Leveraging the HyperX API for Machine Learning with Application to Multiscale Composite Cryotank Design

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NASA Glenn Research Center

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NASA Langley Research Center
Hampton, VA

Objective

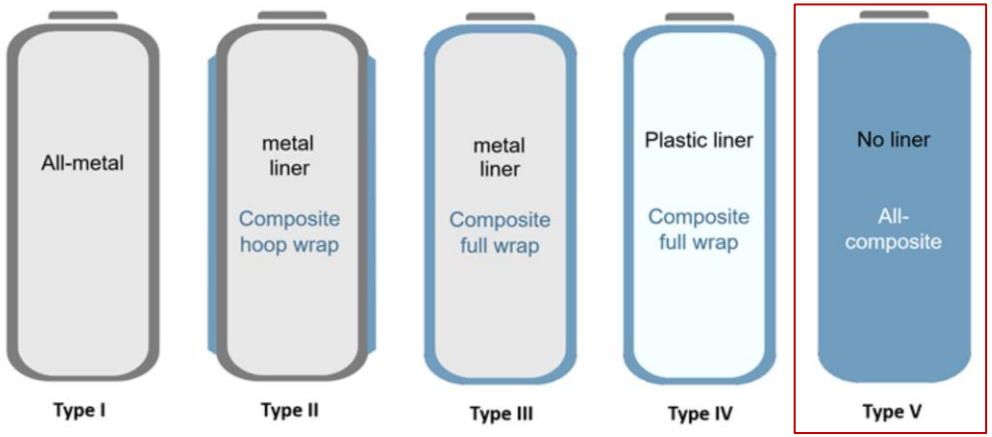
- Develop Machine Learning (ML) capability (Bayesian Optimization) for optimizing choice of Laminate Families (LFs) in HyperX
  - Enable discovery of LFs
- Application to NASA composite Cryogenic Hydrogen Tank with multiple options for the thermoplastic matrix material

Agenda

- Composite cryotanks and laminate families
- Material modeling to obtain ply properties
- Workflows with HyperX in-the-loop
- Trained ML model
- Optimized cryotank design

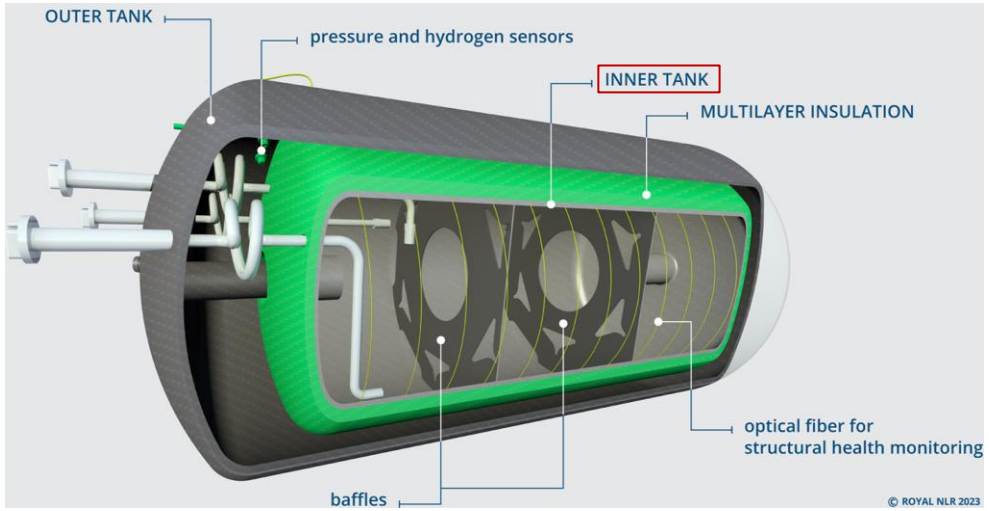
Cryogenic Hydrogen Tanks

Pressure Vessel Classifications



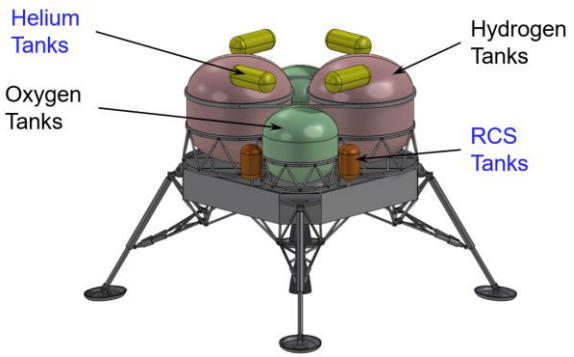
CompositesWorld, 2021

Cryotank



Space Applications

Space Shuttle External Tank



NASA FLEX-2 Lander Tank Configuration

SLS Core Stage Liquid Hydrogen Tank

NASA/Boeing Composite Cryotank Technologies and Demonstration 5.5 m cryotank (2015)

Cryotanks for Hydrogen Powered Aircraft

E.J. Adler and J.R.R.A. Martins

Progress in Aerospace Sciences 141 (2023) 100922

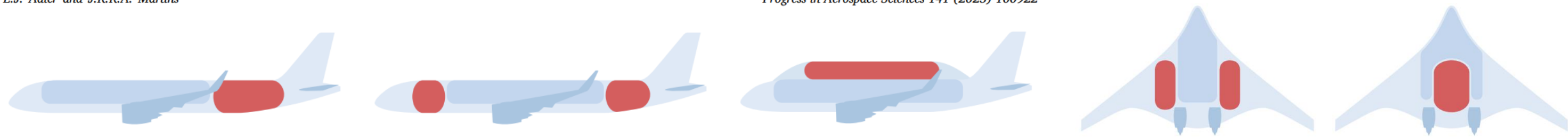


Fig. 7.1. Proposed tube-and-wing configurations store the hydrogen in the fuselage. The darker area of the fuselage shows the passenger cabin.

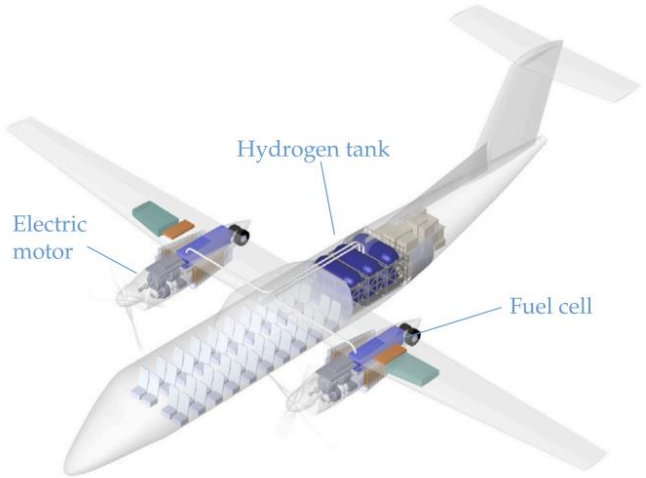
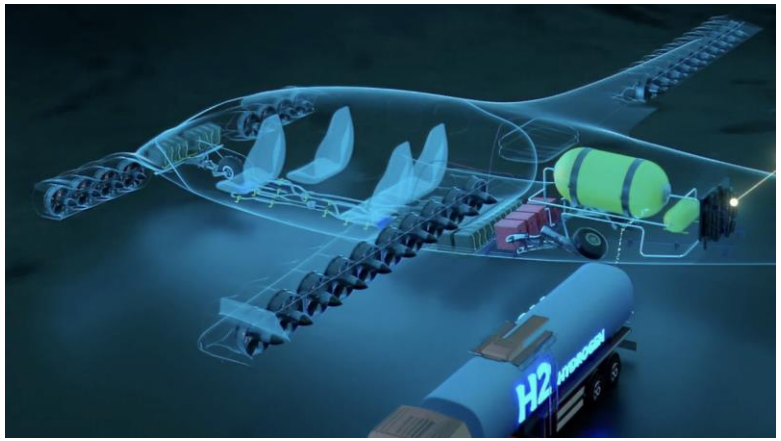


