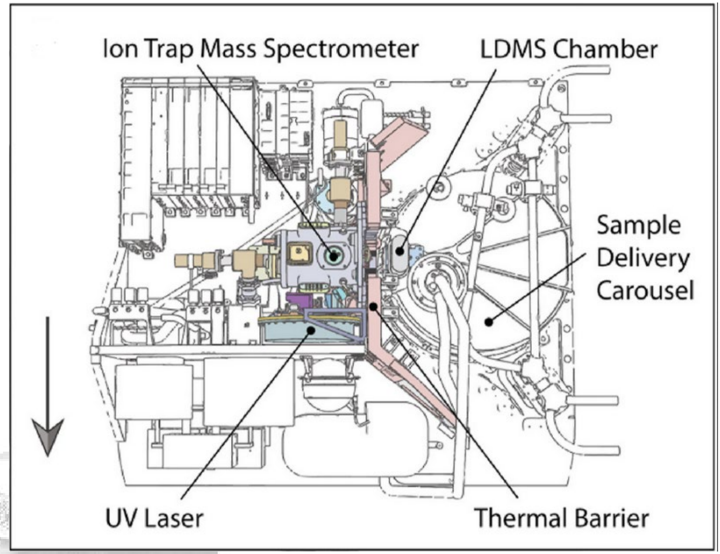


Figure 1. The *Dragonfly* "Attic" Cold Zone and Warm Zone. [1]

Requirements for the Cold Zone

- Within the DraMS cold zone
  - 4 of 6 sides are near room temperature
  - Must be insulated to prevent excessive heat loss
- Within the Sample Delivery Carousel
  - Sample cups must stay cold to preserve sample integrity before test and during storage
  - The use of materials is limited to prevent overwhelming the mass spectrometer with reading of the lander itself



[2]

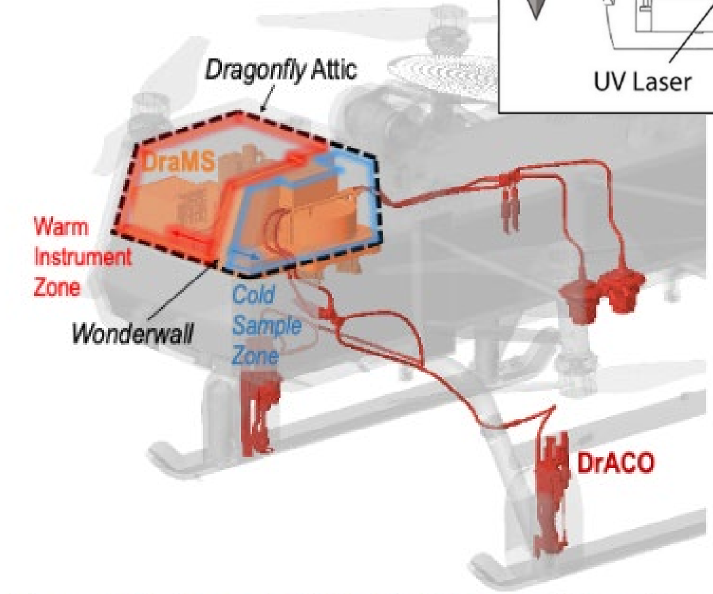
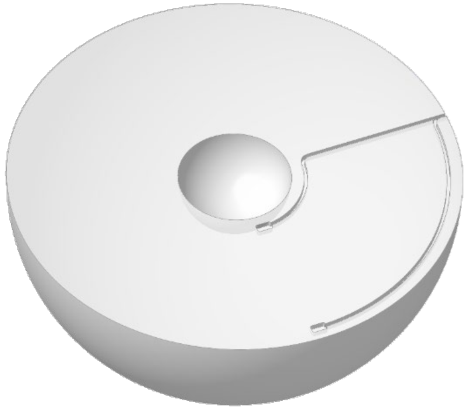
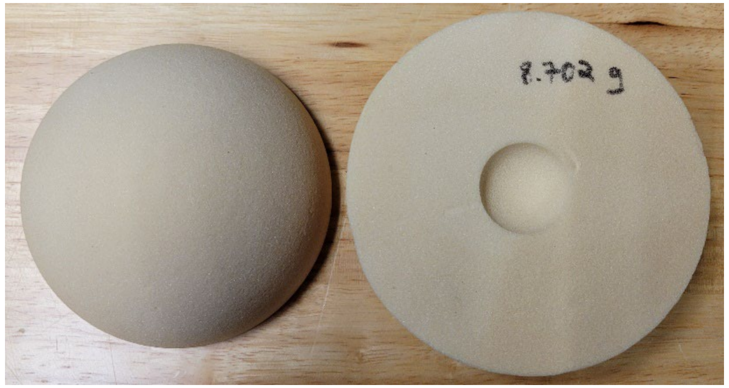


