AutoHood3D: A Multi-Modal Benchmark for Automotive Hood Design and Fluid–Structure Interaction

Vansh Sharma

Harish Jai Ganesh

Maryam Akram

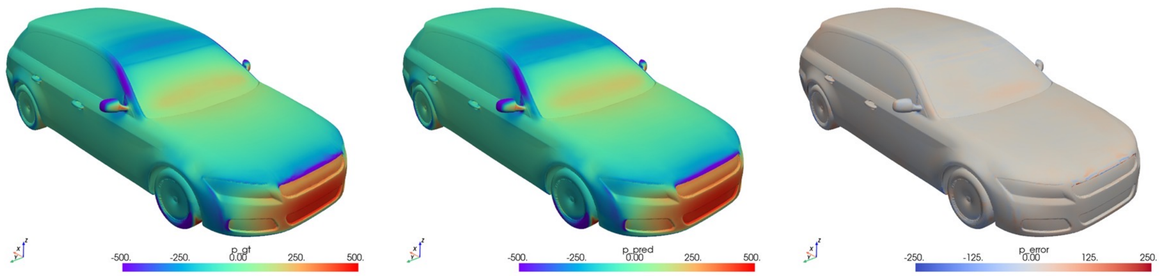
Wanjiao Liu

Venkat Raman

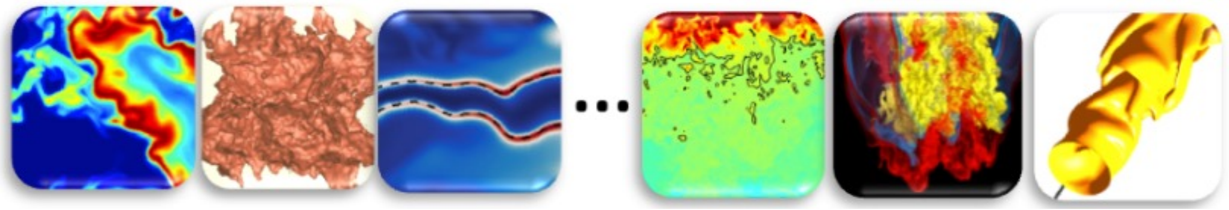
COLLEGE OF ENGINEERING
AEROSPACE ENGINEERING
UNIVERSITY OF MICHIGAN

Existing Physics Datasets

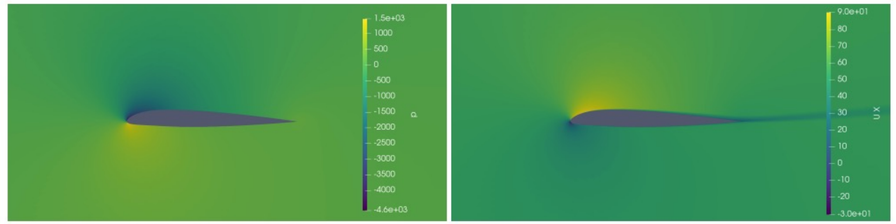
DrivAerNet++



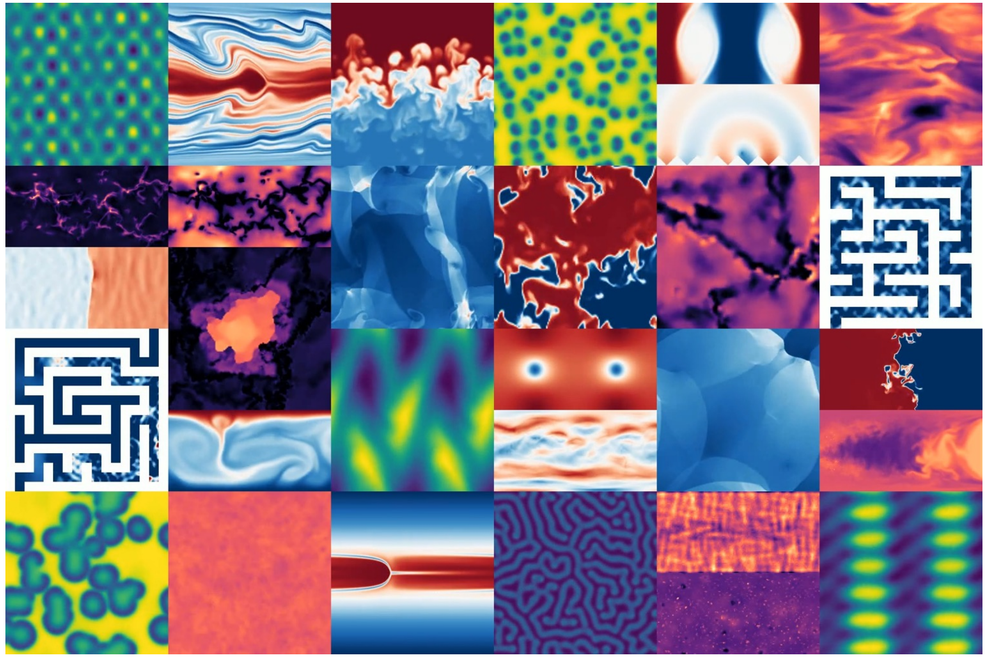
BLASTNet



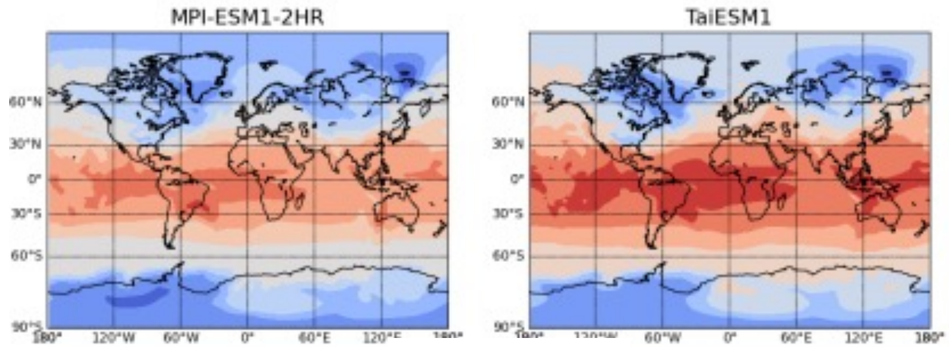
AirfRANS



The Well

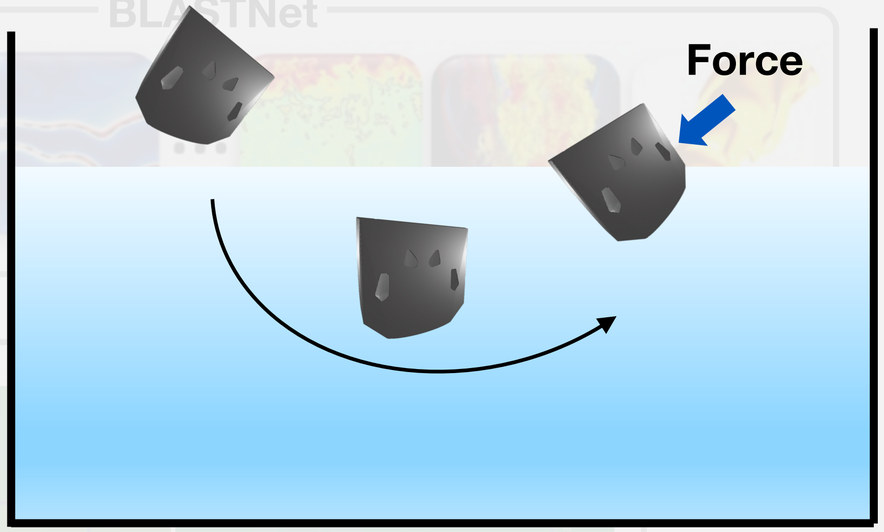


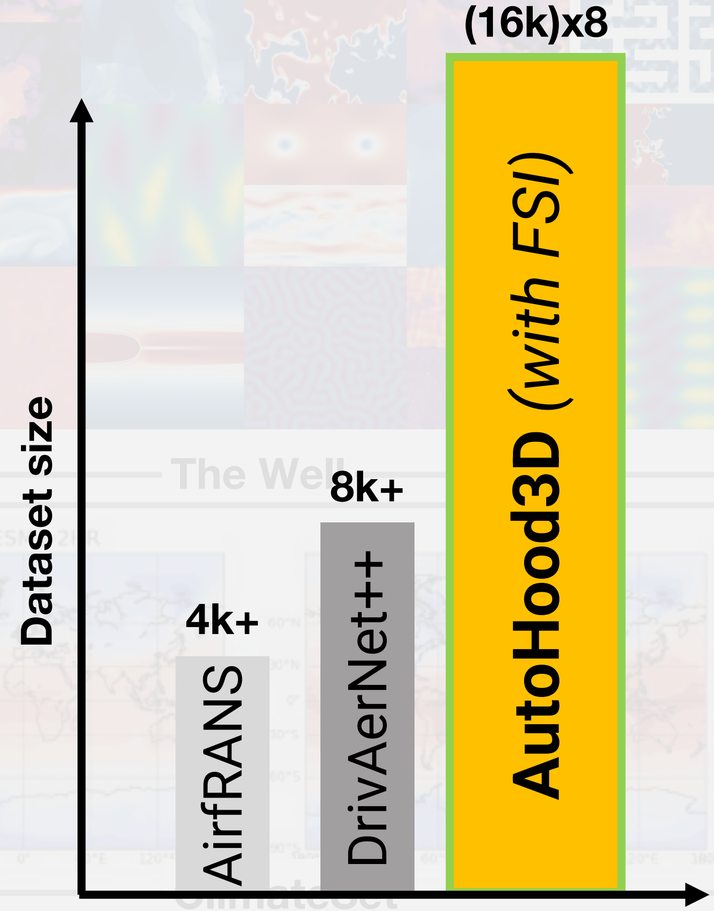
ClimateSet



Existing Physics Datasets