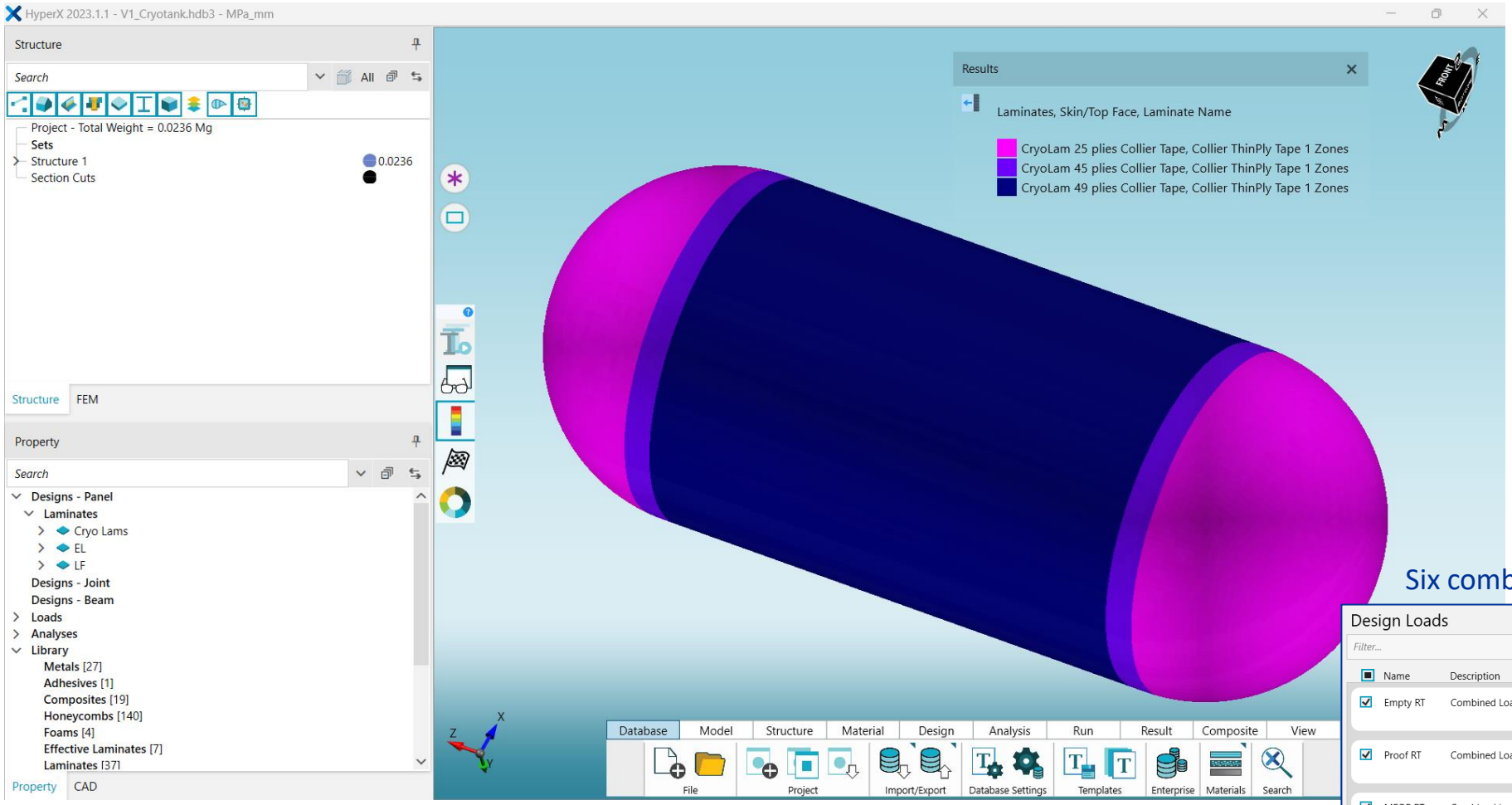
Fig. 2.3. Universal Hydrogen's turboprop fuel cell retrofit concept (Universal Hydrogen image).

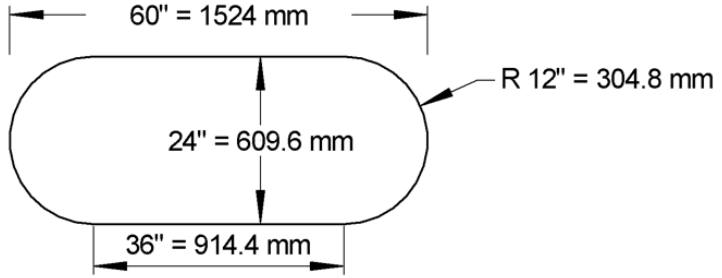
Fig. 2.5. Airbus' ZEROe hydrogen-powered turbofan concept (Airbus image).



https://www.thecooldown.com/green-tech/futuristic-aircraft-designs-estol-evtol-hybrid-hydrogen-planes/

NASTRAN Cryotank model in HyperX





- Maximum Expected Operating Pressure (MEOP) = 150 psi

Six combined mech/therm load cases, SF of 2 (MEOP)

Design Loads

Name	Description	Type	$T_{Initial}$(°C)	$T_{Analysis}$(°C)	LF_{Lim}	LF_{Ult}	Multiplier	Subcase	Rundeck	Subcase Type	Subcase Description
Empty RT	Combined Load Case; Mec...	Static	Analysis	20	1 1	2 1	1 1	7 10	1 1	Static Thermal	LC7_EMPTY_P_ONLY LC10_RT_T_ONLY
Proof RT	Combined Load Case; Mec...	Static	Analysis	20	1 1	1 1	1 1	8 10	1 1	Static Thermal	LC8_PROOF_P_ONLY LC10_RT_T_ONLY
MEOP RT	Combined Load Case; Mec...	Static	Analysis	20	1 1	2 1	1 1	9 10	1 1	Static Thermal	LC9_MEOP_P_ONLY LC10_RT_T_ONLY
Empty Cryo	Combined Load Case; Mec...	Static	20	-253	1 1	2 1	1 1	7 11	1 1	Static Thermal	LC7_EMPTY_P_ONLY LC11_CRYO_T_ONLY
Proof Cryo	Combined Load Case; Mec...	Static	20	-253	1 1	1 1	1 1	8 11	1 1	Static Thermal	LC8_PROOF_P_ONLY LC11_CRYO_T_ONLY
MEOP Cryo	Combined Load Case; Mec...	Static	20	-253	1 1	2 1	1 1	9 11	1 1	Static Thermal	LC9_MEOP_P_ONLY LC11_CRYO_T_ONLY

HyperX Laminate Families (LFs)

Example LF

Laminate Family: Polyimide_P166_L2_X6Xb0E

Name: Polyimide_P166_L2_X6Xb0E

Layer	Thickness (in)	Material	Angle	1	2	3	4	5	6	7	8	9
1	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	10	10	10	10	10	10	10	10	10	10
2	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
3	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	10	10	10	10	10	10	10	10	10	
4	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-10	-10	-10	-10	-10	-10	-10	-10	-10	
5	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	20	20	20	20	20	20	20	20		
6	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-20	-20	-20	-20	-20	-20	-20	-20		
7	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	20	20	20	20	20	20	20			
8	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-20	-20	-20	-20	-20	-20	-20			
9	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	30	30	30	30	30	30				
10	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-30	-30	-30	-30	-30	-30				
11	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	30	30	30	30	30					
12	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-30	-30	-30	-30	-30					
13	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	40	40	40	40						
14	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-40	-40	-40	-40						
15	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	40	40	40							
16	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-40	-40	-40							
17	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	50	50								
18	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-50	-50								
19	0.004	AS4 Unidirectional_Polyimide_VF60_NG56 - Th	60	60	60	60	60	60	60	60	60	60
20	0.004	AS4 Unidirectional_Polyimide_VF60_NG56 - Th	-60	-60	-60	-60	-60	-60	-60	-60	-60	-60
21	0.004	AS4 Unidirectional_Polyimide_VF60_NG56 - Th	0	0	0	0	0	0	0	0	0	0
22	0.004	AS4 Unidirectional_Polyimide_VF60_NG56 - Th	-60	-60	-60	-60	-60	-60	-60	-60	-60	-60
23	0.004	AS4 Unidirectional_Polyimide_VF60_NG56 - Th	60	60	60	60	60	60	60	60	60	60
24	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-50	-50								
25	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	50	50								
26	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-40	-40	-40							
27	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	40	40	40							
28	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-40	-40	-40	-40						
29	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	40	40	40	40						
30	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-30	-30	-30	-30	-30					
31	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	30	30	30	30	30					
32	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-30	-30	-30	-30	-30	-30				
33	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	30	30	30	30	30	30				
34	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-20	-20	-20	-20	-20	-20				
35	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	20	20	20	20	20	20	20			
36	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-20	-20	-20	-20	-20	-20	-20			
37	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	20	20	20	20	20	20	20			
38	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-10	-10	-10	-10	-10	-10	-10	-10	-10	
39	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	10	10	10	10	10	10	10	10	10	
40	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-10	-10	-10	-10	-10	-10	-10	-10	-10	