Figure 1. The *Dragonfly* “Attic” Cold Zone and Warm Zone. [1]

Insulation Options (Published Room Temp Data)



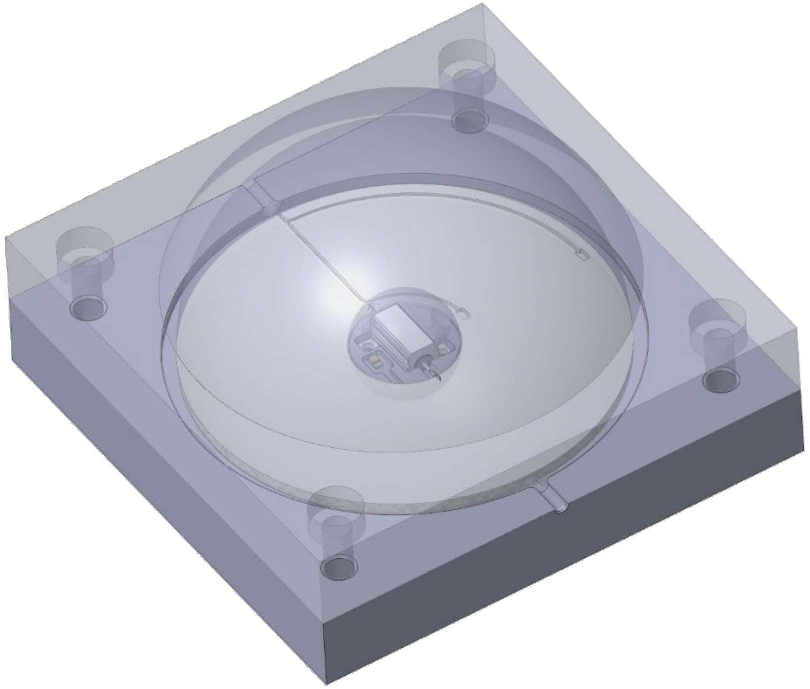
- Rohacell 31-HF (polymethacrylimide)
  - Density: 32 ±7 kg/m^3 [3]
  - 31 mW/(m-K) @ 20°C [4]
- ELFOAM P200 (polyisocyanurate)
  - Density: 32 kg/m^3 [5]
  - 24 mW/(m-K) @ 24°C [5]



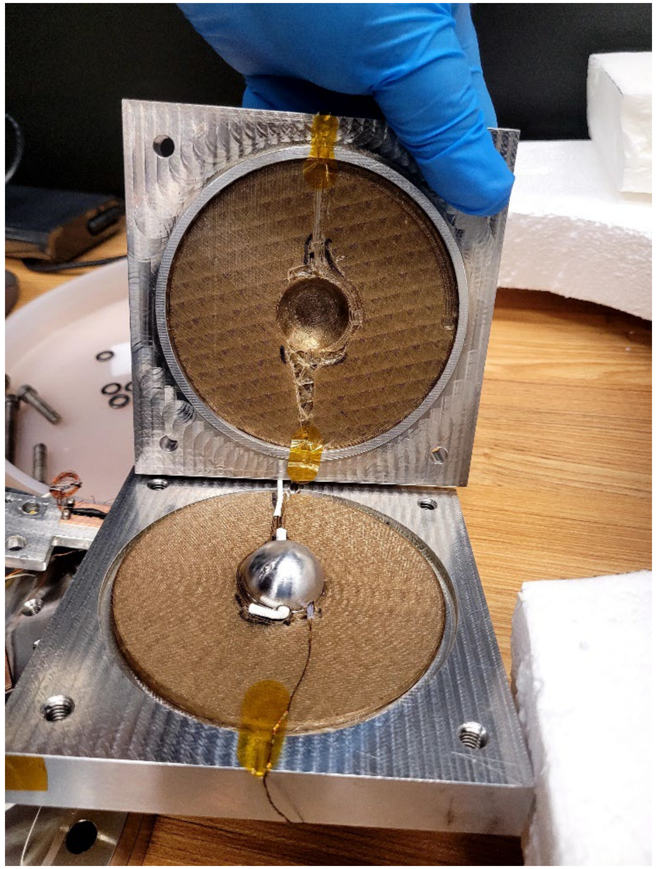
- PEEK (polyetheretherketone)
(3D Printed, with cubic cell infill)
  - Density: 1300 kg/m^3 (bulk, printed density depends on infill) [6]
  - 300 mW/(m-K) @ 25°C [7]
- There is a need for testing these materials at cryogenic temperatures