- Extensive geometric and solution data but **lack generative workflows** for creating new variants
- Some datasets provide generative workflows but are **2D domains with idealities**
- 3D datasets have **limited design variations**
- Datasets for **Fluid-Structure Interaction (FSI) missing**





AutoHood3D Dataset and Generation Workflow

Dataset Specs

- 16000+ parametrized hood datapoints
- 16000 x 8 temporal solutions for each impact scenario
- 1750+ engineered curves for designing new variants
- 2500+ GenAI Text-to-CAD pairs

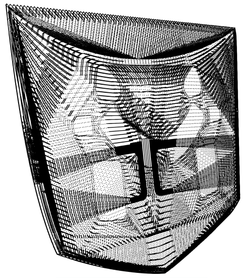
Data Generation

- Co-Simulation workflow with CFD and FEA solvers
- Solvers are fully customizable
- Additional physics for different force scenarios possible
- Curate new 3D FSI datasets

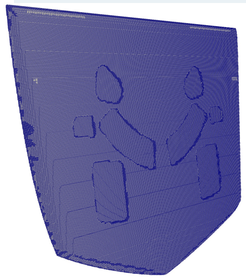
Dataset Modalities

3D Mesh (STL)

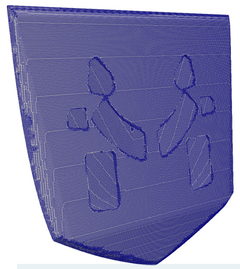
Point Cloud



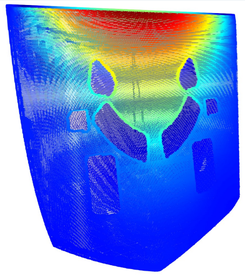
Mesh – Solid (VTP)



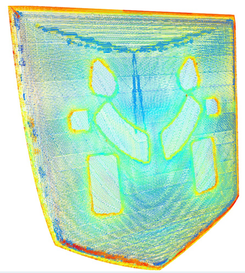
Mesh – Fluid (VTP)



Surface Field Displacement



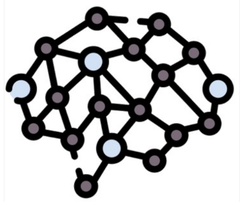
Surface Field Pressure Gradient



SFT: Paired Inputs

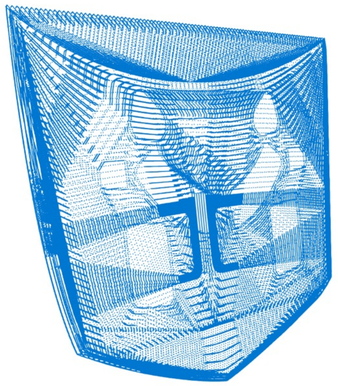
User Input

Generate a point cloud representing a hood panel with a tapered inner … with a minimum curve distance of 0.026 and a center distance of 0.043...



