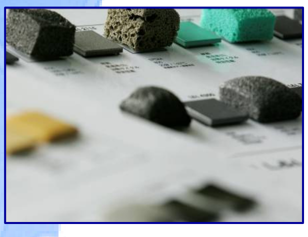
Increasing Customer Value Using HyperStudy and Topology Optimization While Considering Manufacturing Constraints

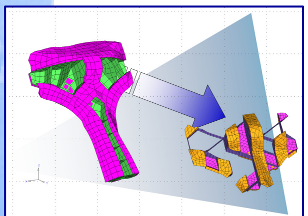
April 28, 2010

L&L Products®

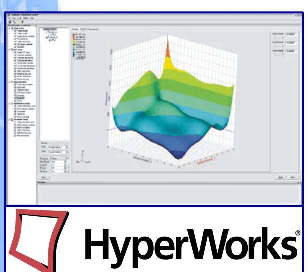
Overview



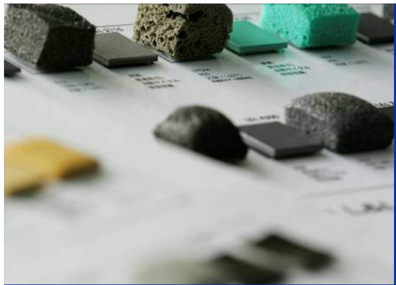
- ❑ **Who is L&L and what do they do?**



- ❑ **What do you use HyperWorks to do?**



- ❑ **What did you learn?**



L & L Corporate Overview

- L&L Products France
- L&L Products Spain
- L&L Products Germany
- L&L Products Italy
- L&L Products Sweden
- L&L Products Poland
- L&L Products Turkey
- L&L Products USA
- L&L Products Japan
- L&L Products Mexico
- L&L Products Brazil
- L&L Products China
- L&L Products Korea
- L&L Products UK

- Founded 1958 we currently employ
  Nearly 800 people worldwide
- Specialty chemical formulator, full service design and manufacturing company
- L&L Goal: Science and Innovation:
  High Value, High Performing - Customer Centric Solutions
- Strong Chemistry Backbone
  Nearly 10% of all employees in R&D
- Advanced Simulation Tools
  Predictable & Reliable
- Experienced Engineering
  Develop – Design - Deliver

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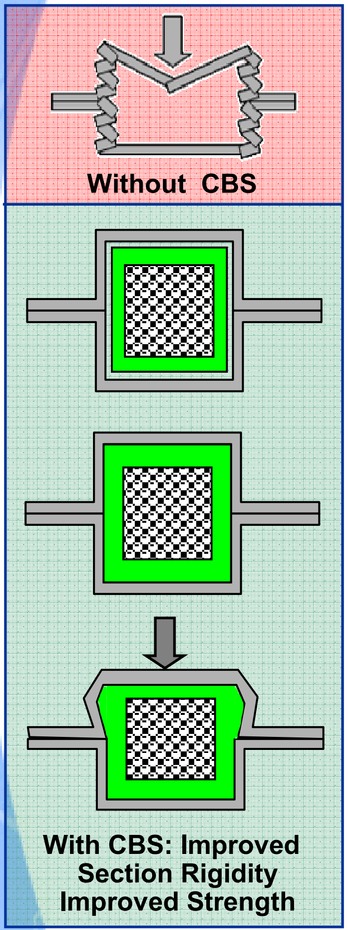
L & L Engaged Industries

- Our primary customer is the worldwide automotive industry.

- Other industries include commercial aerospace & defense.

L & L Composite Body Solutions®



CBS® is an L&L Structural Solution consisting of Heat Activated Expanding Adhesive and an engineered Carrier that cavities and bonds individual loading carrying members to create a *unified* structure with significantly improved *Stiffness* and *Strength* attributes.

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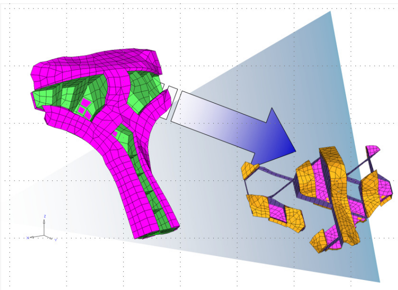
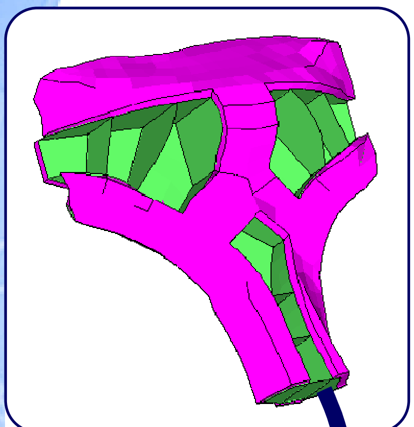


