Novel Noise Liner Development Enabled by Advanced Manufacturing
Project 79

Lead investigator: Nicholas Meisel, The Pennsylvania State University
Project manager: Pierre Mulgrave, FAA

October 16, 2025
Alexandria, VA

This research was funded by the U.S. Federal Aviation Administration Office of Environment and Energy through ASCENT, the FAA Center of Excellence for Alternative Jet Fuels and the Environment, project 79 through FAA Award Number 13-C-AJFEPSU Amendment 079 under the supervision of Pierre Mulgrave. Any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the FAA.

ASCENT

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Novel Noise Liner Development Enabled by Advanced Manufacturing

The Pennsylvania State University

PI: Nicholas Meisel

PM: Pierre Mulgrave

Cost Share Partner(s): RTX Technology Research Center, Altair Engineering, Cornerstone Research Group

Objective:

Develop and demonstrate a methodology for rapid design, analysis, fabrication, and testing of novel structure that can enhance noise attenuation in aircraft engines

Project Benefits:

Novel acoustic liner designs and materials will provide a new approach for aircraft engine manufacturers to realize simultaneous noise, emissions, and fuel burn reductions

Research Approach:

1. Establish a set of acoustic requirements for future aircraft engine designs
2. Design and analyze lattice-based acoustic liners using advanced software tools
3. Perform rapid, iterative prototyping and testing to identify promising designs and materials
4. Conduct detailed assessments of manufacturability
5. Perform acoustic and structural evaluations of novel liners
6. Document results and archive data for the FAA

Major Accomplishments (to date):

1. Computational comparison of a variety of liner designs along with sensitivity analysis of underlying variables
2. Established method for quantifying and accounting for manufacturing variations

Future Work / Schedule:

October 2025: Manufacturing Error Model

November 2025: Automated Meshing Capabilities

February 2025: Demonstrating Two Liner Designs

March 2025: Documentation and Data Archiving

April 2025: Transition to Metal AM

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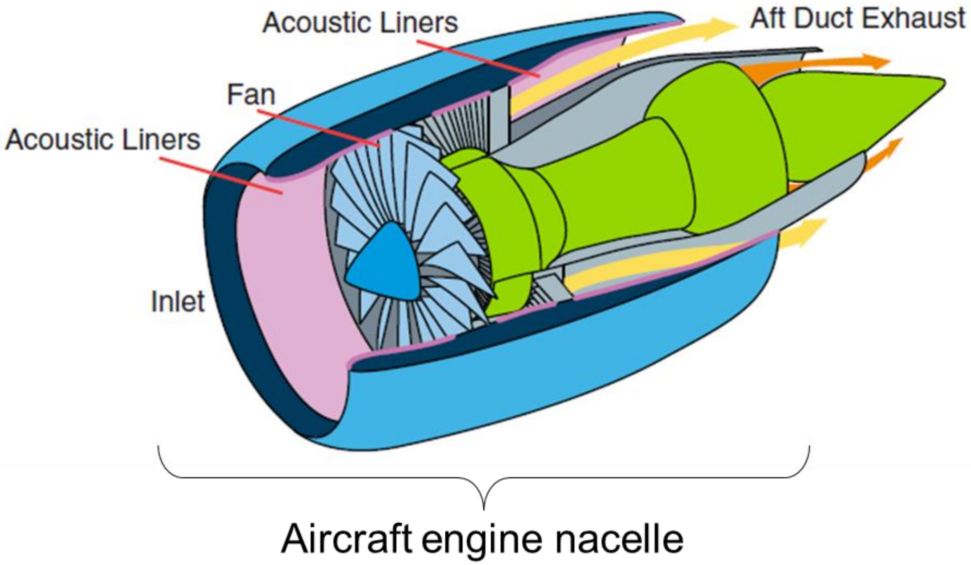
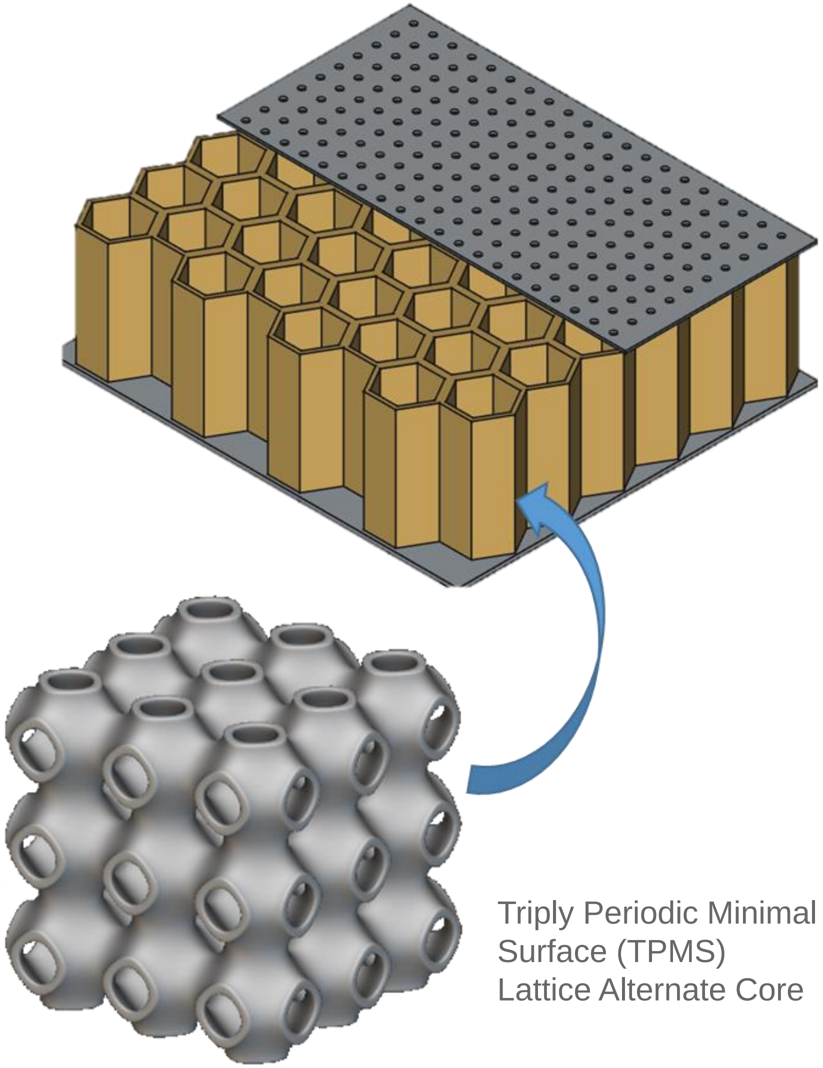
Acoustic liners are placed in the nacelle of aircraft to reduce noise