Language Model

Let me think through the requirements. We have a curve count of 1 per side, implying symmetrical curves…sampling of the two specified curves as well as the outer face…



Solution

AutoHood3D Dataset and Generation Workflow

Dataset Specs

- 16000+ parametrized hood datapoints
- 16000 x 8 temporal solutions for each impact scenario
- 1750+ engineered curves for designing new variants
- 2500+ GenAI Text-to-CAD pairs

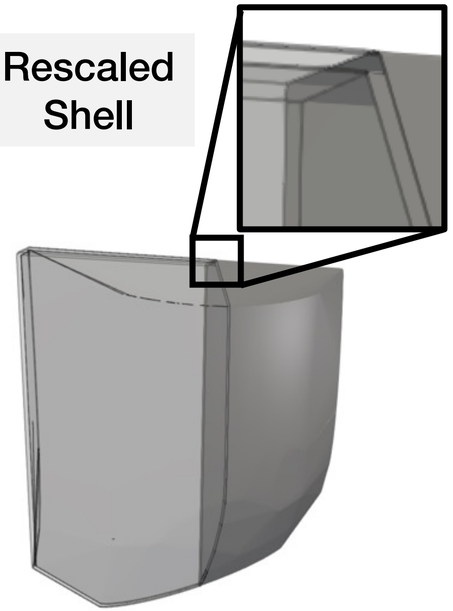
Data Generation

- Co-Simulation workflow with CFD and FEA solvers
- Solvers are fully customizable
- Additional physics for different force scenarios possible
- Curate new 3D FSI datasets

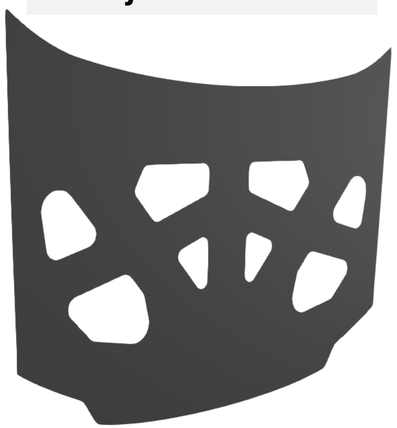
Developing Diverse Designs

STL (Inner Hood[1])