Today's Example:

Using RADIOSS, HyperStudy, and OptiStruct to Bring Value to Customers … and our Company



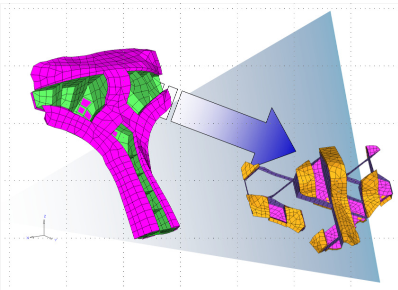
The goal of this optimization study is to qualify, quantify and document optimal designs and/or material properties for a variety of potential solutions to a linear NVH, structural mechanics problem.

In order to facilitate the goal effectively, this study will focus on the two leading cost drivers and will break the design task into three phases.

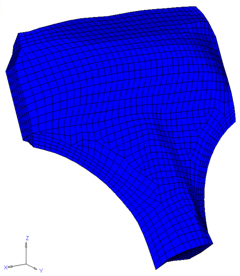
- **Cost Driver(s)**
  - Design /Geometry **or** Materials/Processing

Phased Approach

- Phase I: Solid Material Opt. ← Manufacturing
- Phase 2: Inj. Molded Nylon Opt. ← Design & Processing
- Phase 3: Inj. Molded Material Opt. ← Manufacturing