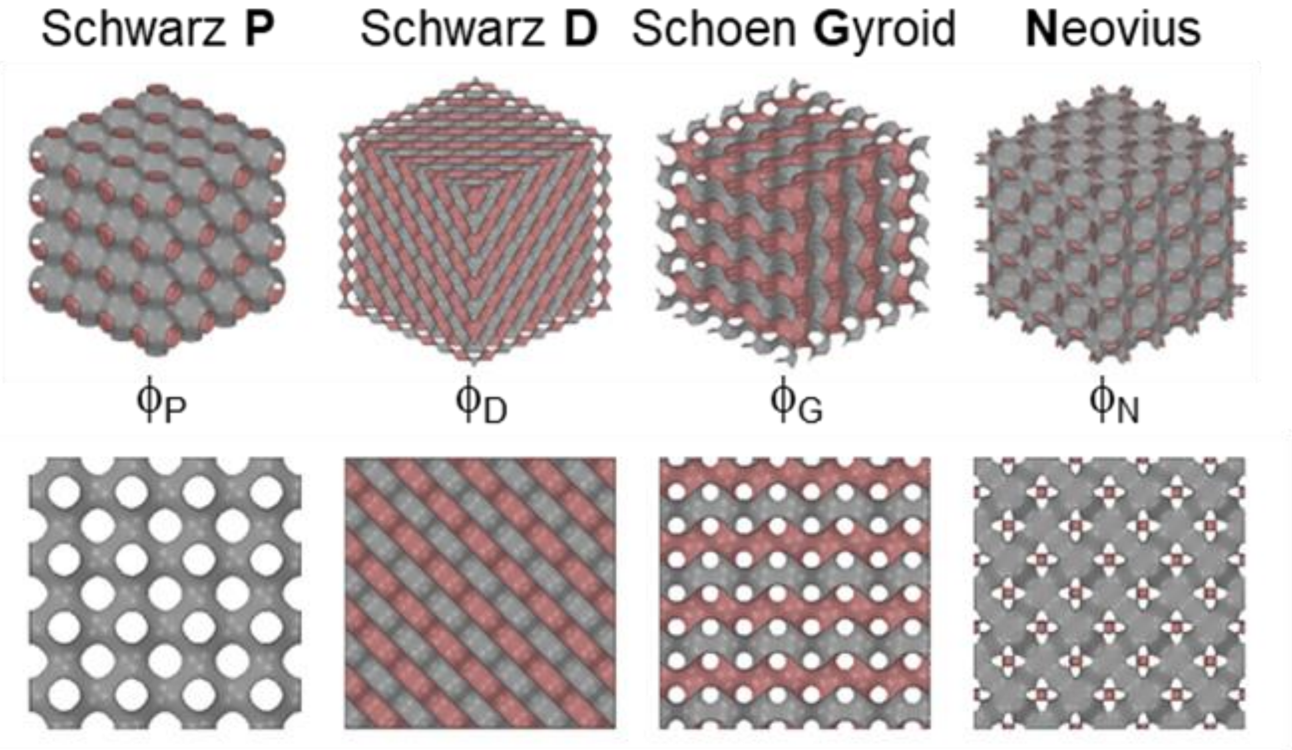
Novel acoustic liner designs are needed to address the noise profile of modern engine designs, while meeting space and weight constraints.





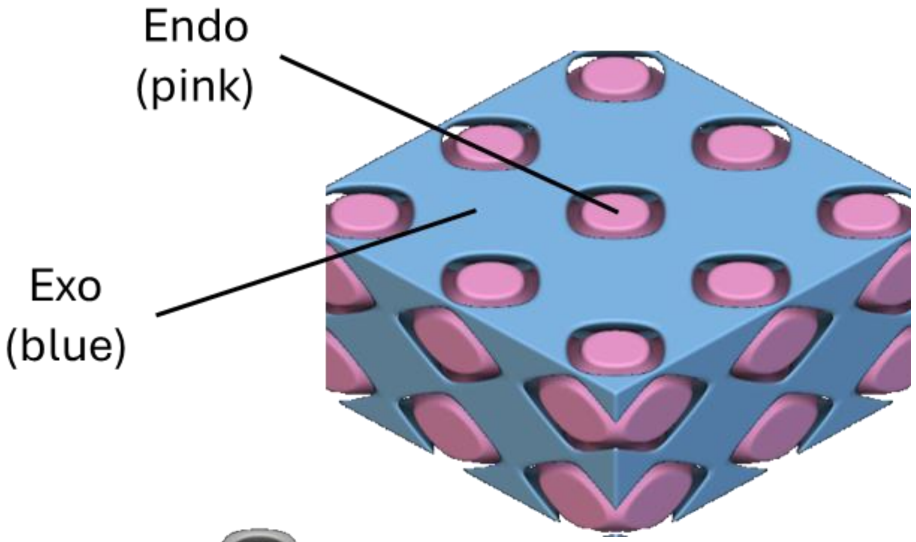
Triply Periodic Minimal Surface (TPMS) Lattice Alternate Core

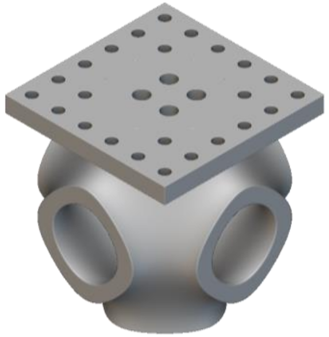
To show viability, a comparison against traditional liners is needed



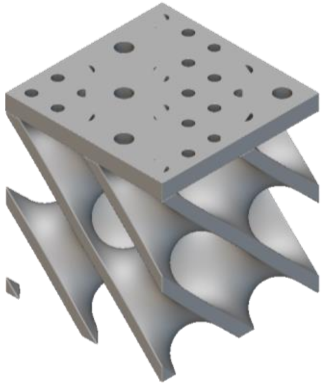
$$\phi_P = \cos(x)+\cos(y)+\cos(z) = C$$
$$\phi_D = \cos(x)\cos(y)\cos(z)-\sin(x)\sin(y)\sin(z) = C$$
$$\phi_G = \sin(x)\cos(y)+\sin(y)\cos(z)+\sin(z)\cos(x) = C$$
$$\phi_N = 3[\cos(x)+\cos(y)+\cos(z)]+4\cos(x)\cos(y)\cos(z) = C$$