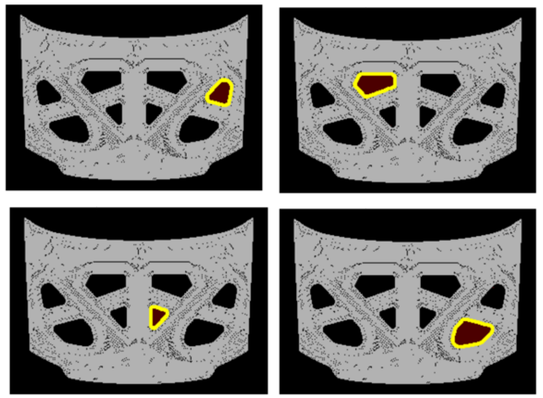
Rescaled Shell



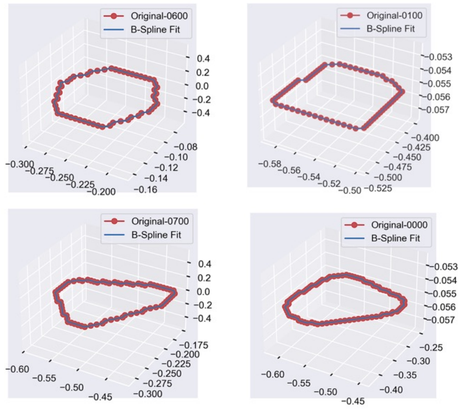
Projected Shell



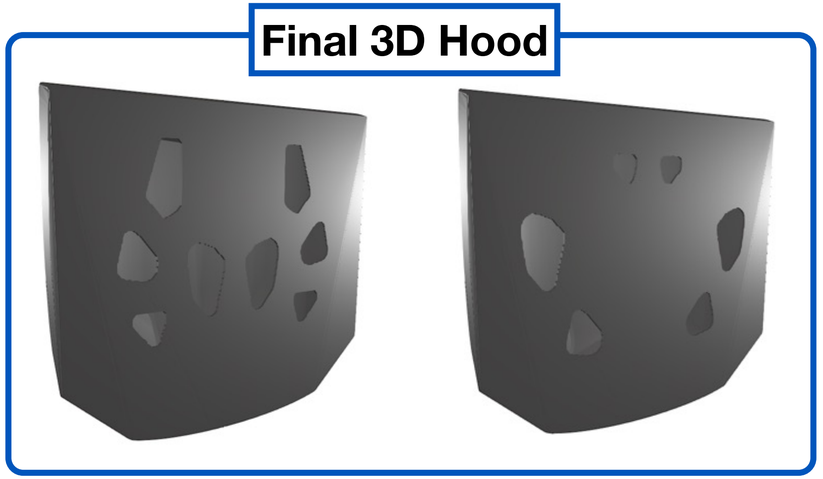
Segmentation



Database of Curves

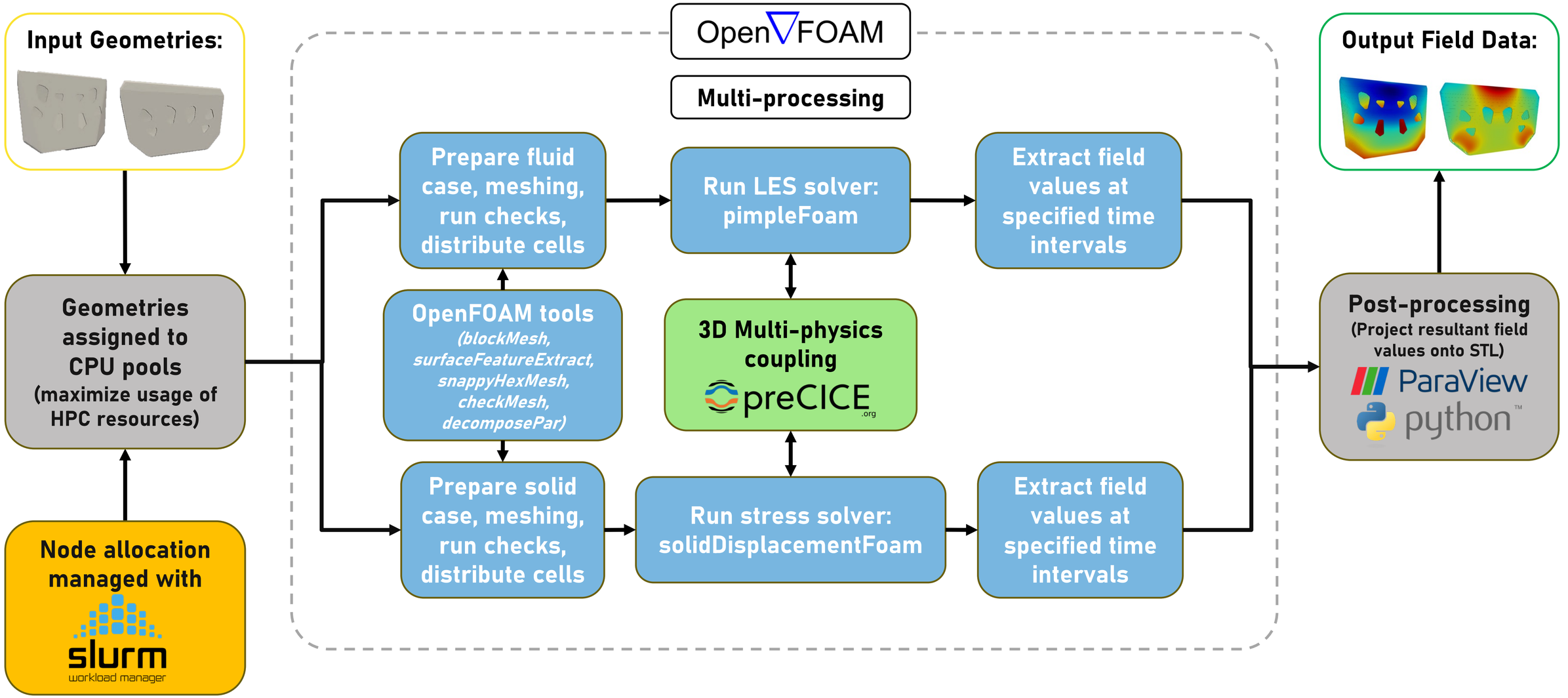


Final 3D Hood