Conductivity Rig – Sample Chamber

- Uses concentric spheres with an insulation sample in between.
- This method is superior to the longitudinal method since all thermal paths must go through the material
- Samples are 4” OD, 1” ID hemispheres.
- The inner sphere (T_{hot}) and outer sphere shell (T_{cold}) are both independently temperature controlled

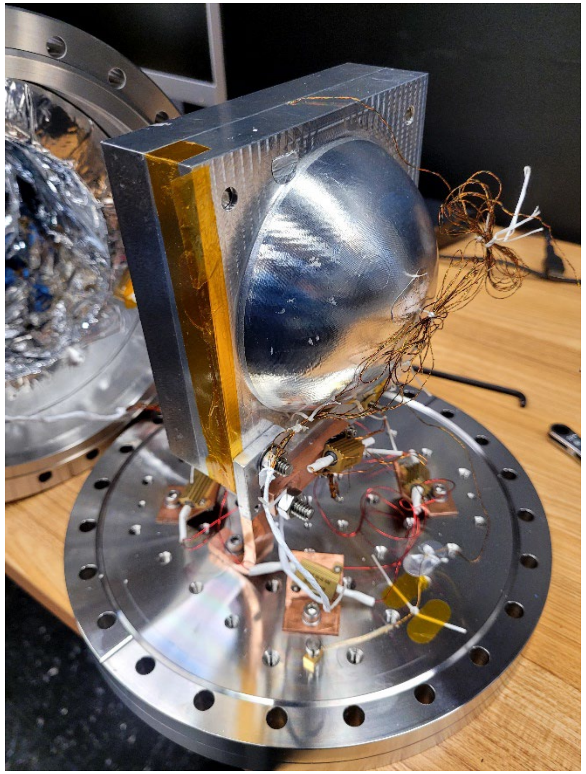


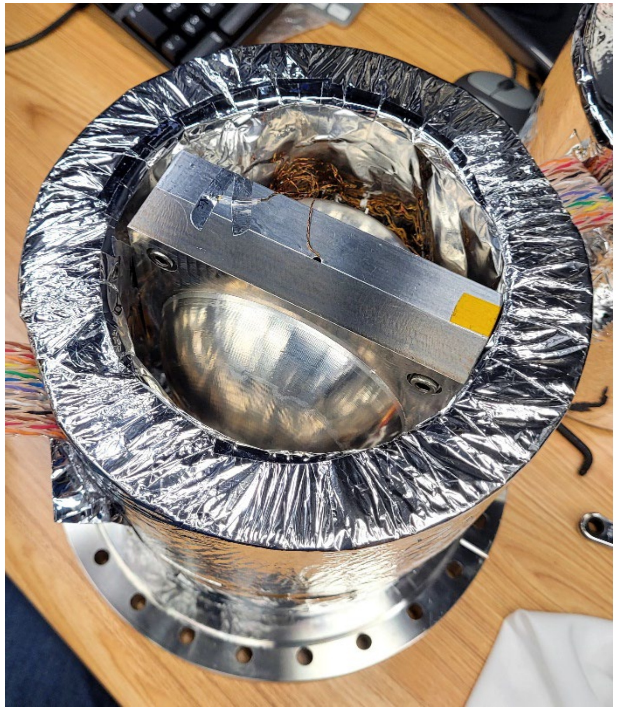
$$Q = \frac{4\pi k (T_{in} - T_{out}) r_{in} r_{out}}{r_{out} - r_{in}}$$