TPMS Lattices include two intersecting fluid regions along with a facesheet

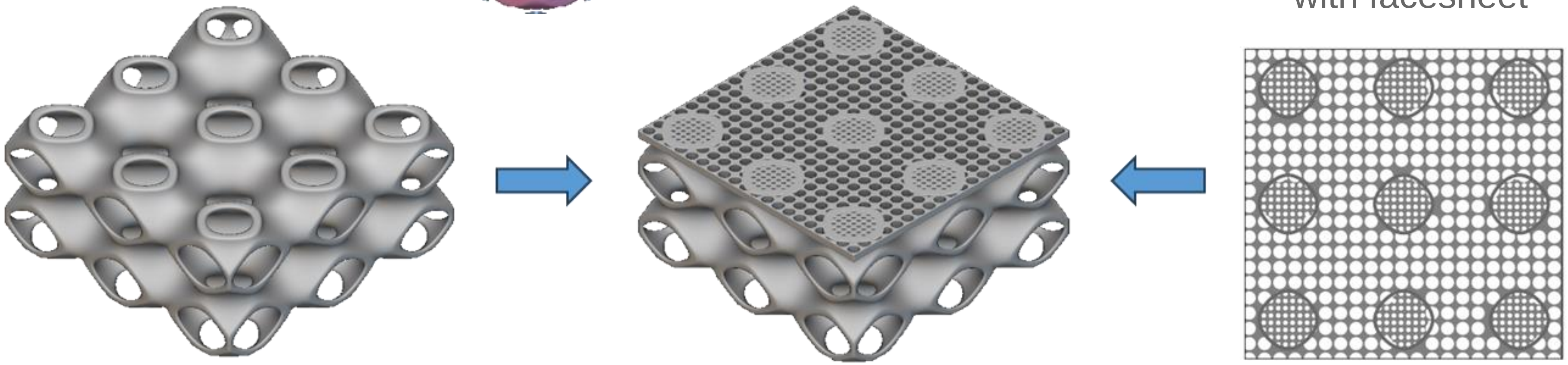




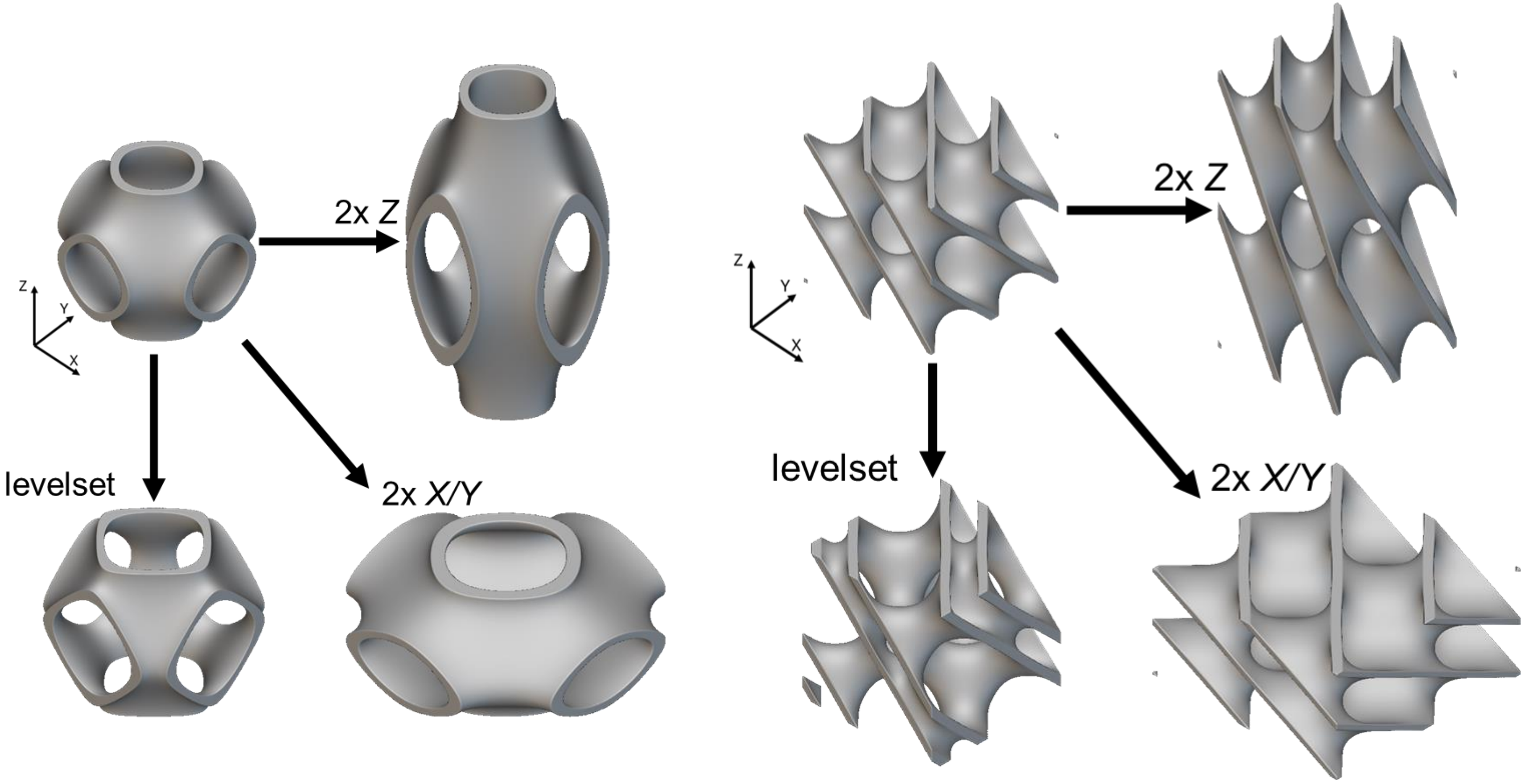
Schwarz P unit cell
with facesheet



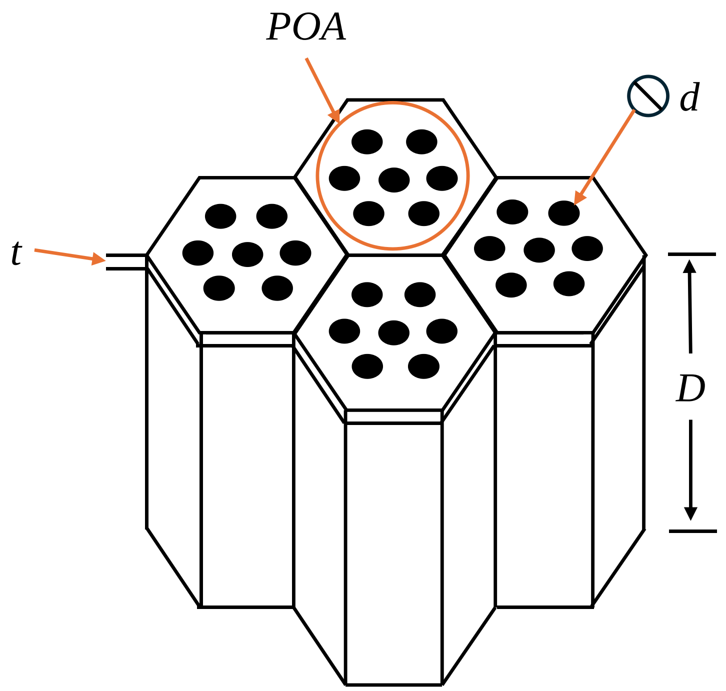
Diamond unit cell
with facesheet



The design of TPMS structures can be adjusted through certain variables

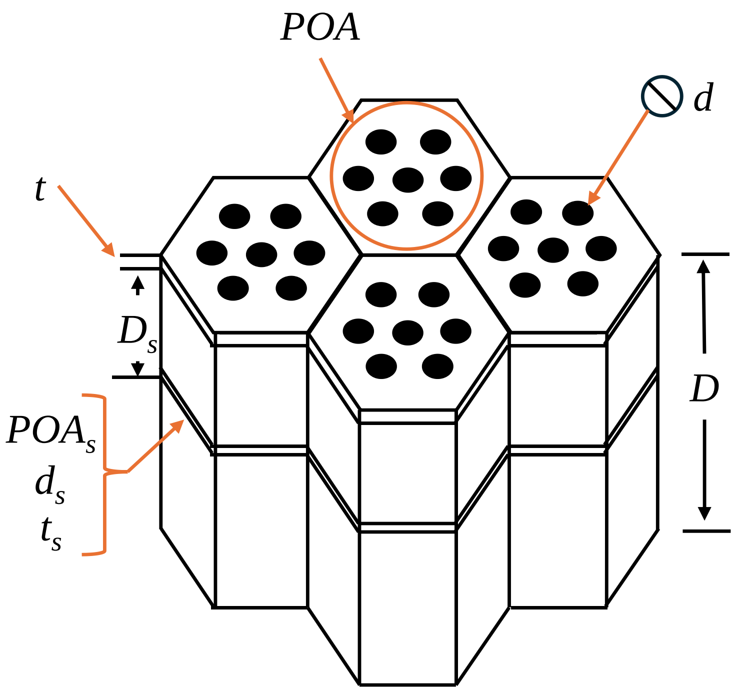


This contrasts with current honeycomb-based liners



Single Degree of Freedom (SDOF)

- Honeycomb core
- Perforated facesheet



Double Degree of Freedom (DDOF)

- Honeycomb core
- Perforated facesheet
- Perforated septum

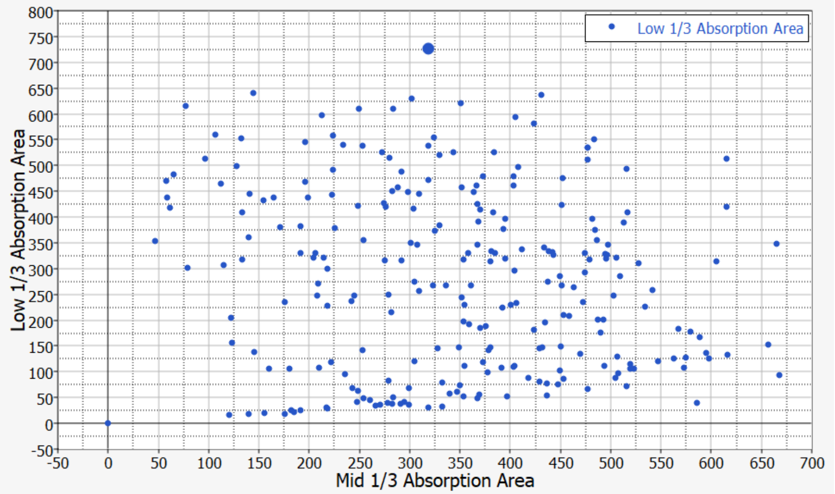
We need to understand the impact of each variable on performance

SDOF	DDOF	TPMS
# of Facesheet Perforations	# of Facesheet Perforations	X/Y Unit Cell Size
Perforation Diameter	Perforation Diameter	Z Unit Cell Size
Facesheet Thickness	Facesheet Thickness	Z: # of Cells
Liner Depth	Liner Depth	Levelset (Facesheet)
	# of Septum Perforations	Levelset (Backplate)
	Septum Perf. Diameter	Facesheet Thickness
	Septum Thickness	Endo Perf. Diameter