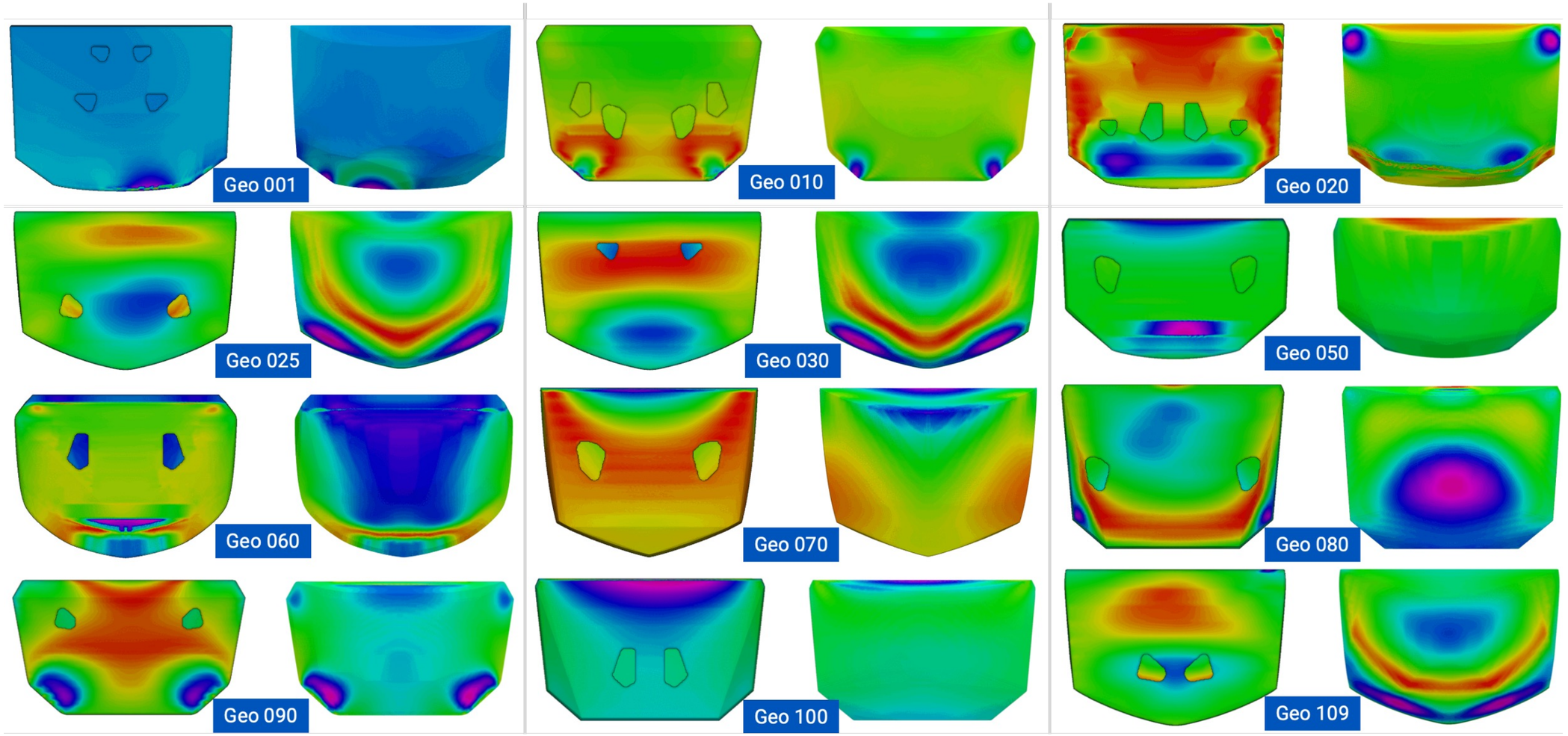
Total of 16000 variations created with cluster sampling and additional 16000 with random sampling

Co-Simulation Workflow



Simulations conducted on 16x8 NVIDIA H100 GPUs and a total of 1536 CPU cores: 5000+ core hours