Conductivity Rig – Sample Chamber

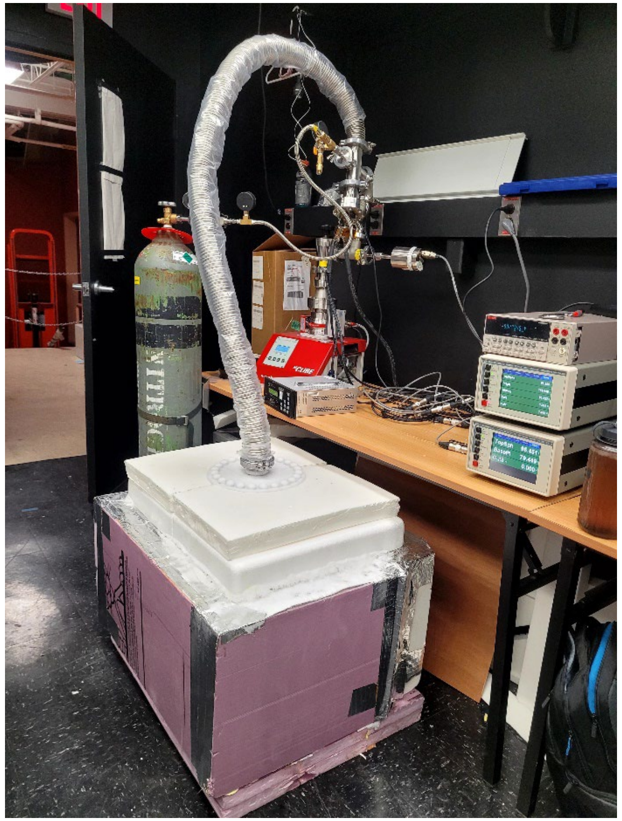
- The shell is attached above a temperature-controlled plate.
- The shell is then covered on all sides with Rohacell insulation.
- Everything is then inserted into a Stainless Steel chamber