	Septum Depth	# of Endo Perforations
		Exo Perf. Diameter
		# of Exo Perforations

Variables were used in a DOE via the dashboard discussed last year

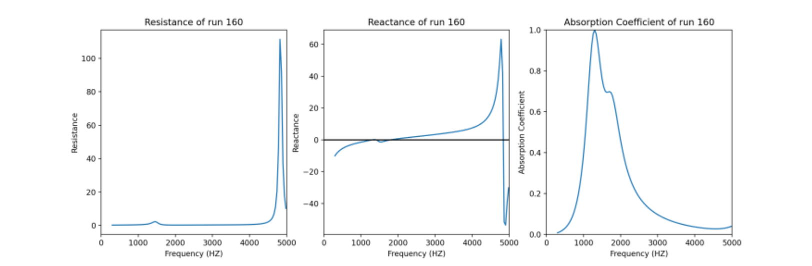
Show in Study Directory | Show in Explorer | Verify

	Face...ness	Exo ...eter	Exo POA	End...ter	Endo POA	levelset
156	0.0015117	8.44e-04	0.2322080	6.83e-04	0.1195695	-0.6784271
157	7.28e-04	6.52e-04	0.2218080	7.55e-04	0.1998507	-0.5038098
158	0.0010077	8.92e-04	0.1698080	0.0011147	0.1984582	-0.0270289
159	0.0012877	0.0011318	0.1178080	8.75e-04	0.2701534	-0.3505666
160	0.0015677	7.72e-04	0.0658080	6.35e-04	0.1148737	-0.2767683
161	0.0018477	0.0010118	0.2738080	9.95e-04	0.1536936	-0.1202179
162	7.84e-04	0.0011798	0.0554080	7.07e-04	0.2353299	-0.1166366
163	0.0010637	8.20e-04	0.2634080	0.0010667	0.1607373	-0.0227061
164	0.0013437	0.0010598	0.2114080	8.27e-04	0.1995572	-0.5661557
165	0.0019037	9.40e-04	0.1074080	9.47e-04	0.2771971	-0.2530549
166	0.0019597	8.68e-04	0.2010080	8.99e-04	0.2725013	-0.5513960



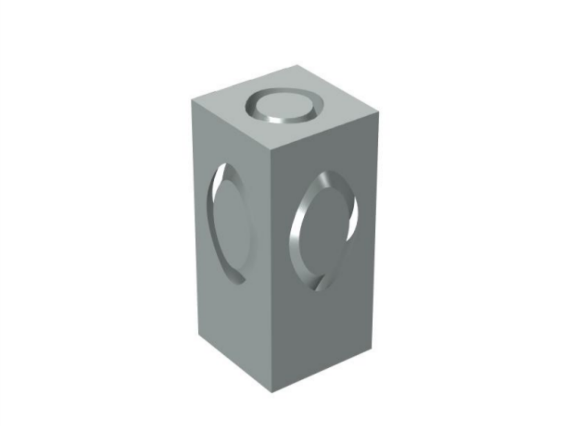
160 160 | Play as Animation | Differences | Previous Image | Next Image | 1 of 3