Surface Fields and Features



Predicting Surface Pressure and Deformations

- Five Models:
  - PointGNNCon
  - GraphUNet
  - GraphSAGE
  - PointNet
  - MLP

- Additional tests for Homophily, Ablation and Neighbor sensitivity of the graphs included in the article

In-Distribution Test with MSE error

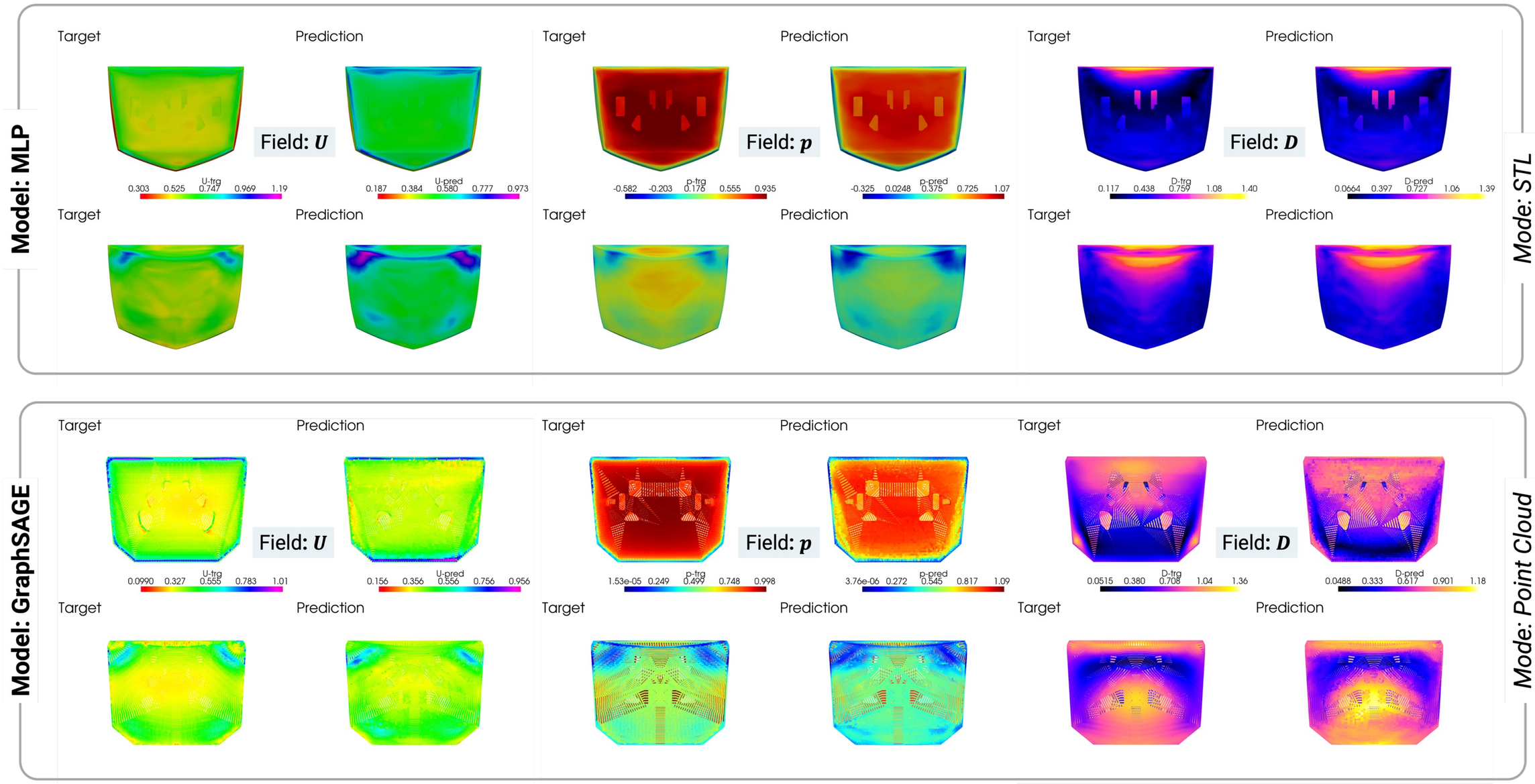
Model	U_x ($\times 10^{-2}$)	U_y ($\times 10^{-2}$)	U_z ($\times 10^{-2}$)	p ($\times 10^{-2}$)	D_x ($\times 10^{-2}$)	D_y ($\times 10^{-2}$)	D_z ($\times 10^{-2}$)
MLP	**0.25**	0.27	**0.44**	**0.37**	2.80	0.51	0.76
PointNet	0.31	**0.26**	0.48	0.55	**0.29**	**0.40**	**0.43**
GraphSAGE	4.89	1.31	2.04	4.22	14.88	3.98	6.86
Graph U-Net [2]	1.91	0.86	1.18	3.09	2.89	0.92	0.97
PointGNNConv	4.50	1.42	2.69	7.70	11.71	8.92	15.41