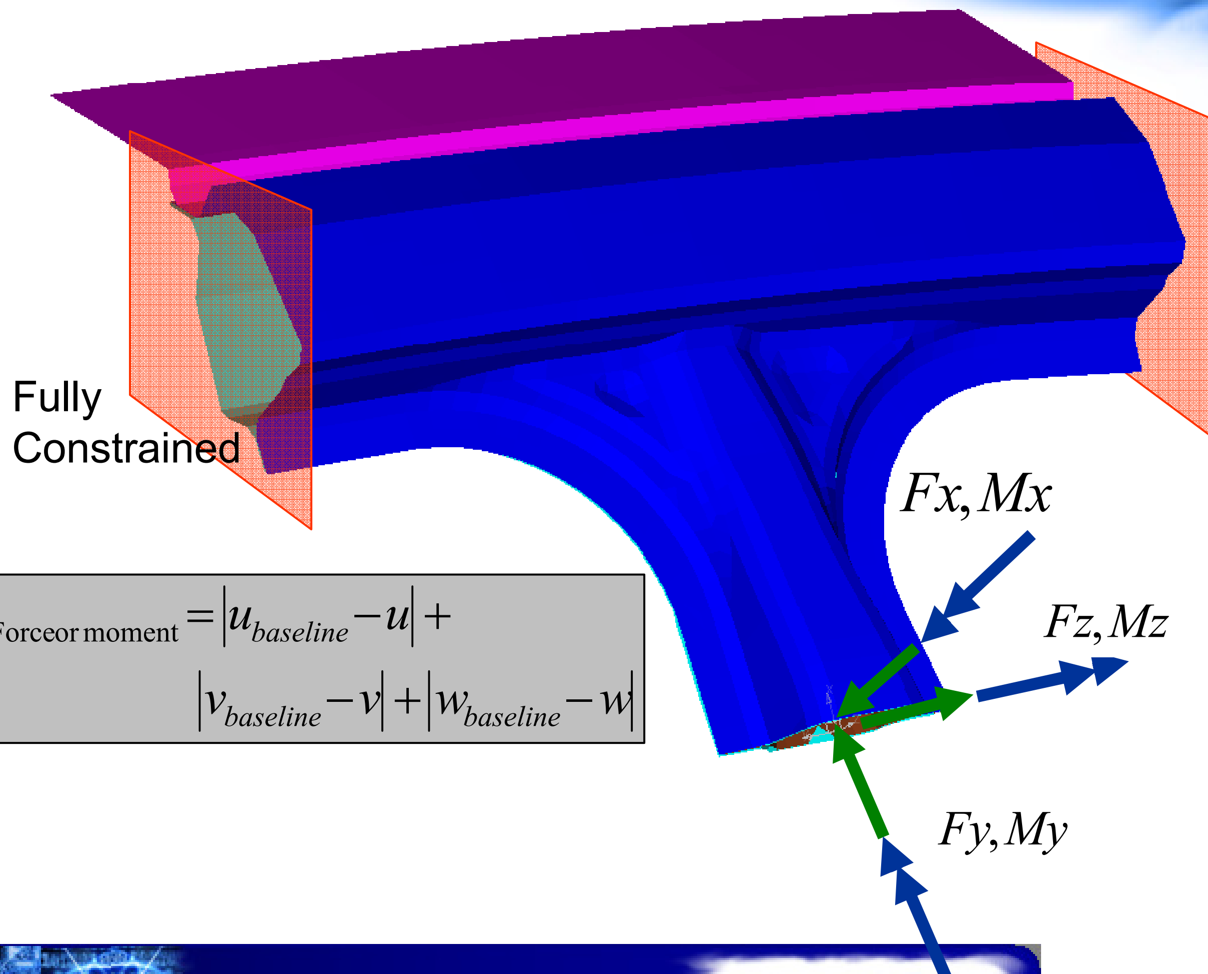


Phase 1
Solid Material Optimization

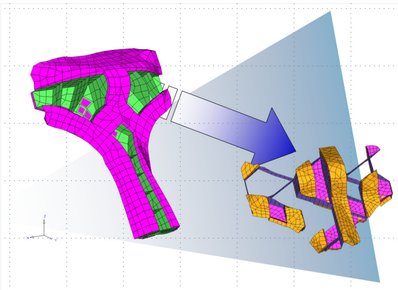


Boundary Conditions:
Forces & Moments applied positively in local coordinate system.

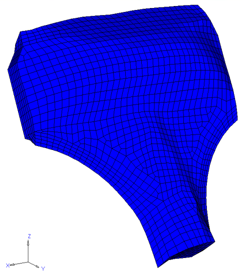
Objective:
Minimize L_1 norm of displacement difference



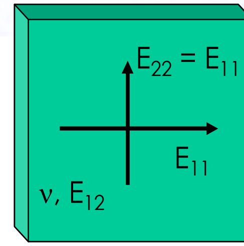
$$\mathrm{Obj}_{\text{Force or moment}} = |u_{baseline} - u| + |v_{baseline} - v| + |w_{baseline} - w|$$



Phase 1
Baseline Performance



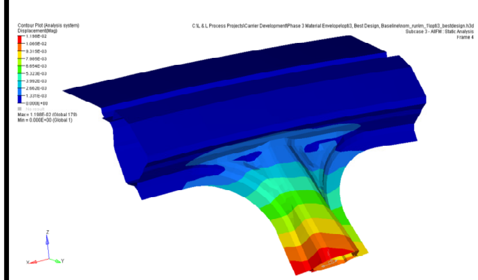
Simple four node shell & eight node solid elements and isotropic material definition.



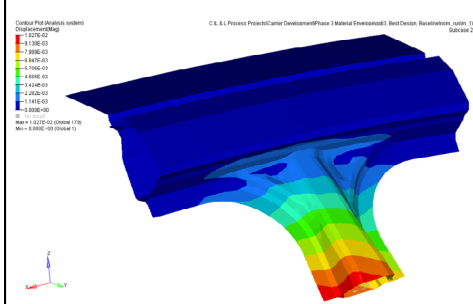
CQUAD 4 Elements
MAT1 Material Definition

Comparator is a realistically engineered CBS part.

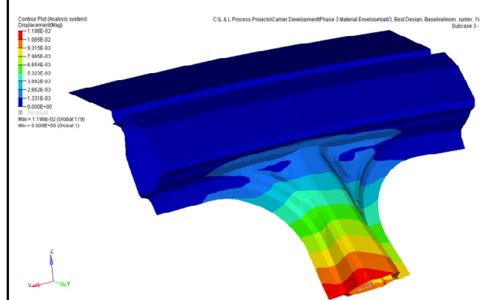
Linear stiffness under force and moment application given.



All forces applied:
Max displ. = 0.001776 on node 241

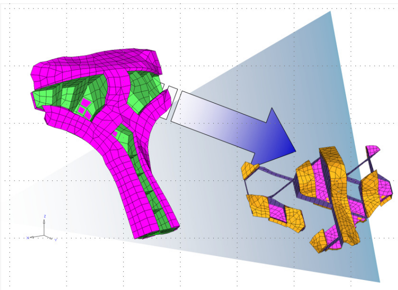


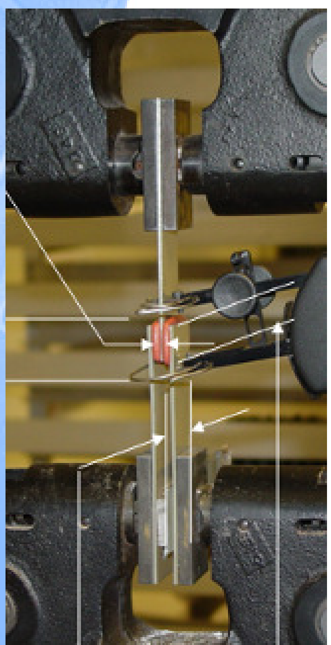
All moments applied:
Max displ. = 0.01027 on node 179