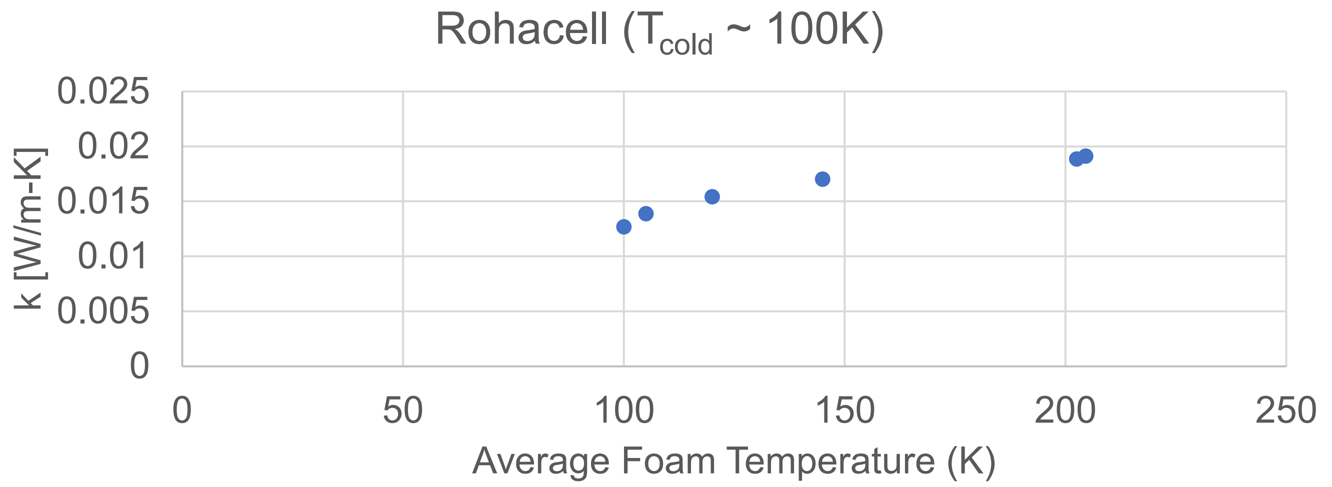
Conductivity Rig

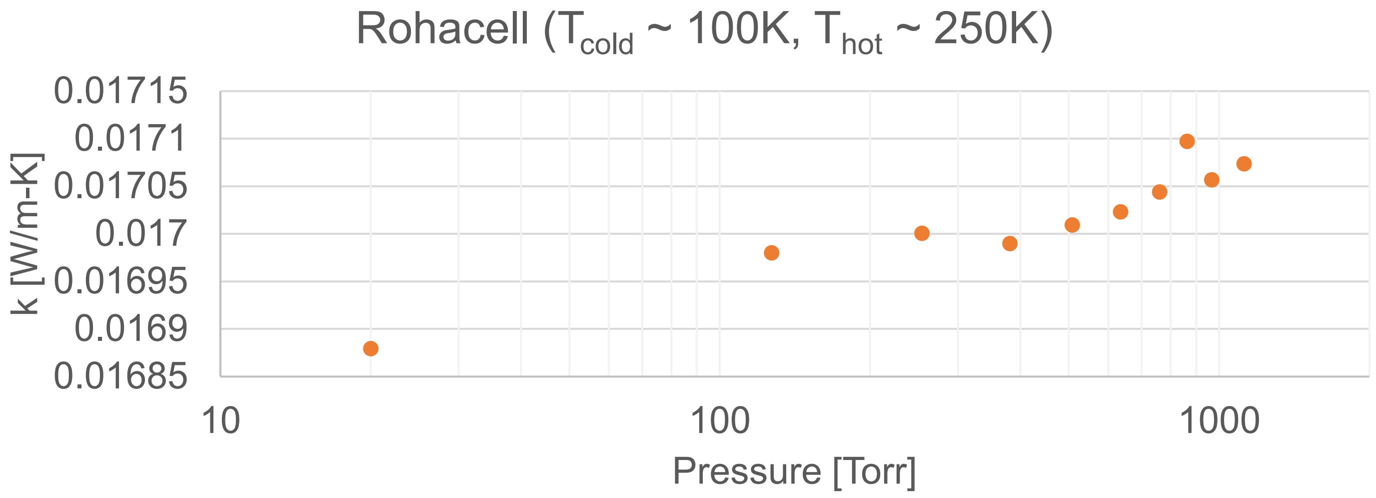
- The sample chamber is placed inside a LN2 bath
- The sample chamber has been designed to work from vacuum to 1.5 atm (absolute) to simulate Titan’s environment
- Temperature readout and control done with two Stanford Research Systems CTC-100
- Heater output read by Keithley 2700



Results - Rohacell

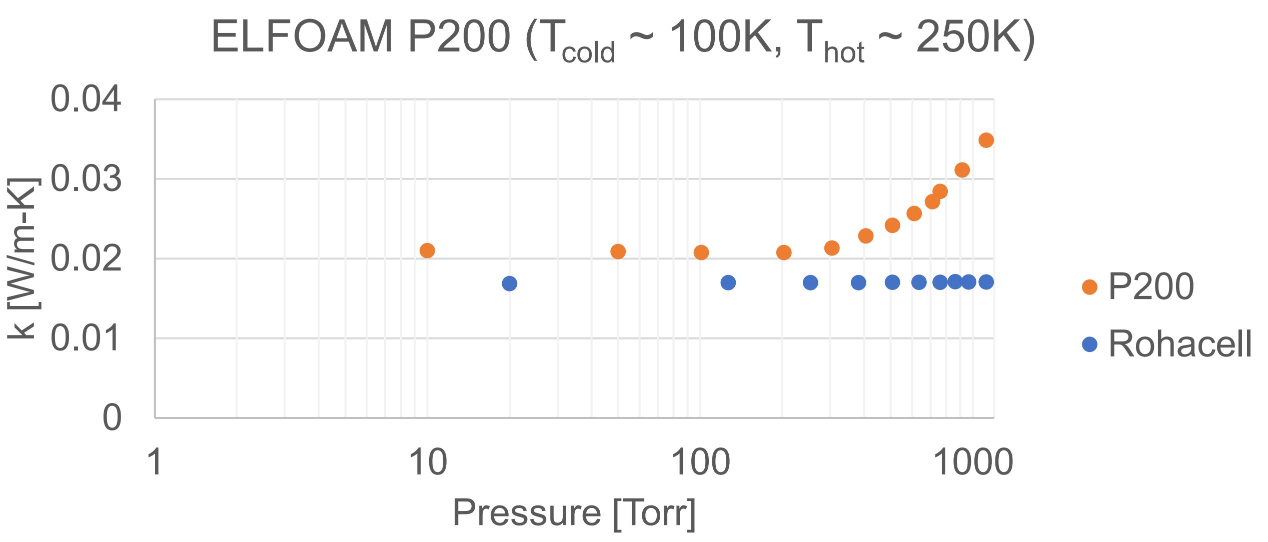
- Resulting conductivity is an effective conductivity that includes convective, conductive and radiative effects.
- Rohacell is temperature dependent
- Rohacell is a closed cell foam, thus the conductivity is minimally affected by pressure