Run 160
Response Plots

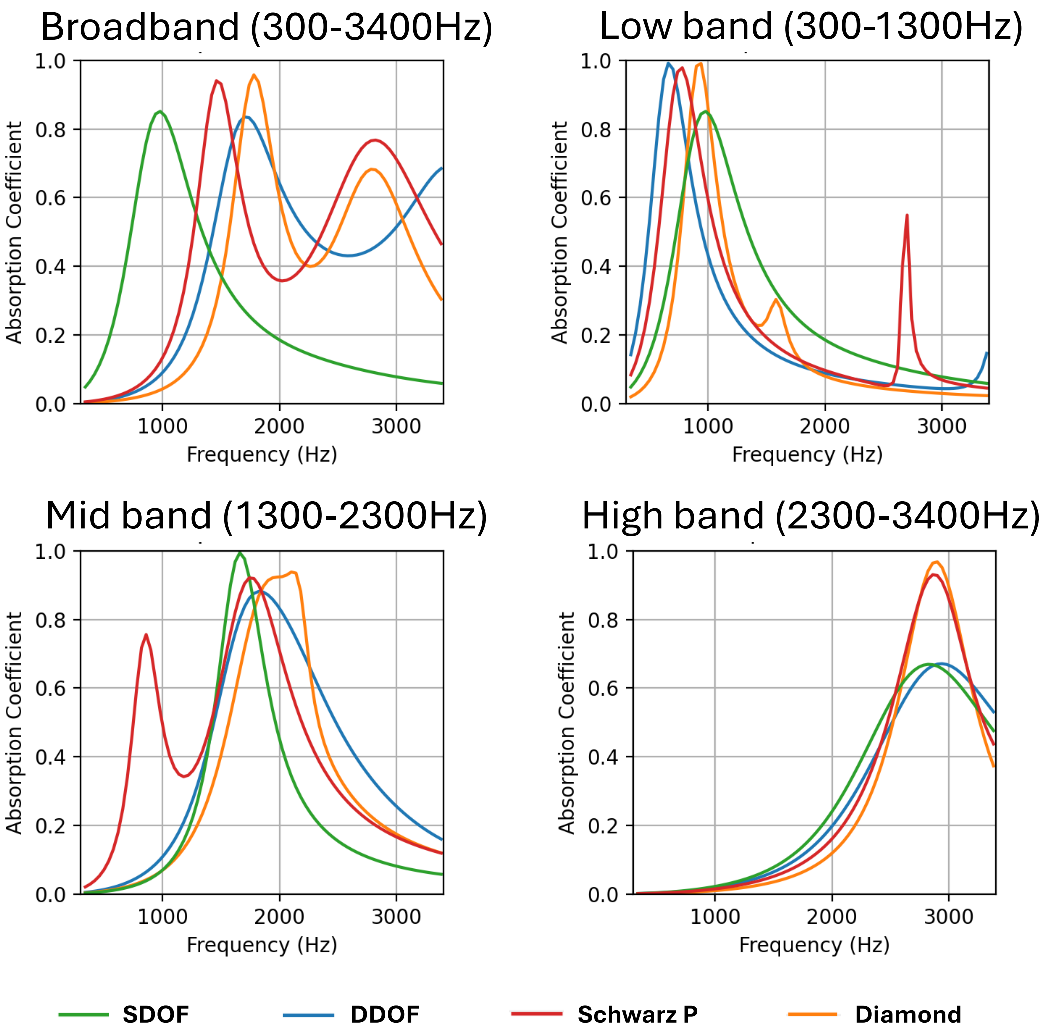


160 160 | Play as Animation | Differences | Previous Image | Next Image | 2 of 3

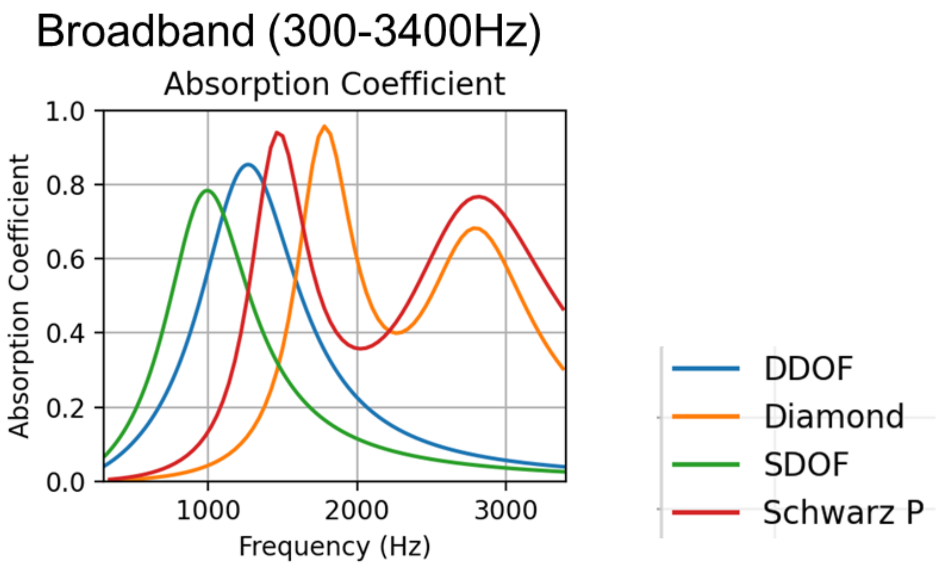
Run 160
Lattice Image



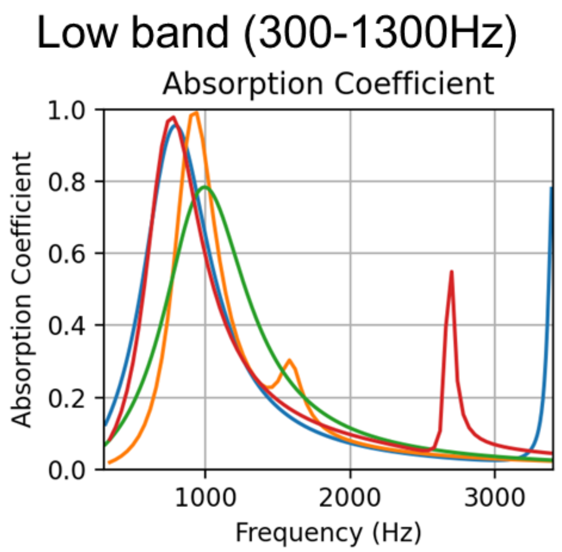
COMSOL shows top TPMS designs matching or exceeding honeycombs



Findings show that top TPMS designs require less depth than honeycombs



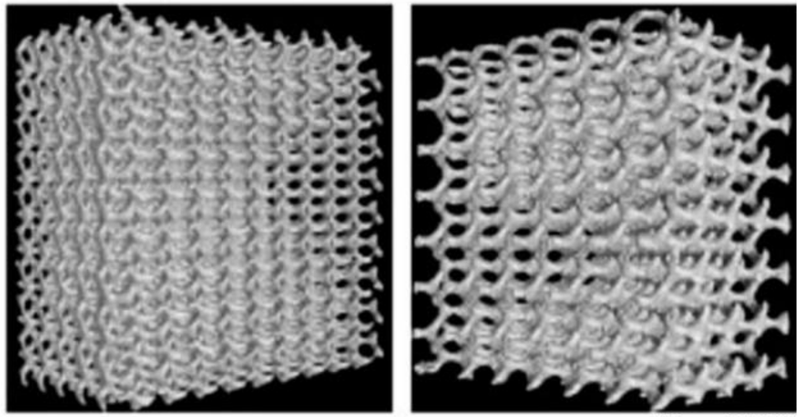
Liner Type	Depth (mm)
SDOF	36.0 mm
DDOF	24.0 mm
Schwarz P	11.9 mm
Diamond	11.6 mm