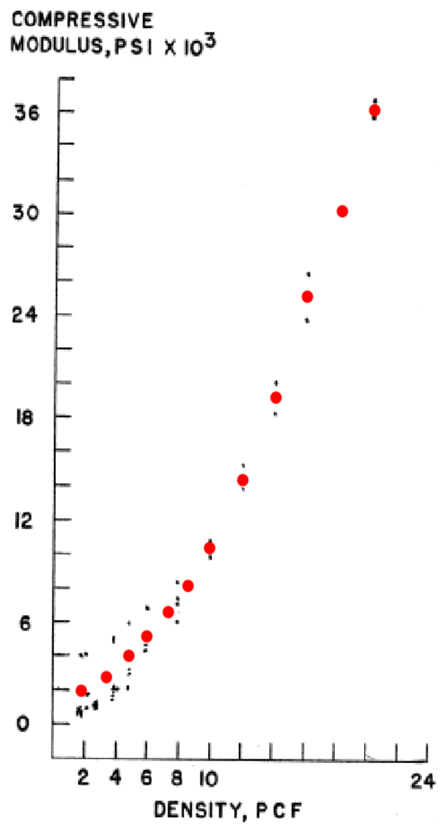


All forces & moments applied:
Max displ. = 0.01198 on node 179

Phase 1
Relate Mechanical Properties to Density

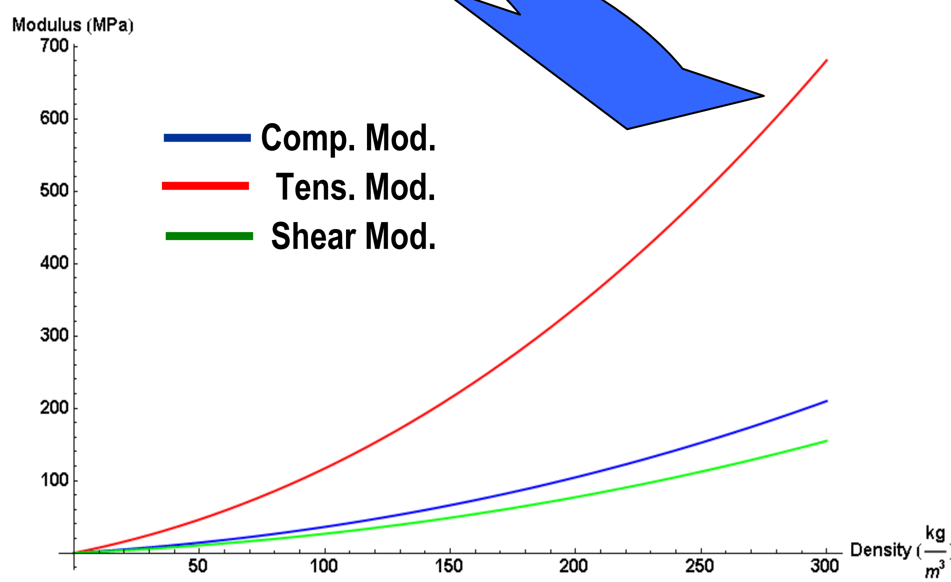






Ref: “Rigid Plastic Foams” by T. Ferrigno, 1967
in conjunction with L&L test data