Current HyperX LF trades – evaluated 190 LFs, 25 Layups Each, 15 Zones in ~15 min on laptop

Laminate Family Design Study

Input Selection

Zones: 1:11.13:16

Designs: Zone

Input Laminate Families

DD_Hourglass_0,0 (25)

DD_Hourglass_0,10 (25)

DD_Hourglass_0,15 (25)

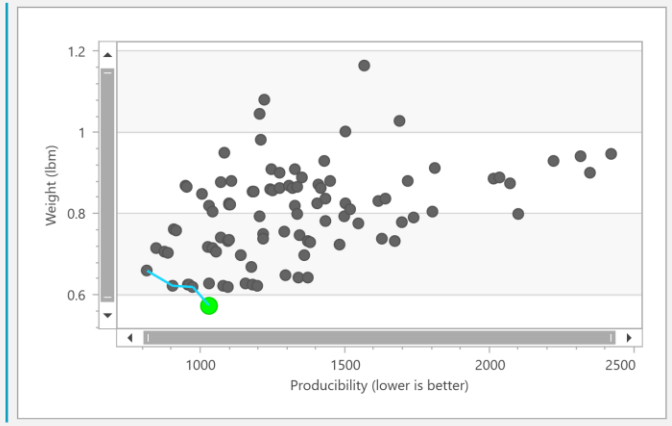
Trials to run: 190

Run Trials

Output

Producibility Complexity: AFP and Tape | Hand Fabric and Uni's

Trial	FamilyName	Weight	Metric A	Metric B	Metric C	Plies	Ply Cuts
	Inputs		Producibility (lower is better)				
7	DD_Hourglass_0,35	0.783	1436.7642	905.3599		112	5200
8	DD_Hourglass_0,40	0.698	1362.1507	843.9242		104	4484
9	DD_Hourglass_0,45	0.645	1341.765	818.9872		100	3948
10	DD_Hourglass_0,5	1.165	1570.146	1006.9251		136	7028
11	DD_Hourglass_0,50	0.624	1198.4151	706.4425		88	3944
12	DD_Hourglass_0,55	0.621	1096.6512	629.2947		80	3780
13	DD_Hourglass_0,60	0.576	1032.5109	591.8723		76	3092
14	DD_Hourglass_0,65	0.624	907.0294	508.6919		68	3416
15	DD_Hourglass_0,70	0.661	818.4224	457.3504		64	3400
16	DD_Hourglass_0,75	0.716	848.9081	480.2574		68	3948
17	DD_Hourglass_0,80	0.87	952.9579	552.5334		80	5300
18	DD_Hourglass_0,85	1.083	1222.2131	688.8131		100	6564
19	DD_Hourglass_0,90	1.185	1117.7388	658.2592		100	7432
20	DD_Hourglass_10,10	0.911	1248.29	895.2371		116	5796



Selected Trial

General	
Family	DDHourglass_0,60
Weight (lbm)	0.576
Producibility (lower is better)	1032.5109

Critical Margins of Safety	
Criteria	Composite, Tsai-Hahn
Zone	Created Zone 8
Margin	0.0046

Laminate Statistics	
Plies	76
Sequences	64
Ply Cuts	3092

Producibility (lower is better)	Laminate	Avg Ply
Metric A	1032.5109	13.5857
Metric B	591.8723	7.7878

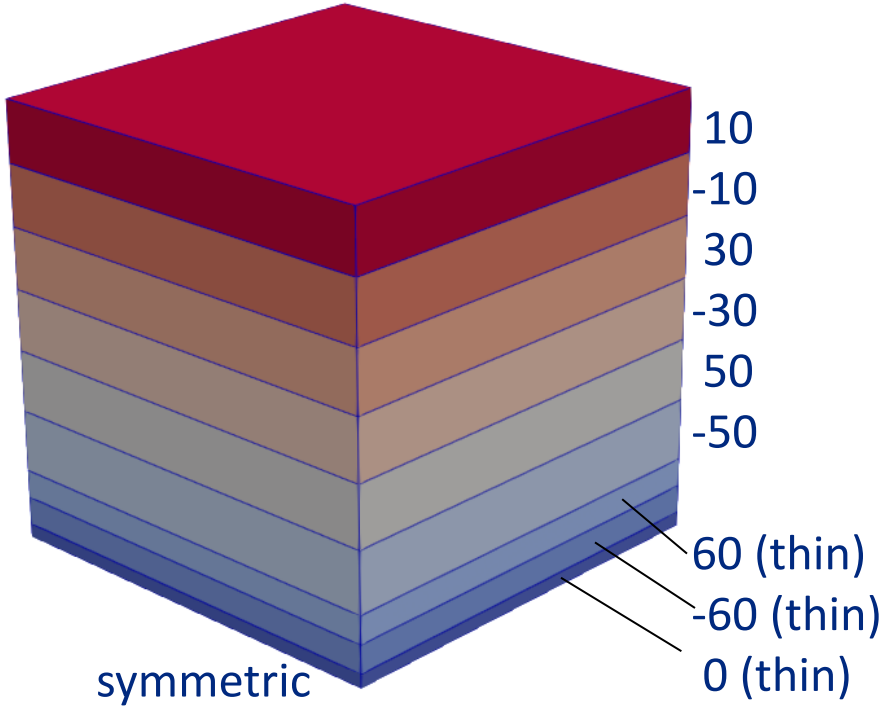
Make Design | Update Design | Close

- These LF trades can take a long time
- No guarantee user has included best LFs

CryoLam Layups for Reduced Permeability

- "CryoLam" layups established in NASA/Boeing Composite Cryotank Technologies Demonstration (~2015)
- Avoids quads (0/±45/90) due to poor microcracking performance at cryo
- ± angle pairs, with gradual angle changes
- Thin middle ply pack $[\pm 60,0\_]_s$

- Using CryoLam concept, but employing new rules to generate candidate CryoLam laminate families



Laminate Family Generator for Cryotank Applications

- Define 4 sets of rules for generating CryoLam Laminate families
  - Permutations of rules for +/- angles and ply repetition until max number of plies is met
  - Rules are fully customizable within Python scripts

+/- Pairs Adjacent	**Stacks of angles repeat**
+/- Pairs Not Adjacent	**Angles individually repeat**

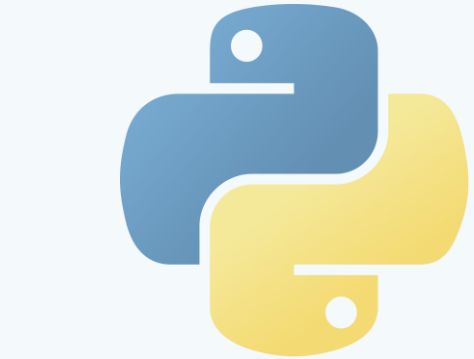
Ply	MSS	1	2	3	4	5	6	7
1	10							
2	-10							
3	20	20						
4	-20	-20						
5	30	30	30					
6	-30	-30	-30					
7	40	40	40	40				
8	-40	-40	-40	-40				
9	50	50	50	50	50			
10	-50	-50	-50	-50	-50			
11	-50	-50	-50	-50	-50	-50		
12	50	50	50	50	50	50		
13	-40	-40	-40	-40	-40	-40	-40	
14	40	40	40	40	40	40	40	
15	-30	-30	-30	-30	-30	-30	-30	-30
16	30	30	30	30	30	30	30	30
17	-20	-20	-20	-20	-20	-20	-20	-20
18	20	20	20	20	20	20	20	20
19	-10	-10	-10	-10	-10	-10	-10	-10
20	10	10	10	10	10	10	10	10
21	10	10	10	10	10	10	10	10
22	-10	-10	-10	-10	-10	-10	-10	-10
23	20	20	20	20	20	20	20	20
24	-20	-20	-20	-20	-20	-20	-20	-20
25	30	30	30	30	30	30	30	30
26	-30	-30	-30	-30	-30	-30	-30	-30
27	40	40	40	40	40	40	40	40
28	-40	-40	-40	-40	-40	-40	-40	-40
29	50	50	50	50	50	50	50	50
30	-50	-50	-50	-50	-50	-50	-50	-50
31	60	60	60	60	60	60	60	60
32	-60	-60	-60	-60	-60	-60	-60	-60
33	0	0	0	0	0	0	0	0