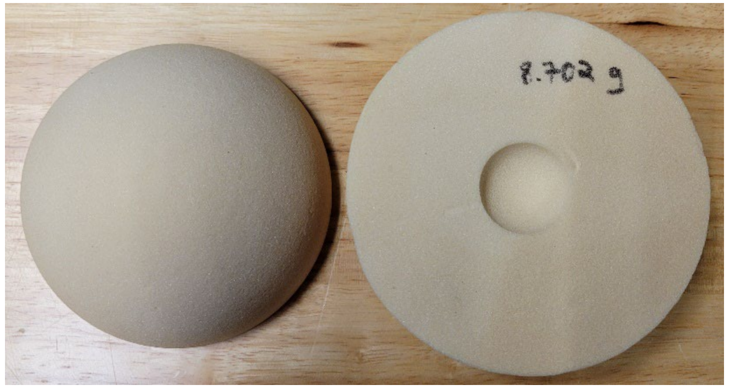




Results - P200

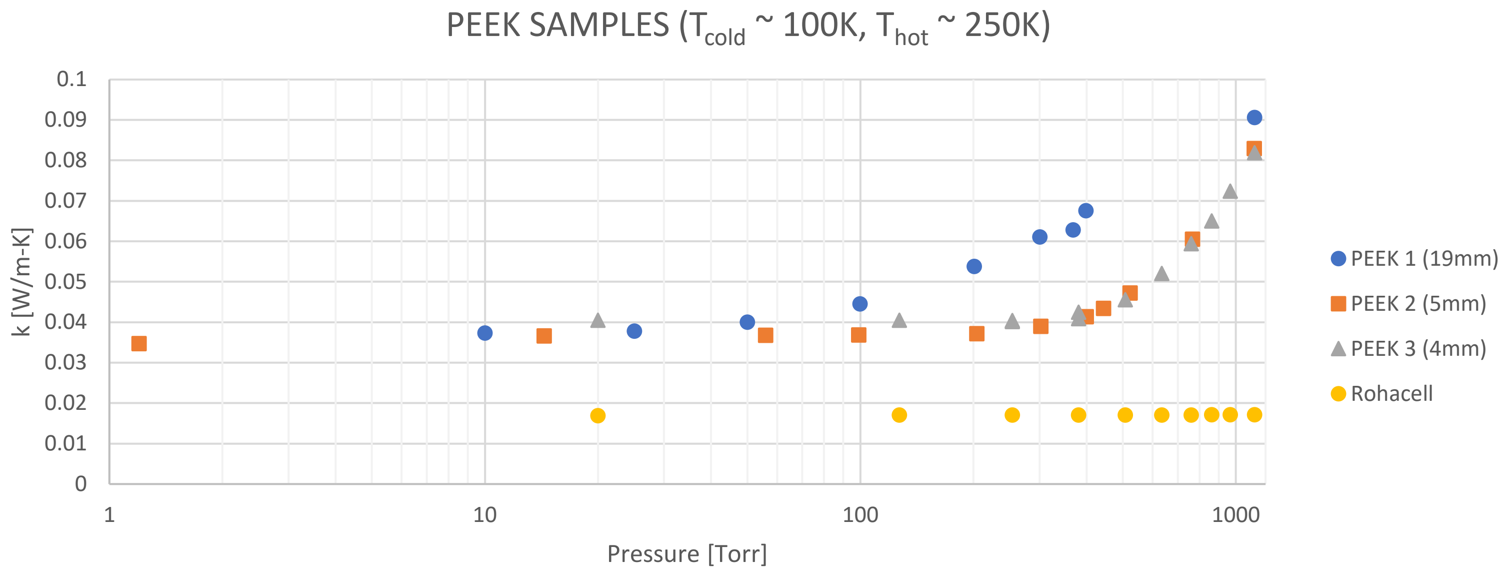
- ELFOAM P200 is less expensive and less volatile than Rohacell
- It is closed cell foam
- It is about 25% more conductive than Rohacell
- It does have a pressure dependence