Out-of-Distribution Test with MSE error

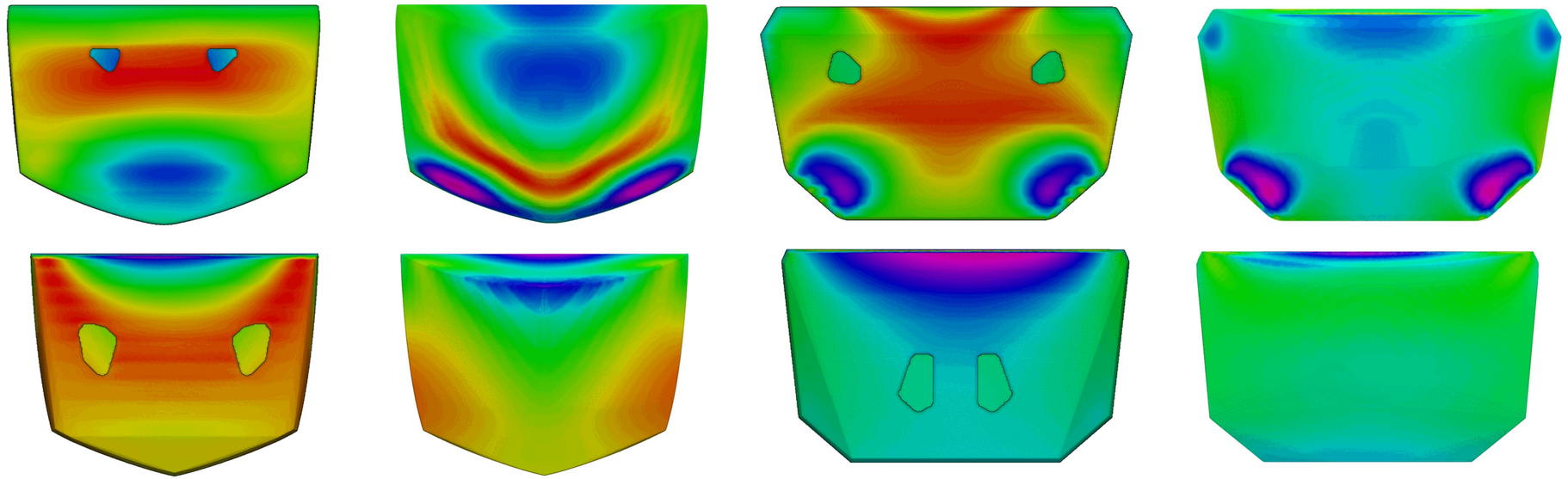
Model	U_x ($\times 10^{-2}$)	U_y ($\times 10^{-2}$)	U_z ($\times 10^{-2}$)	p ($\times 10^{-2}$)	D_x ($\times 10^{-2}$)	D_y ($\times 10^{-2}$)	D_z ($\times 10^{-2}$)
MLP	**1.49**	1.89	2.97	4.96	181.02	5.87	19.81
PointNet	3.48	2.89	6.87	15.45	**73.79**	17.83	25.55
GraphSAGE	3.24	1.81	2.65	6.99	84.34	6.07	21.71
Graph U-Net [2]	2.04	1.29	1.45	**4.05**	126.62	7.69	16.13
PointGNNConv	2.84	**1.51**	**1.20**	5.79	130.08	**4.78**	**13.67**

U: Velocity; p: Pressure; D: Displacement or Deformation and subscript x, y, z are vector components

Multi-Physics Loss Objective Needed!



AutoHood3D: A Multi-Modal Benchmark for Automotive Hood Design and Fluid–Structure Interaction



COLLEGE OF ENGINEERING
AEROSPACE ENGINEERING
UNIVERSITY OF MICHIGAN