Overall Workflow

1. Generate Ply Level Temperature Dependent Material Properties

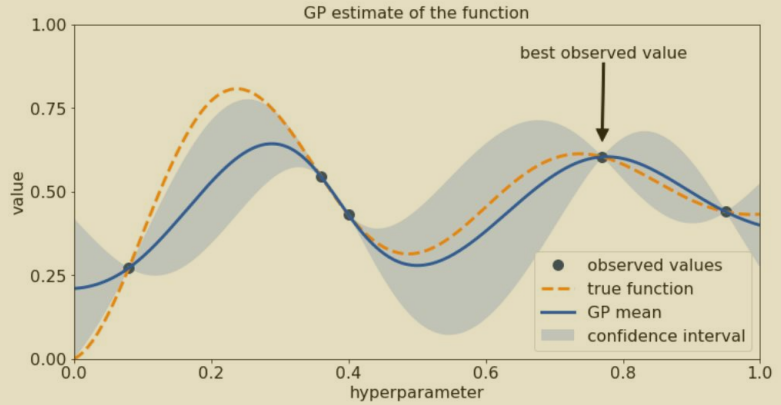
NASMAT
NASA Multiscale Analysis Tool

2. Generate Training Data Evaluating Laminate Families



HYPERX
Center your design

3. Develop Machine Learning Algorithm For Determining Best Laminate Family

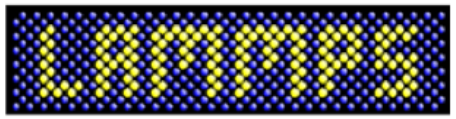


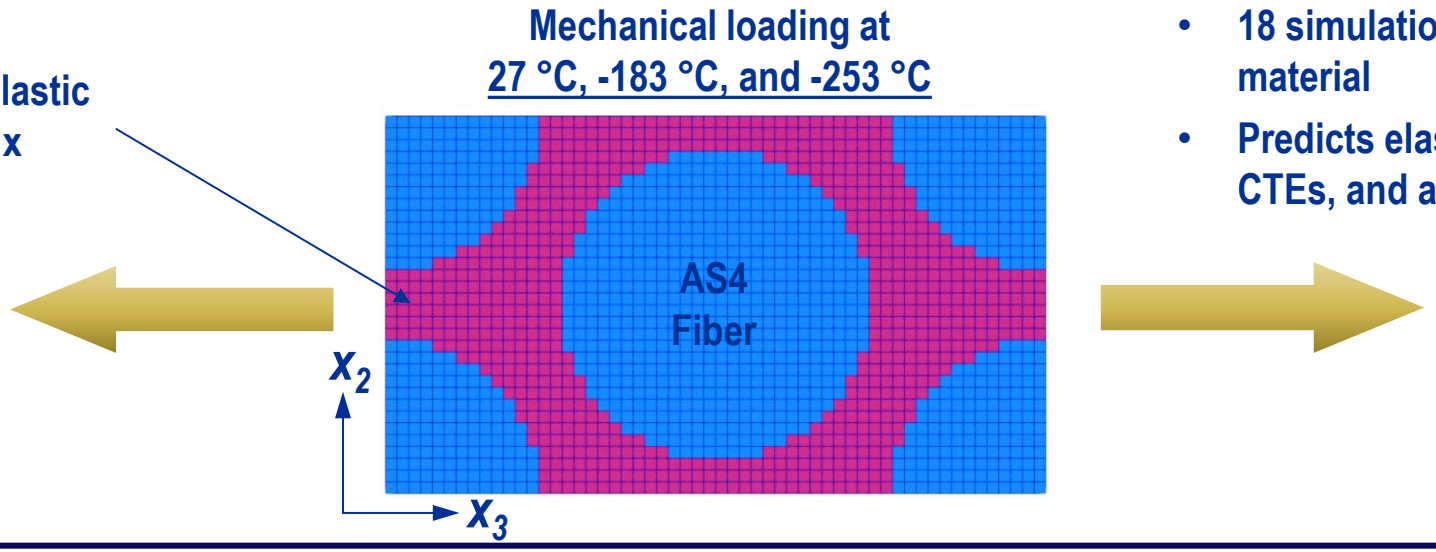
Prior to optimization to establish ply properties

In-the-loop Bayesian optimization

Cryo Performance of Thermoplastic Matrix Composites

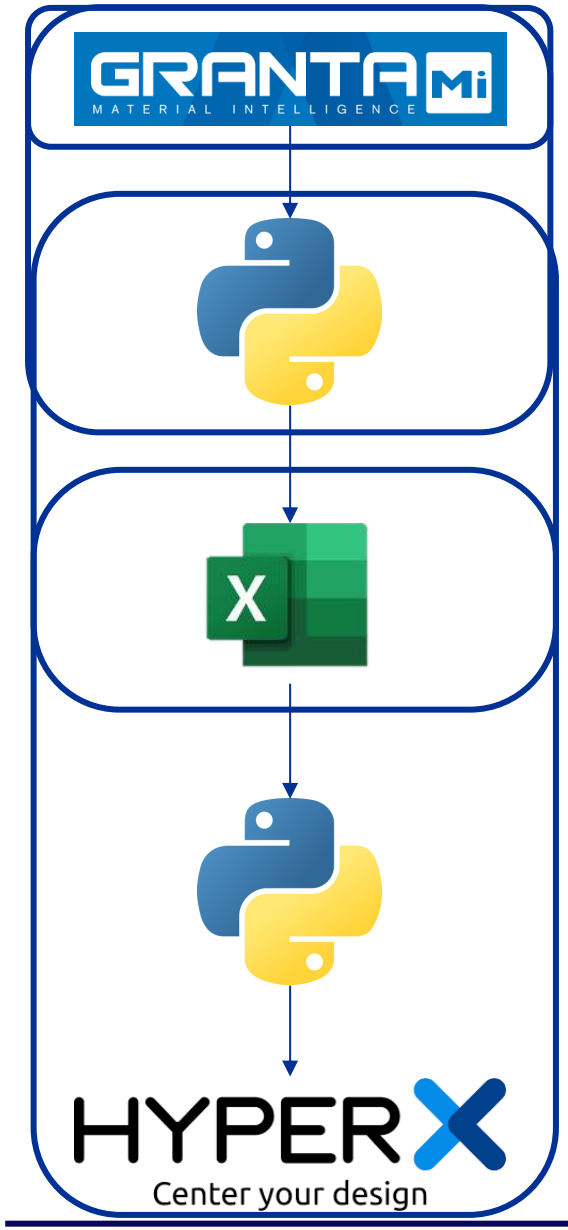
- Thermoplastic composites have been targeted for cryotank applications mainly due to their toughness (to resist microcracking)
- Mich. Tech. molecular dynamics simulations of thermoplastics at 27 °C, -183 °C, and -253 °C
  - PEEK, Arkema Elium, LM-PAEK, PEKK, Ultem 100 PEI, Huntsman Matrimid 5218 Polyimide
- Composites with MD materials and AS4 carbon fiber, Vf = 0.6
- Locally brittle subvolume elimination damage (does not consider matrix toughness)
- Model set-up and execution is scripted
- Apply all components of loading individually (one by one)





- 18 simulations per matrix material
- Predicts elastic properties, CTEs, and allowables

Connecting Granta MI with HyperX



- [illegible]

Laminate Family

```
db.ImportMaterialsFromExcel(fname)
```

Laminate Families

Search...