Results - PEEK

- Tested three infills
  - 19mm cell wall (~5% infill), 0.4mm wall thickness
  - 5mm cell wall (~9% infill), 0.3mm wall thickness
  - 4mm cell wall (~10% infill), 0.3mm wall thickness
- Poor compared conductivity but has the advantage of being any shape and minimal volatility issues.

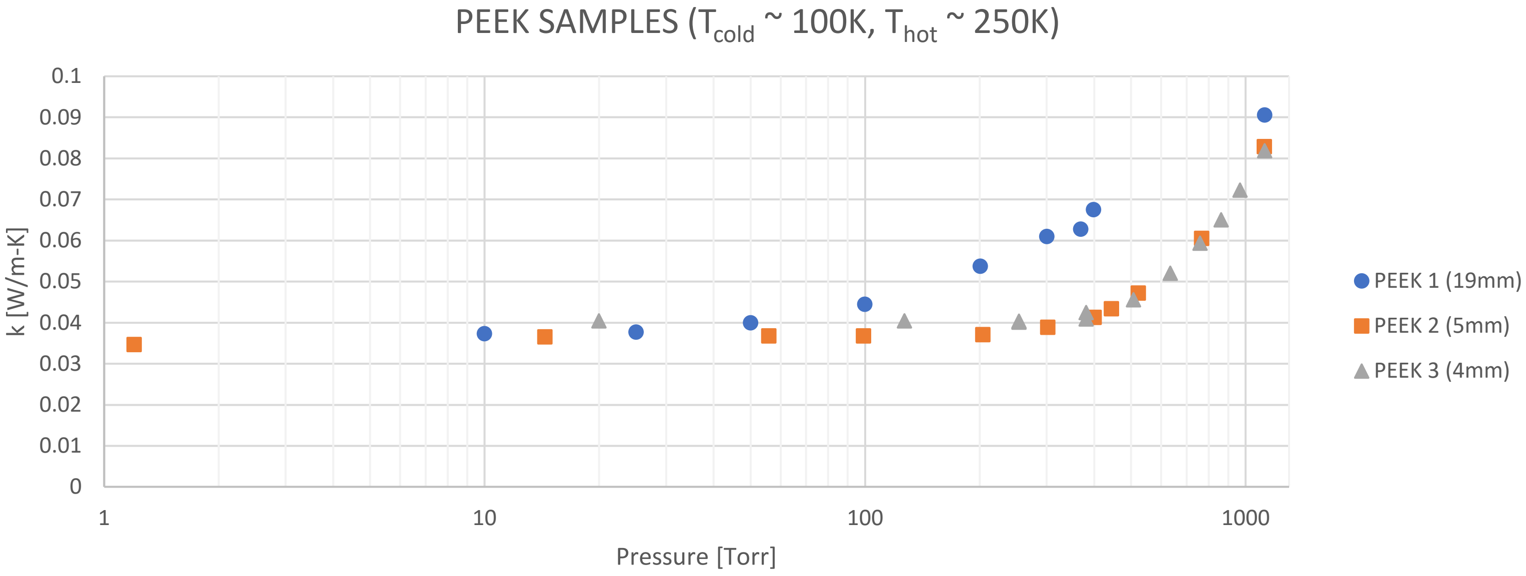


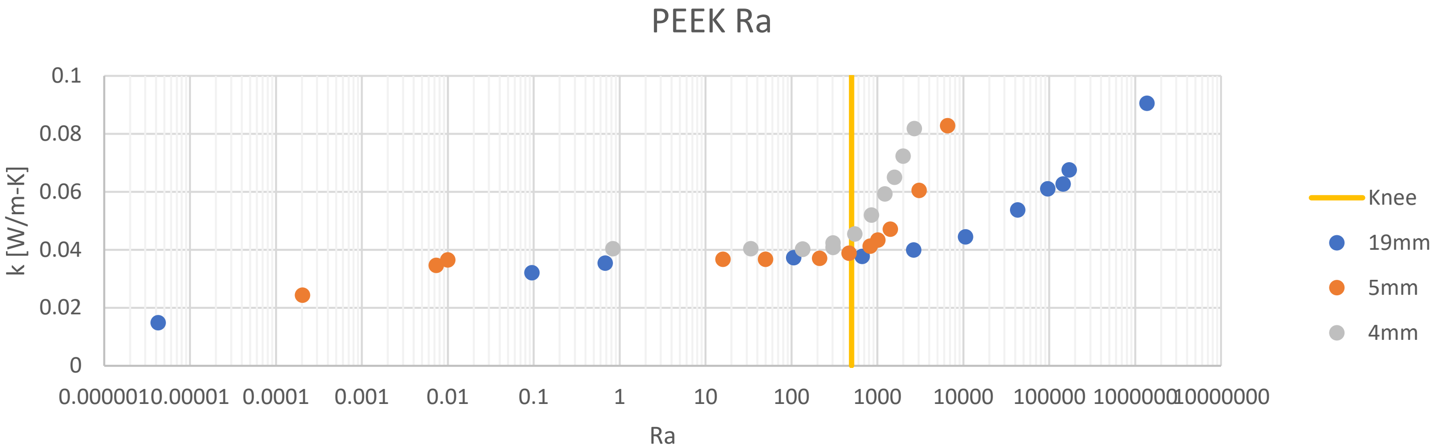
Results - PEEK

- As cell size decreases
  - Convective flow occurs at higher pressure, knee at Ra~500
  - Conductive contribution from the PEEK increases
- Converting P to Ra

$$Ra = \frac{g\,\beta\,dT\,l^3\rho}{\alpha\mu}$$

g: accel. of gravity
β(T,P): volumetric expansion coeff. of N_2
dT: Temp. difference of a cell = ΔT * (cell size/full radial distance)
l: cell size
ρ(T,P): density of N_2
α(T,P): Thermal diffusivity of N_2
μ(T,P): viscosity of N_2





Conclusions

- Rohacell has the lowest thermal conductivity
- However, because Rohacell outgases, PEEK is a better option for the sample carousel. Covered or encapsulated Rohacell is a possible option
- P200 can be used as a less expensive replacement for Rohacell for testing purposes.

Mike Yakovlev, John Hopkins APL

DraMS Cryo Team

Peter Barfknecht