Liner Type	Depth (mm)
SDOF	36.0 mm
DDOF	38.0 mm
Schwarz P	27.1 mm
Diamond	18.7 mm

While the performance is promising, we need ways of evaluating quality

X-ray Computed Tomography (XCT)



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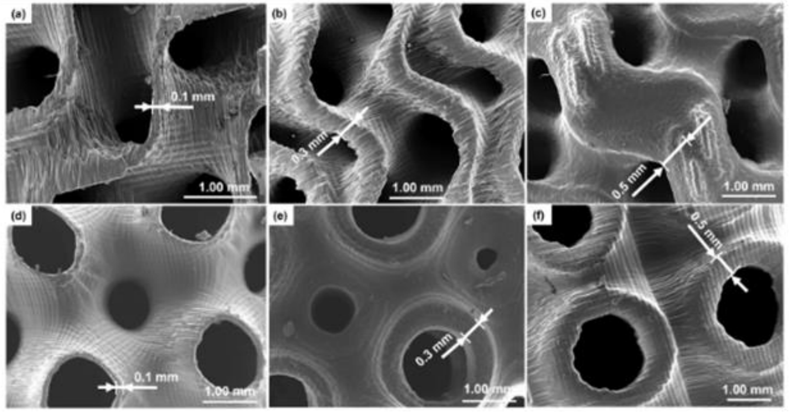
Scanning Electron Microscopy



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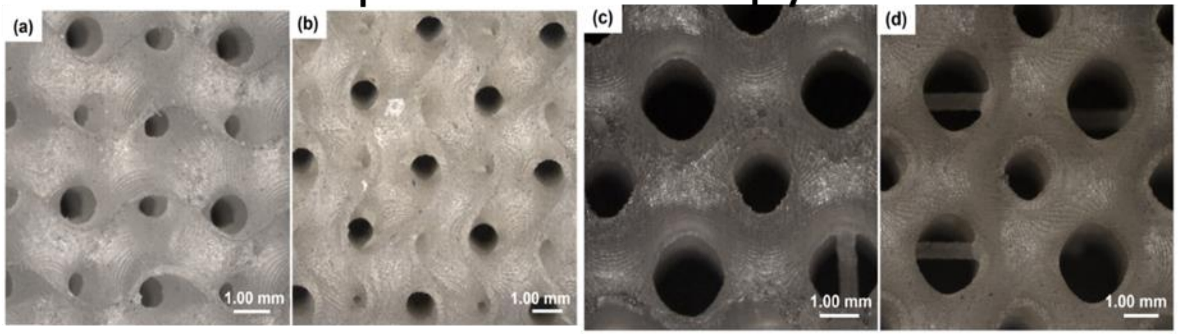
Optical Microscopy



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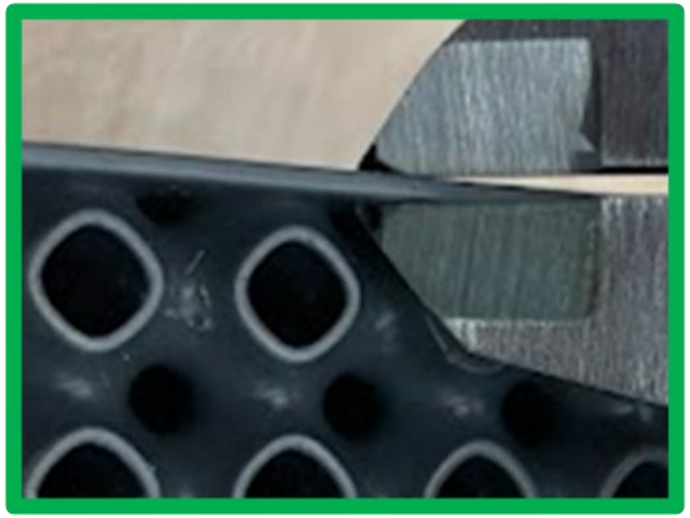
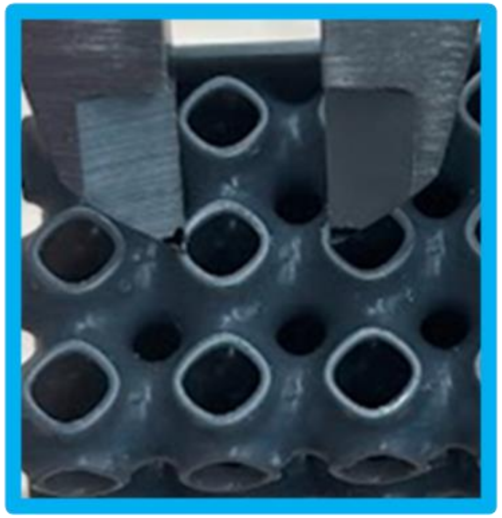
As an alternative, we're developing low-cost methods for quality checks

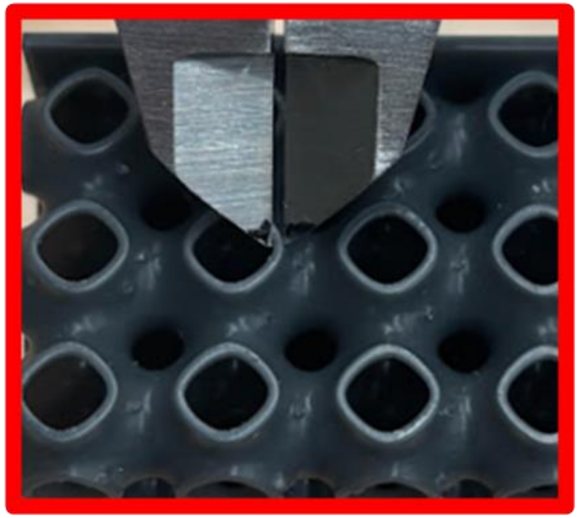
Manual Measurement Method	Automated Screening Method
• Uses a combination of physical measurements and image analyses. • Provides direct quantitative data on the dimensions of several design variables. • Measured distributions can be used to evaluate the stochastic error within the parts. • The results can be used to make design adjustments and dial in the manufactured dimensions.	• Uses image processing and analysis along with machine learning to evaluate several geometric characteristics. • Outputs the total number of print defects based on user defined pass/fail criteria. • Can be used to quickly judge the quality of a finished printed part and determine whether a new print is necessary.

Our manual methods are focusing on standardized use of calipers

Measurement Tool	Variable	Measurement Technique
Digital calipers	Face Sheet Thickness	Measure the thickness around the edge of the face sheet.
	Unit Cell Size	Measure the offset unit cell size by finding the distance from the pore edge of one cell to the corresponding pore edge of an adjacent cell.
	Wall Thickness	Measure the wall thickness around the exposed lattice pore edges.