Profile: All

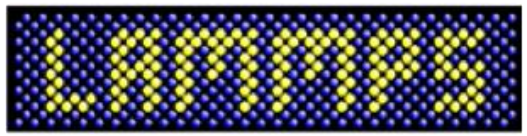
Laminate Family Name	# Laminates	Min Plies	Max Plies	Pattern
Amorphous PEEK_P205_L1_3pSEZI	51	5	205	None
Amorphous PEEK_P205_L1_9jZC30	51	5	205	None
Amorphous PEEK_P205_L3_5iXAUd	101	5	205	None
Amorphous PEEK_P205_L3_FVIpaS	101	5	205	None
Amorphous PEEK_P205_L4_Kf5mxy	101	5	205	None
Amorphous PEEK_P205_L4_N2x6vj	101	5	205	None
Amorphous PEEK_P213_L2_79Tbqr	53	5	213	None
Amorphous PEEK_P221_L1_eYShA8	55	5	221	None
Amorphous PEEK_P221_L3_FpVLhU	109	5	221	None
Amorphous PEEK_P221_L3_a48gNd	109	5	221	None
Amorphous PEEK_P221_L4_0VA7Kn	109	5	221	None
Amorphous PEEK_P221_L4_hOKaUK	109	5	221	None
Amorphous PEEK_P229_L1_oOzyC0	57	5	229	None
Amorphous PEEK_P229_L1_siHh3e	57	5	229	None
Amorphous PEEK_P229_L1_tnDU9B	57	5	229	None
Amorphous PEEK_P229_L3_7L3ge7	113	5	229	None
Amorphous PEEK_P229_L3_X2vrqY	113	5	229	None
Amorphous PEEK_P229_L3_bRHRGR	113	5	229	None
Amorphous PEEK_P229_L4_UVBwFW	113	5	229	None
Amorphous PEEK_P245_L1_ygW2w4	61	5	245	None
Amorphous PEEK_P245_L3_bESLtP	121	5	245	None
Amorphous PEEK_P261_L1_JQESuF	65	5	261	None
Bisphenol A Epoxy_P205_L1_WbD5EI	51	5	205	None
Bisphenol A Epoxy_P213_L2_eOgdTI	53	5	213	None
Bisphenol A Epoxy_P229_L1_3dISiG	57	5	229	None

Create | Edit... | Copy... | Delete... | Import | Export... | Cancel

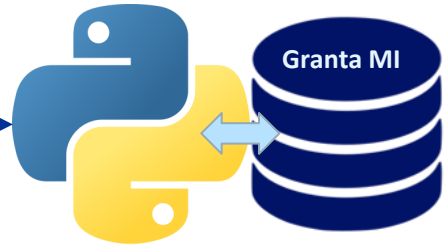
```
return mat_list
```

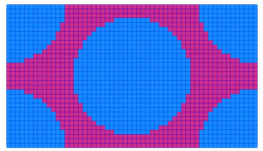
Material Model Type | Transversely Isotropic

Materials Definition Workflow

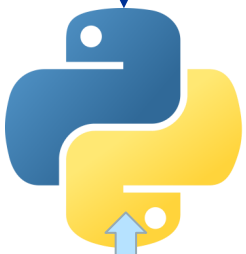


Populate Database with Temperature Dependent Matrix Materials Properties





Select a matrix from the database, define the volume fraction, and generate the RUC and material model



For each temperature run six NASMAT simulations to failure:

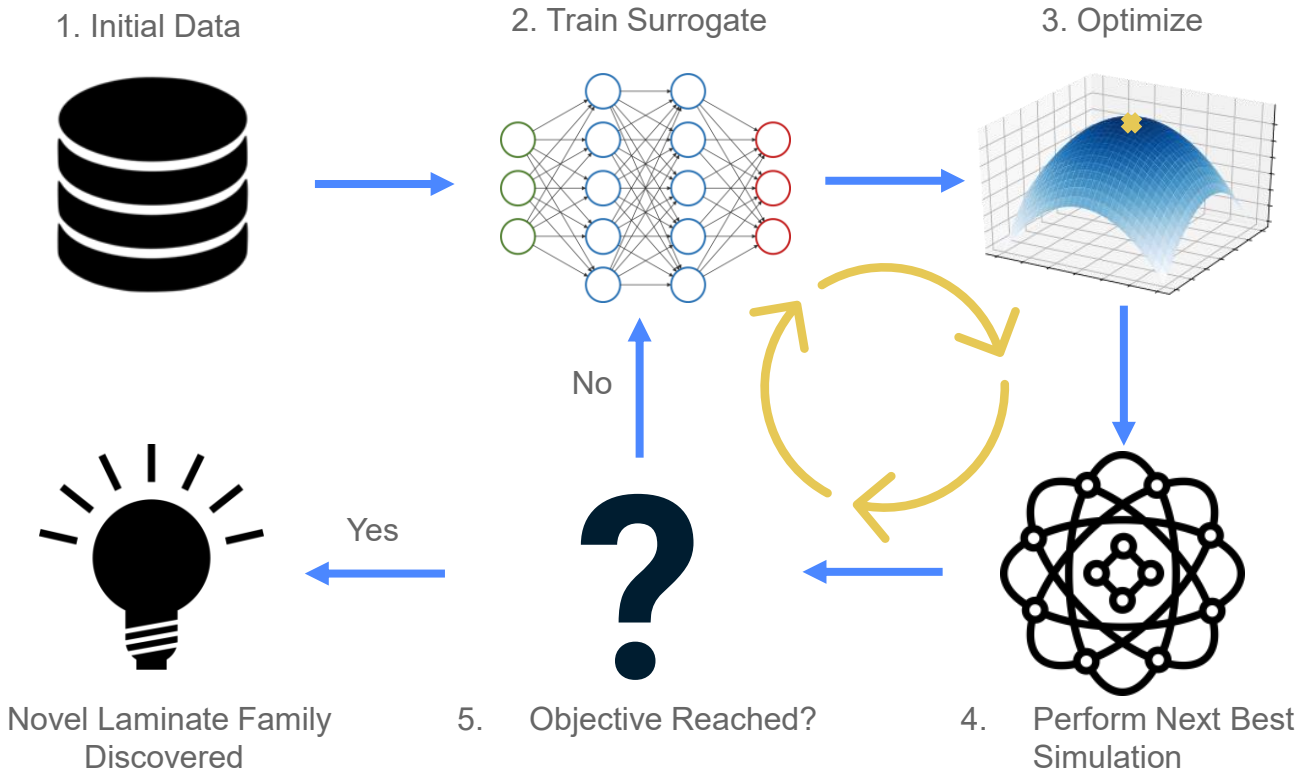
- Strain controlled loading – 11, 22, 33, 13, 23, and 12 components – until failure

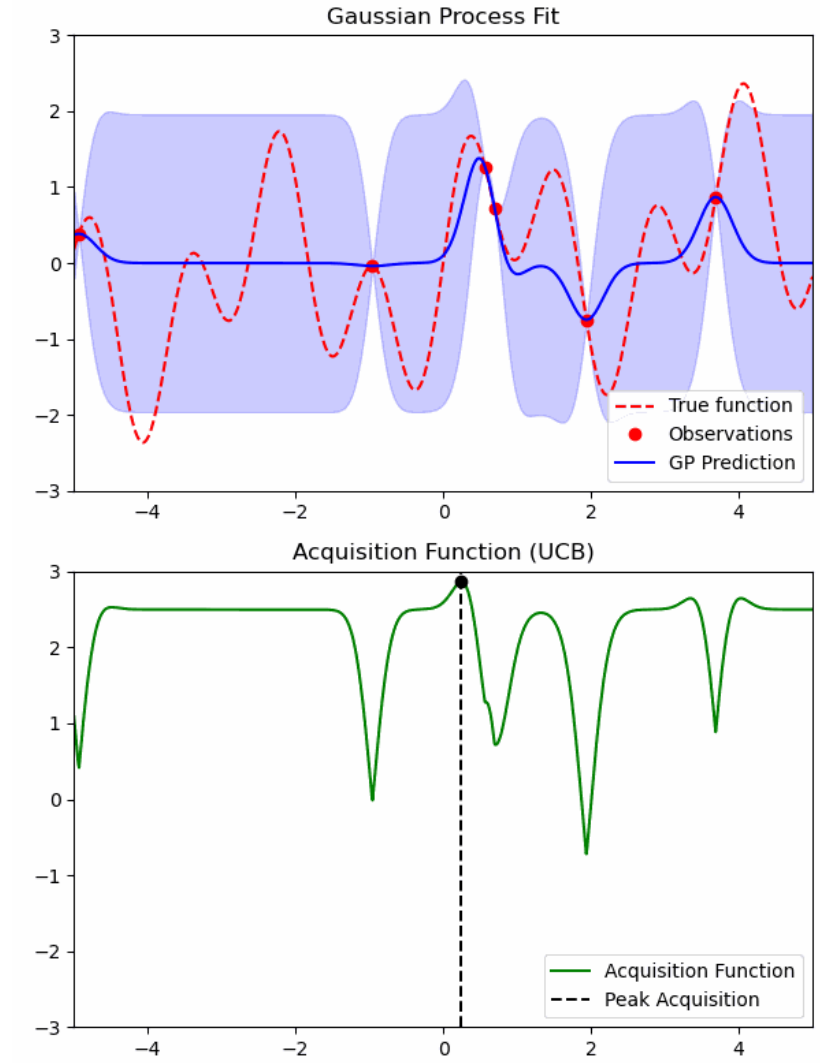
Repeat for All Matrix Materials in the Database