Kelly Burch
Hak Seung Lee
Steven Cale
Brian Comber
Richard Ottens
Paul Rueger
Matt Francom

References

1. Trainer, M. G., et al. "Development of the Dragonfly Mass Spectrometer (DraMS) for Titan." *52nd Lunar and Planetary Science Conference*. No. 2548. 2021.
2. Grubisic, Andrej, et al. "Laser desorption mass spectrometry at Saturn's moon Titan." *International Journal of Mass Spectrometry* 470 (2021): 116707.
3. Evonik Corporation. "Product Information Roahcell HF", https://performance-foams.evonik.com/en/products-and-solutions/rohacell/attachment/140034?rev=794f98c8bd5fde83bf7a48c583636425
4. Emkay Plastics. "Rohacell Foam Technical Product Manual", https://www.emkayplastics.co.uk/wp-content/uploads/2019/10/Thermal-Properties.pdf
5. Elliott Company. "ELFOAM P200: Polyisocyanurate Foam", https://www.elliottfoam.com/pdf/ELFOAM%20P200%20TDS%20%20May2016.pdf, 2016
6. MatWeb. "Overview of materials for Polyetheretherketone, Unreinforced", https://www.matweb.com/search/DataSheet.aspx?MatGUID=2164cacabcde4391a596640d553b2ebe&ckck=1
7. Rule, D. L., et al. "Low-Temperature Thermal Conductivity of Composites: Alumina Fiber/Epoxy and Alumina Fiber/PEEK", NIST, MISTIR 89-3914, 1989.