Measurements are grouped by orientation as taken from the lattice

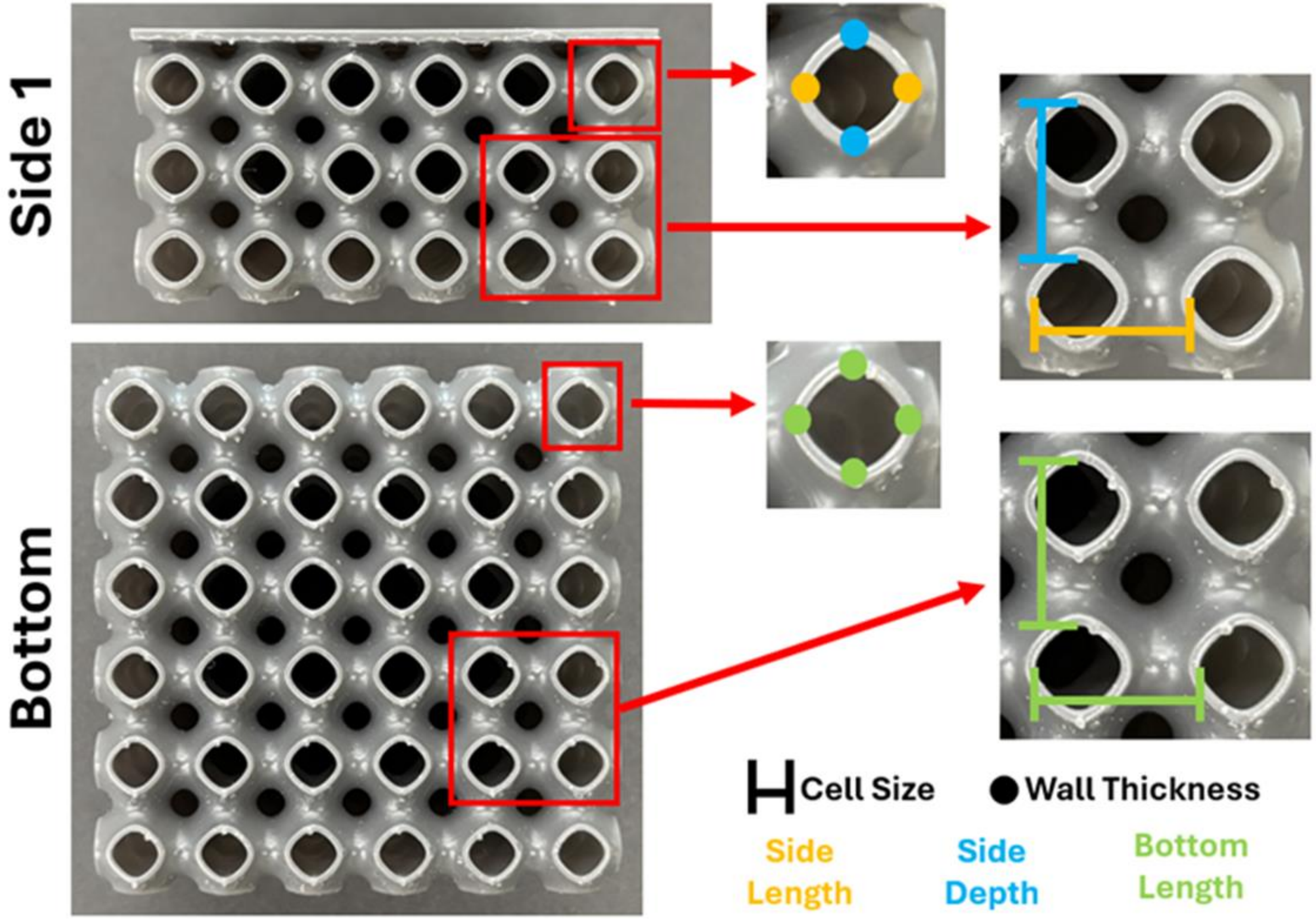
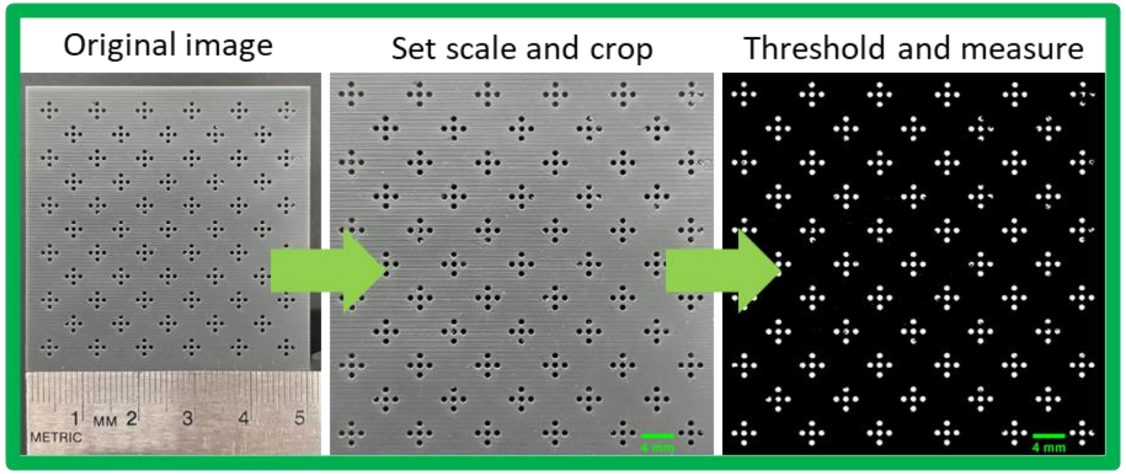
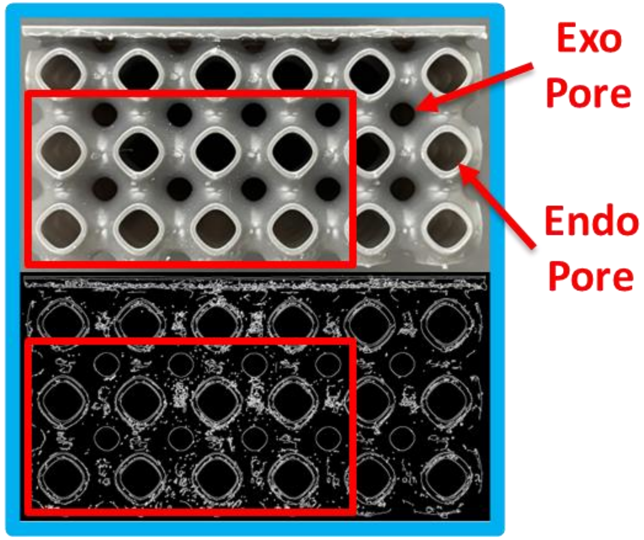