Write **Ply Material Model** to the database

- HyperX Requires Ply Material Properties

Bayesian Optimization Workflow





Bayesian Optimization For Cryotank Design

Bayesian Optimization: Find the best material, angle difference between plies, and laminate family configuration by minimizing the objective function

Objective Function: Find the minimum weight for a given material/laminate family using HyperX Sizing

1. Import the Laminate Family and Material Properties
2. Run HyperX Sizing
3. Collect weight (w) and minimum margin (m) for every zone
4. Return "Score" for the HyperX-optimized design

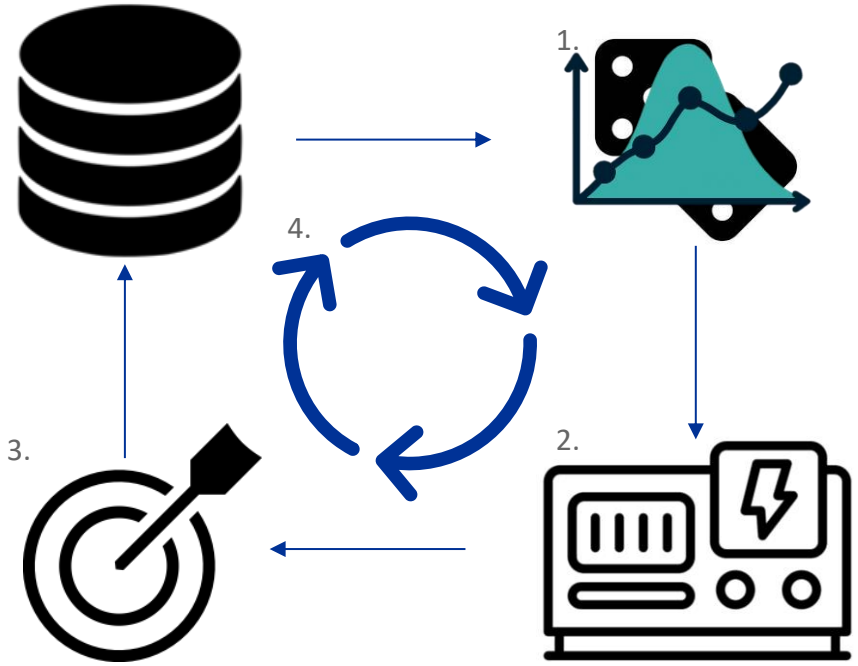
$$score = \sum_{i=1}^{n} \begin{cases} w_i & m_i > 0 \\ 100 * w_1 & m_i < 0 \end{cases}$$

HyperX API Function	Purpose
db = hx.Open(db_file)	Open the HyperX Database
db.ImportMaterialsFromExcel(file)	Import the material properties and laminate family
project = db.SelectProject(proj_name)	Get the project
db.DesignProperties.Get(dprop). DesignVariables.Get(1). RemoveSizingMaterials()	Remove the previous laminate family
db.DesignProperties.Get(dprop). DesignVariables.Get(1).AddMaterials(LF_ID)	Add the new laminate family
project.SizeZones()	Resize the zones for optimal laminate
zones = project.Zones	Get all zones information
zone = zones.Get(ids)	Get an individual zone
margin = zone.GetMinimumMargin()	Get the minimum margin for the zone
weight = zone.Weight	Get the weight of the zone

Bayesian Optimization Workflow

Initial Data

1. Randomly select a material, angle difference, and laminate family rule set
2. Generate the laminate family and HyperX Import File
3. Evaluate the optimal stacking sequence with HyperX
4. Repeat for n (10) iterations to build an initial data model for Bayesian Optimization

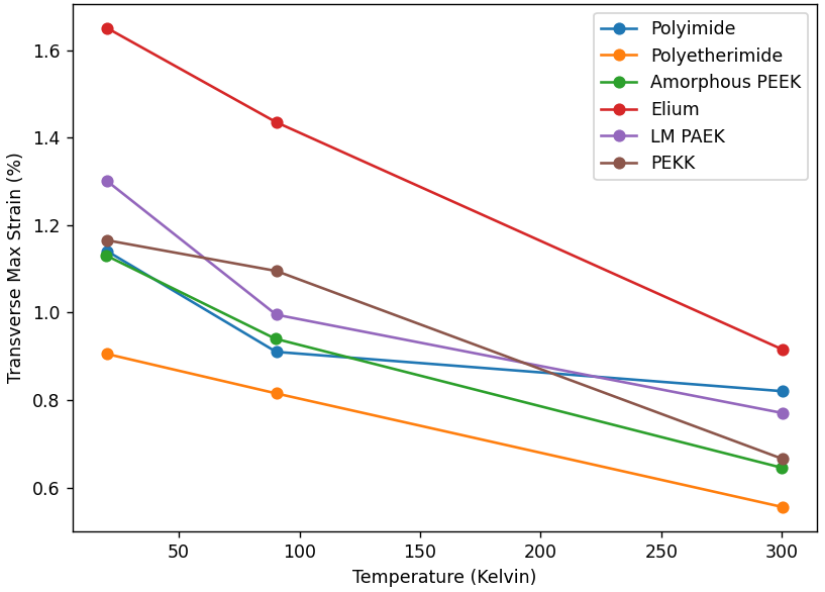


Bayesian Optimization

1. Use BayBE Python Package to determine the next best material, angle difference, and laminate family rule set to try
2. Generate the laminate family and HyperX Import File
3. Evaluate the optimal stacking sequence with HyperX
4. Repeat for n iterations until model converges on a best global configuration

Design Space in this Study

6 Characterized Matrix Materials



13 Angle Increments: $3° \leq \delta < 15°$

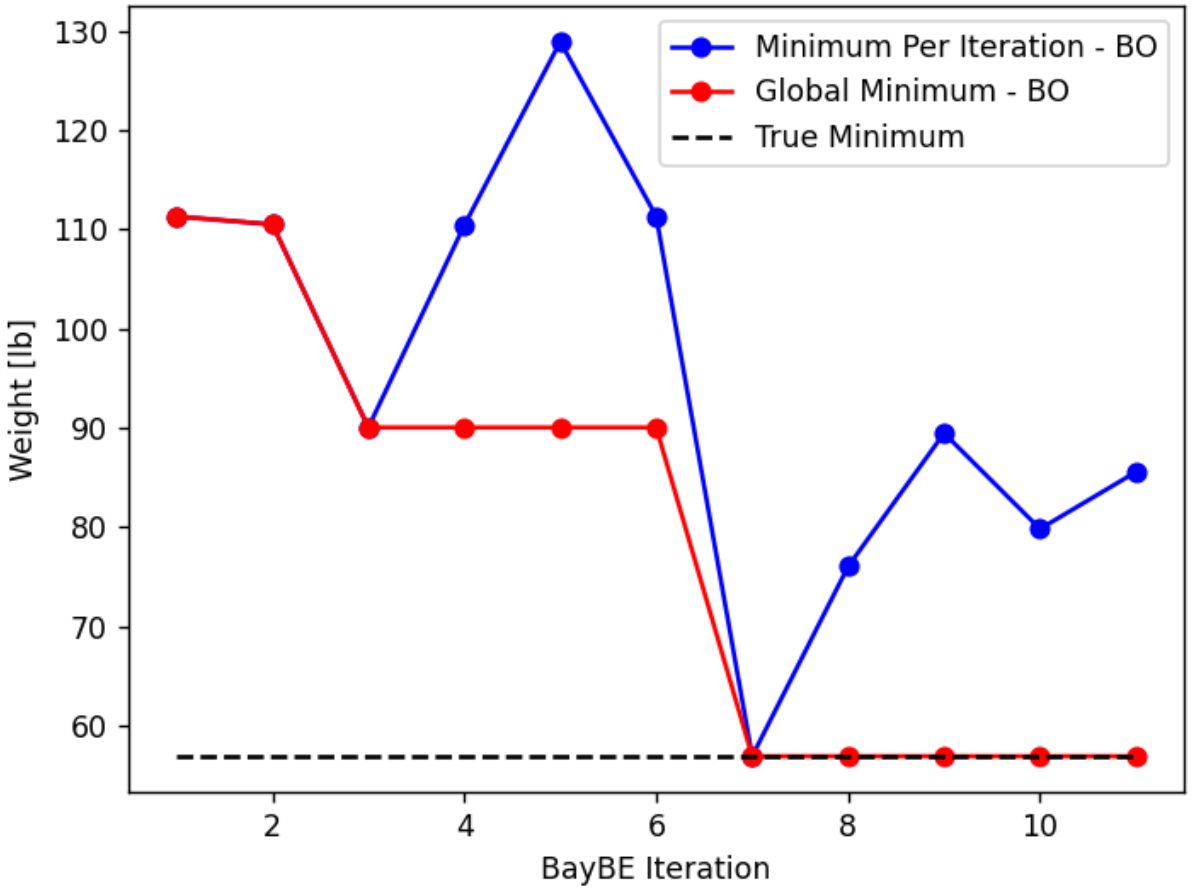
Ply	MSS
1	δ
2	-δ
3	δ
4	-δ
5	2δ
6	-2δ
7	2δ
8	-2δ
9	⋮
10	-60
11	60
12	0
13	60
14	-60
15	⋮
16	-2δ
17	2δ
18	-2δ
19	2δ
20	-δ
21	δ
22	-δ
23	δ

4 Laminate Family Classifications

Layer	Thickness (in)	Material	Angle	1	2	3	4	5	6	7	8	9
1	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	10	10	10	10	10	10	10	10	10	10
2	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
3	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	10	10	10	10	10	10	10	10	10	
4	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-10	-10	-10	-10	-10	-10	-10	-10	-10	
5	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	20	20	20	20	20	20	20	20		
6	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-20	-20	-20	-20	-20	-20	-20	-20		
7	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	20	20	20	20	20	20	20			
8	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-20	-20	-20	-20	-20	-20	-20			
9	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	30	30	30	30	30	30				
10	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-30	-30	-30	-30	-30	-30				
11	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	30	30	30	30	30					
12	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-30	-30	-30	-30	-30					
13	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	40	40	40	40						
14	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-40	-40	-40	-40						
15	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	40	40	40							
16	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-40	-40	-40							
17	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	50	50								
18	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-50	-50								
21	0.004	AS4 Unidirectional_Polyimide_VF60_NG56 - Th	60	60	60	60	60	60	60	60	60	60
22	0.004	AS4 Unidirectional_Polyimide_VF60_NG56 - Th	-60	-60	-60	-60	-60	-60	-60	-60	-60	-60
23	0.004	AS4 Unidirectional_Polyimide_VF60_NG56 - Th	0	0	0	0	0	0	0	0	0	0
24	0.004	AS4 Unidirectional_Polyimide_VF60_NG56 - Th	-60	-60	-60	-60	-60	-60	-60	-60	-60	-60
25	0.004	AS4 Unidirectional_Polyimide_VF60_NG56 - Th	60	60	60	60	60	60	60	60	60	60
28	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-50	-50								
29	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	50	50								
30	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-40	-40	-40							
31	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	40	40	40							
32	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-40	-40	-40	-40						
33	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	40	40	40	40						
34	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-30	-30	-30	-30	-30					
35	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	30	30	30	30	30					
36	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-30	-30	-30	-30	-30	-30				
37	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	30	30	30	30	30	30				
38	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-20	-20	-20	-20	-20	-20	-20			
39	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	20	20	20	20	20	20	20			
40	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-20	-20	-20	-20	-20	-20	-20	-20		
41	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	20	20	20	20	20	20	20	20		
42	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-10	-10	-10	-10	-10	-10	-10	-10	-10	
43	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	10	10	10	10	10	10	10	10	10	
44	0.008	AS4 Unidirectional_Polyimide_VF60_NG56	-10	-10	-10	-10	-10	-10	-10	-10	-10	

312 Configurations → ~6500 Laminate Candidates Per Zone

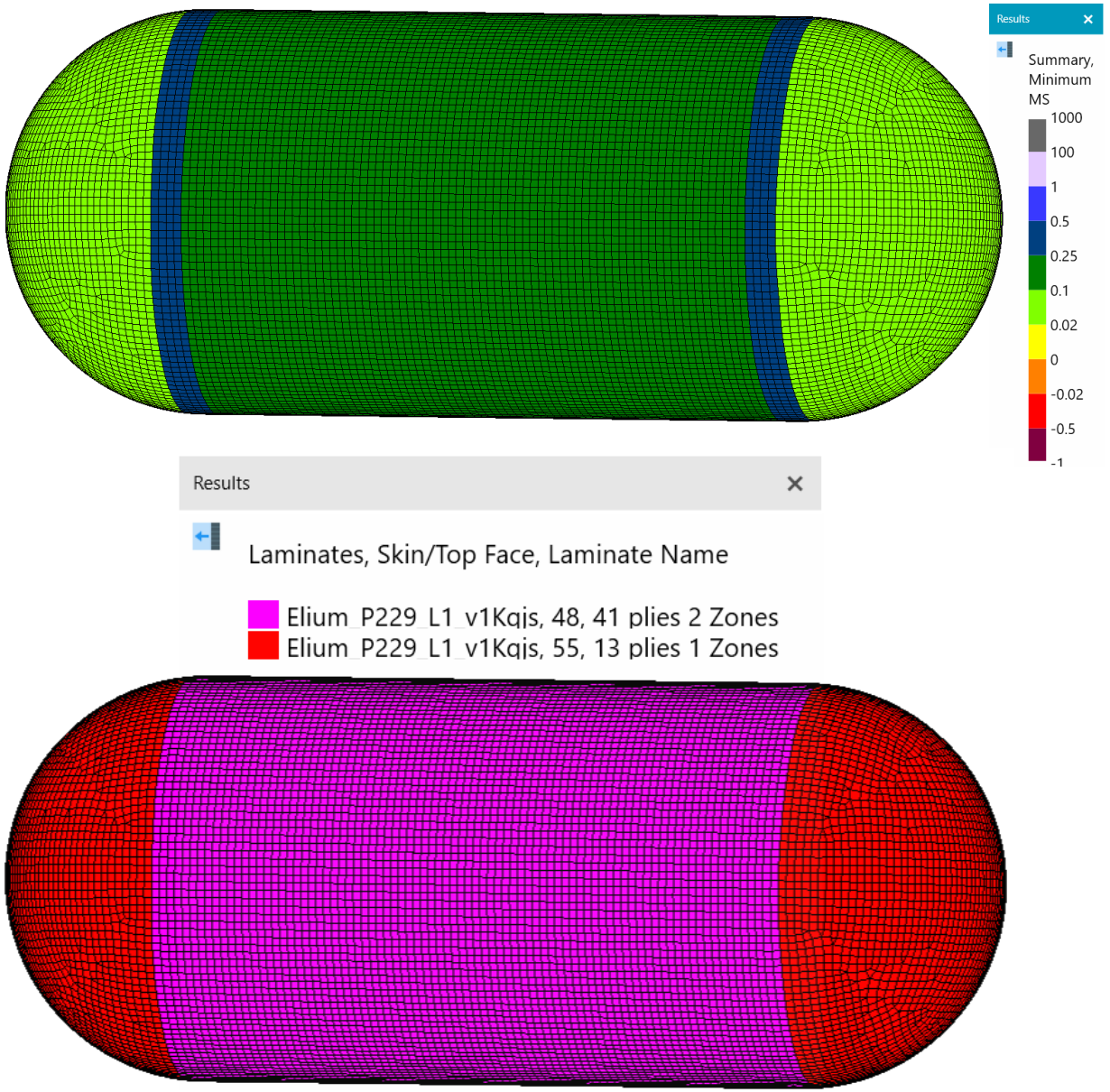
Optimization Results



Parameter	Result
Matrix Material	Arkema Elium
Angle Difference	14°
Laminate Family Structure	Case 1
Weight	56.96 lbs
Minimum Margin	0.0585