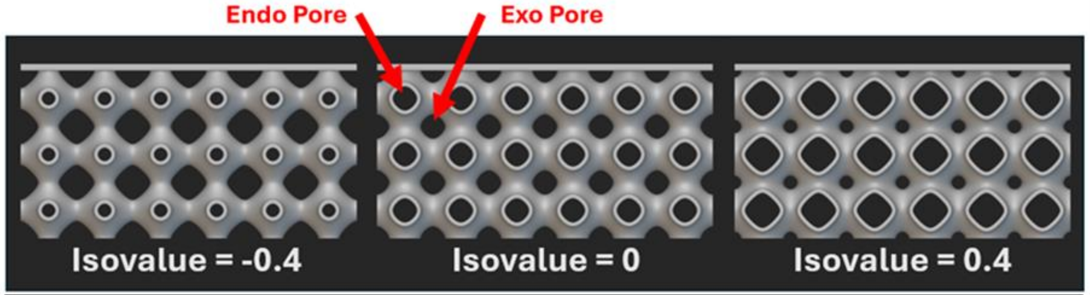
Image processing tools also support manual data collection

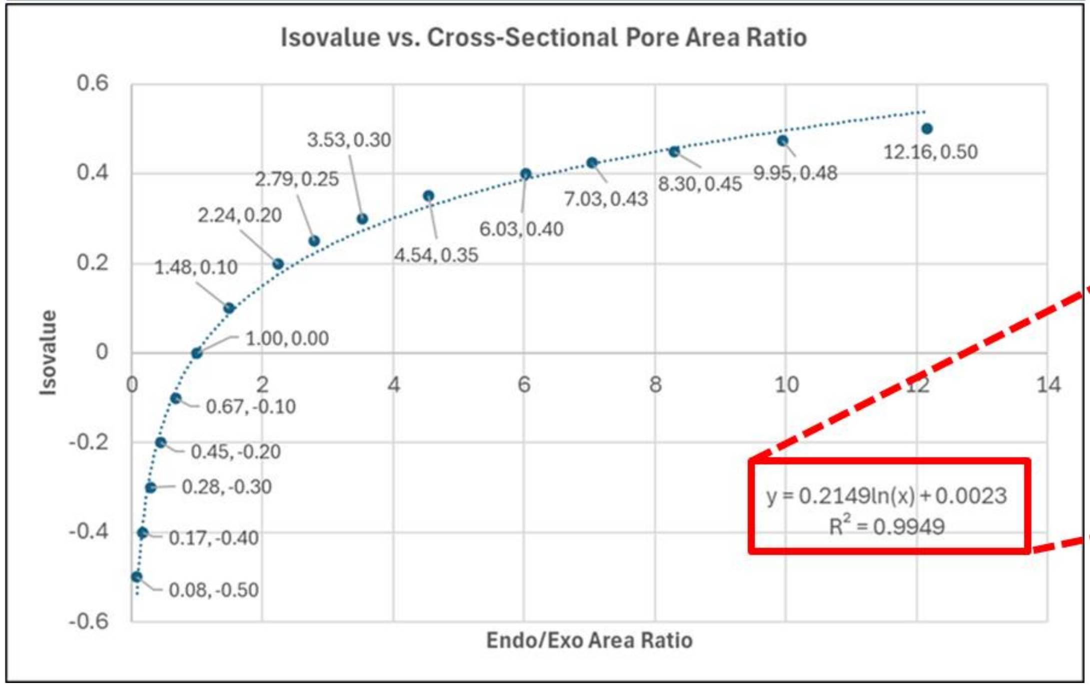
Measurement Tool	Variable	Measurement Technique
Adobe Lightroom and ImageJ	Perforation Diameter	Threshold images of the face sheet so only the perforations are visible. Batch measure the areas of the perforations. Use the areas to estimate the diameter of the perforation.
	Percent open area	Threshold images of the face sheet so only the perforations are visible. Find the total area of the perforations and divide it by the total area of the face sheet.
	Isovalue	Use edge detection to capture clean edges of the lattice pores. Find the cross-sectional area ratio between the corresponding endo and exo pores. Convert the ratios to isovalues using an isovalue vs. area ratio relationship calculated from the ideal model.

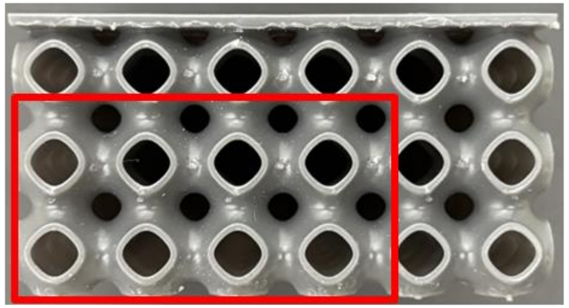




Lattice pore area ratios helped to generate a relationship to isovalues







This equation can be used to estimate the isovalue given the endo/exo pore area ratio.

$$y = 0.2149\ln(x) + 0.0023$$

$$R^2 = 0.9949$$

From these measurements, certain key issues are identified

- All manufactured variables that define solid features were found to be oversized from their nominal dimensions.
- Perforation Diameter, and therefore percent open area, were found to be undersized since they dictate negative features.
- Wall thickness measured along the depth of the core was found to print thicker.
- For some variables, the nominal dimension fell outside the measured range.

Variable	Nominal	Average	Standard Deviation	Minimum	Maximum
Face Sheet Thickness	1 mm	1.17 mm	0.05 mm	1.09 mm	1.29 mm
Unit Cell Size (Side Length)	8.47 mm	8.51 mm	0.04 mm	8.43 mm	8.61 mm
Unit Cell Size (Side Depth)	8.47 mm	8.51 mm	0.05 mm	8.42 mm	8.59 mm
Unit Cell Size (Bottom Length)	8.47 mm	8.50 mm	0.04 mm	8.42 mm	8.59 mm
Wall Thickness (Side Length)	0.6 mm	0.64 mm	0.03 mm	0.55 mm	0.71 mm
Wall Thickness (Side Depth)	0.6 mm	0.73 mm	0.05 mm	0.64 mm	0.87 mm
Wall Thickness (Bottom Length)	0.6 mm	0.63 mm	0.04 mm	0.55 mm	0.72 mm
Perforation Diameter	0.8 mm	0.69 mm	0.02 mm	0.64 mm	0.72 mm
Percent Open Area (POA)	5.94%	4.26%	N/A	N/A	N/A
Isovalue	0.2	0.201	0.003	0.192	0.207

A multidisciplinary team has ensured the innovative potential of the project

Federal Aviation Administration

Pierre Mulgrave (Project Manager)

PennState

Nicholas Meisel (PI)	Allison Beese (Co-PI)	Eric Greenwood (Co-PI)	Alden Packer (PhD Student)	Joseph Windows (MS Student)

RTX

Jeff Mendoza (PI)	Julian Winkler (Co-PI)	Aaron Reimann (Co-PI)	Kenji Homma (Inv.)	Paul Braunwart (Inv.)

ALTAIR

Andy Hughes (PI)	Eric Nelson (co-PI)

CRG

Akiva Wernick (PI)

NASA

Mike Jones (Unfunded)	Doug Nark (Unfunded)