True minimum found by performing HyperX sizing optimization for all material/angle difference/laminate family combinations possible (brute force optimization)

Final Design



Laminate Family: Elium_P229_L1_v1Kqjs

Name: Elium_P229_L1_v1Kqjs

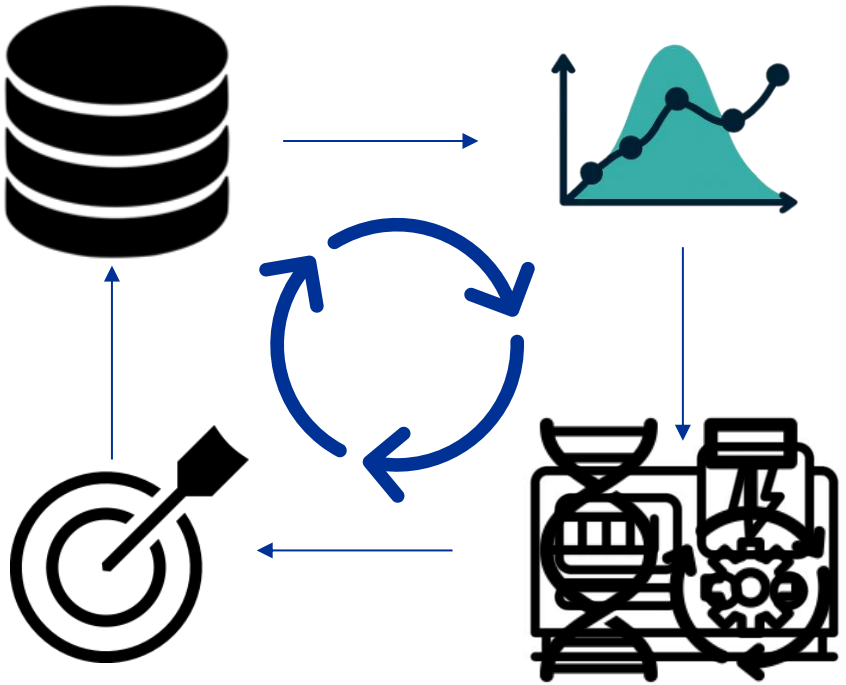
Novel Layups Discovered

	A	C	D	F	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	BK
1	Layer	Thickness (mm)	Material	Angle	46	47	48	49	50	51	52	53	54	55	56	57
95	94	0.2032	AS4 Unidirectional_Elium_VF60_NG56	-42	-42	-42										
96	95	0.2032	AS4 Unidirectional_Elium_VF60_NG56	56	56	56	**56**									
97	96	0.2032	AS4 Unidirectional_Elium_VF60_NG56	-56	-56	-56	**-56**									
98	97	0.2032	AS4 Unidirectional_Elium_VF60_NG56	-56	-56	-56	**-56**	-56								
99	98	0.2032	AS4 Unidirectional_Elium_VF60_NG56	56	56	56	**56**	56								
100	99	0.2032	AS4 Unidirectional_Elium_VF60_NG56	-42	-42	-42	**-42**	-42	-42							
101	100	0.2032	AS4 Unidirectional_Elium_VF60_NG56	42	42	42	**42**	42	42							
102	101	0.2032	AS4 Unidirectional_Elium_VF60_NG56	-28	-28	-28	**-28**	-28	-28	-28						
103	102	0.2032	AS4 Unidirectional_Elium_VF60_NG56	28	28	28	**28**	28	28	28						
104	103	0.2032	AS4 Unidirectional_Elium_VF60_NG56	-14	-14	-14	**-14**	-14	-14	-14	-14					
105	104	0.2032	AS4 Unidirectional_Elium_VF60_NG56	14	14	14	**14**	14	14	14	14					
106	105	0.2032	AS4 Unidirectional_Elium_VF60_NG56	14	14	14	**14**	14	14	14	14	14				
107	106	0.2032	AS4 Unidirectional_Elium_VF60_NG56	-14	-14	-14	**-14**	-14	-14	-14	-14	-14				
108	107	0.2032	AS4 Unidirectional_Elium_VF60_NG56	28	28	28	**28**	28	28	28	28	28	28			
109	108	0.2032	AS4 Unidirectional_Elium_VF60_NG56	-28	-28	-28	**-28**	-28	-28	-28	-28	-28	-28			
110	109	0.2032	AS4 Unidirectional_Elium_VF60_NG56	42	42	42	**42**	42	42	42	42	42	42	42		
111	110	0.2032	AS4 Unidirectional_Elium_VF60_NG56	-42	-42	-42	**-42**	-42	-42	-42	-42	-42	-42	-42		
112	111	0.2032	AS4 Unidirectional_Elium_VF60_NG56	56	56	56	**56**	56	56	56	56	56	56	56	56	
113	112	0.2032	AS4 Unidirectional_Elium_VF60_NG56	-56	-56	-56	**-56**	-56	-56	-56	-56	-56	-56	-56	-56	
114	113	0.1016	AS4 Unidirectional_Elium_VF60_NG56 - Th	60	60	60	**60**	60	60	60	60	60	60	60	60	60
115	114	0.1016	AS4 Unidirectional_Elium_VF60_NG56 - Th	-60	-60	-60	**-60**	-60	-60	-60	-60	-60	-60	-60	-60	-60
116	115	0.1016	AS4 Unidirectional_Elium_VF60_NG56 - Th	0	0	0	**0**	0	0	0	0	0	0	0	0	0
117	116	0.1016	AS4 Unidirectional_Elium_VF60_NG56 - Th	-60	-60	-60	**-60**	-60	-60	-60	-60	-60	-60	-60	-60	-60
118	117	0.1016	AS4 Unidirectional_Elium_VF60_NG56 - Th	60	60	60	**60**	60	60	60	60	60	60	60	60	60
119	118	0.2032	AS4 Unidirectional_Elium_VF60_NG56	-56	-56	-56	**-56**	-56	-56	-56	-56	-56	-56	-56	-56	
120	119	0.2032	AS4 Unidirectional_Elium_VF60_NG56	56	56	56	**56**	56	56	56	56	56	56	56	56	
121	120	0.2032	AS4 Unidirectional_Elium_VF60_NG56	-42	-42	-42	**-42**	-42	-42	-42	-42	-42	-42	-42		
122	121	0.2032	AS4 Unidirectional_Elium_VF60_NG56	42	42	42	**42**	42	42	42	42	42	42	42		
123	122	0.2032	AS4 Unidirectional_Elium_VF60_NG56	-28	-28	-28	**-28**	-28	-28	-28	-28	-28	-28			

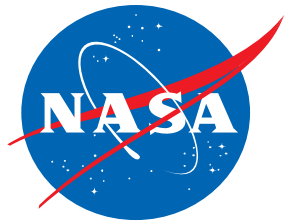
Conclusions

- First-generation ML capability (based on Bayesian Optimization) for optimizing choice of Laminate Families (LFs) in HyperX
- Extensive use of HyperX API to enable HyperX use ***in-the-loop*** as the objective function
- Application to NASA composite Cryogenic Hydrogen Tank
  - Multiple options for the thermoplastic matrix material
  - Multiple Laminate Family rules
- Successfully determined optimum LF and design in 7 iterations

Potential Future Work



- Current Methodology relies on user defined rules for generating the laminate family based on a fixed δ between plies
  - Only enforced that the angle between plies is **at most** δ $\rightarrow$ unexplored design space with varying δ_i
- Future Work: Use Genetic Algorithms at each iteration to define new laminate families to consider
  - After *n* Bayesian Optimization (BayBE) iterations, collect the best performing laminate family main stacking sequences
  - Using a genetic algorithm, generate a new set of *laminate family cases* to evaluate
  - Re-evaluate only the new generation of cases using BayBE
  - Repeat for *m* generations


NASA