Graphical point extraction
and regression



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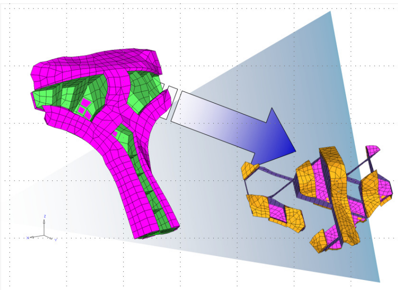
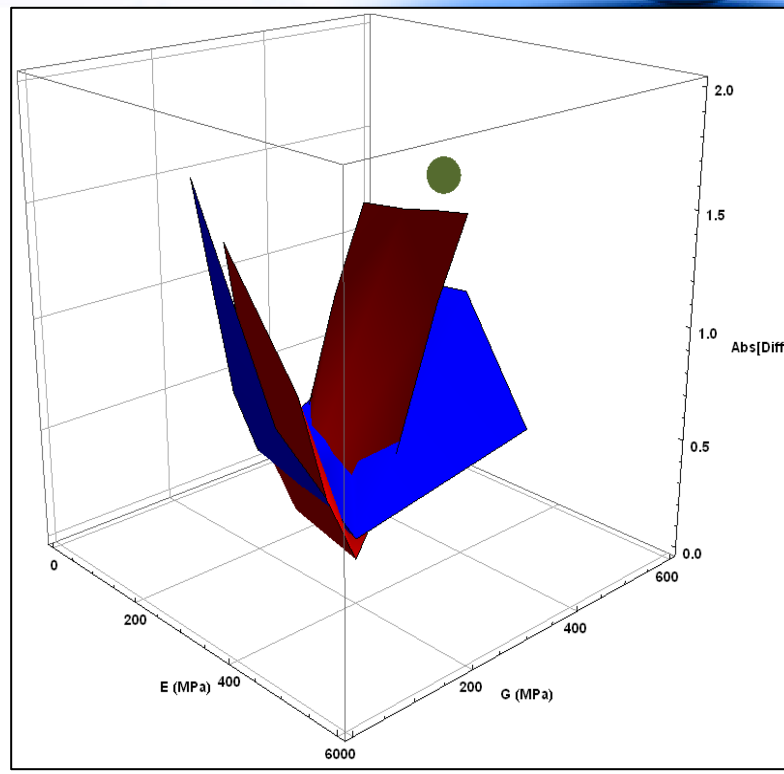


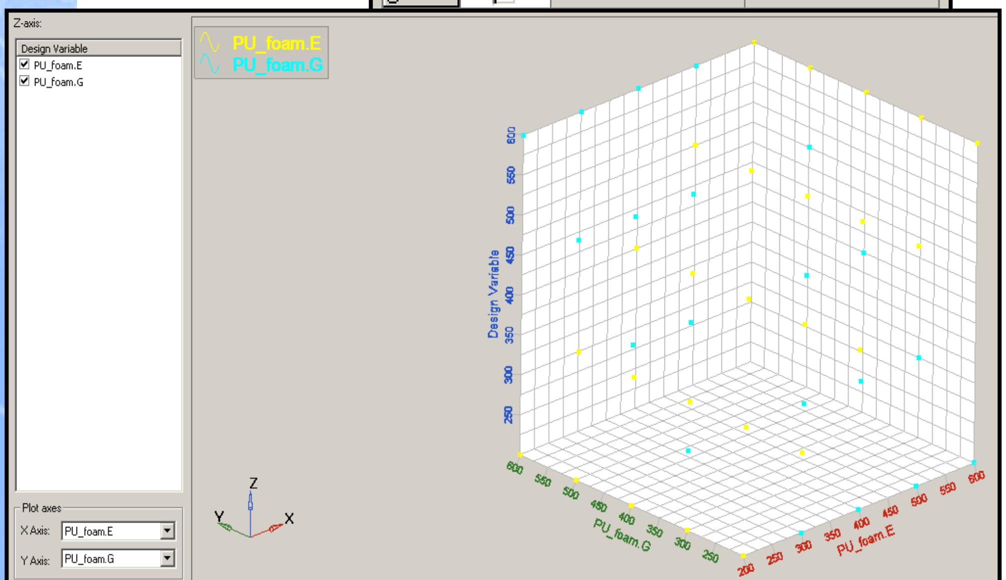
Phase 1

Run Matrix/Summary and Response Surfaces

DOE Run Table | DOE Run Plot | DOE Run 3D Plot

Runs	State	PU_foam.E	PU_foam.G
1	☑	200.00000	200.00000
2	☑	200.00000	300.00000
3	☑	200.00000	400.00000
4	☑	200.00000	500.00000
5	☑	200.00000	600.00000
6	☑	300.00000	200.00000
7	☑	300.00000	300.00000
8	☑	300.00000	400.00000





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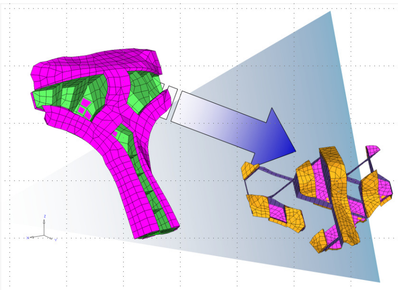
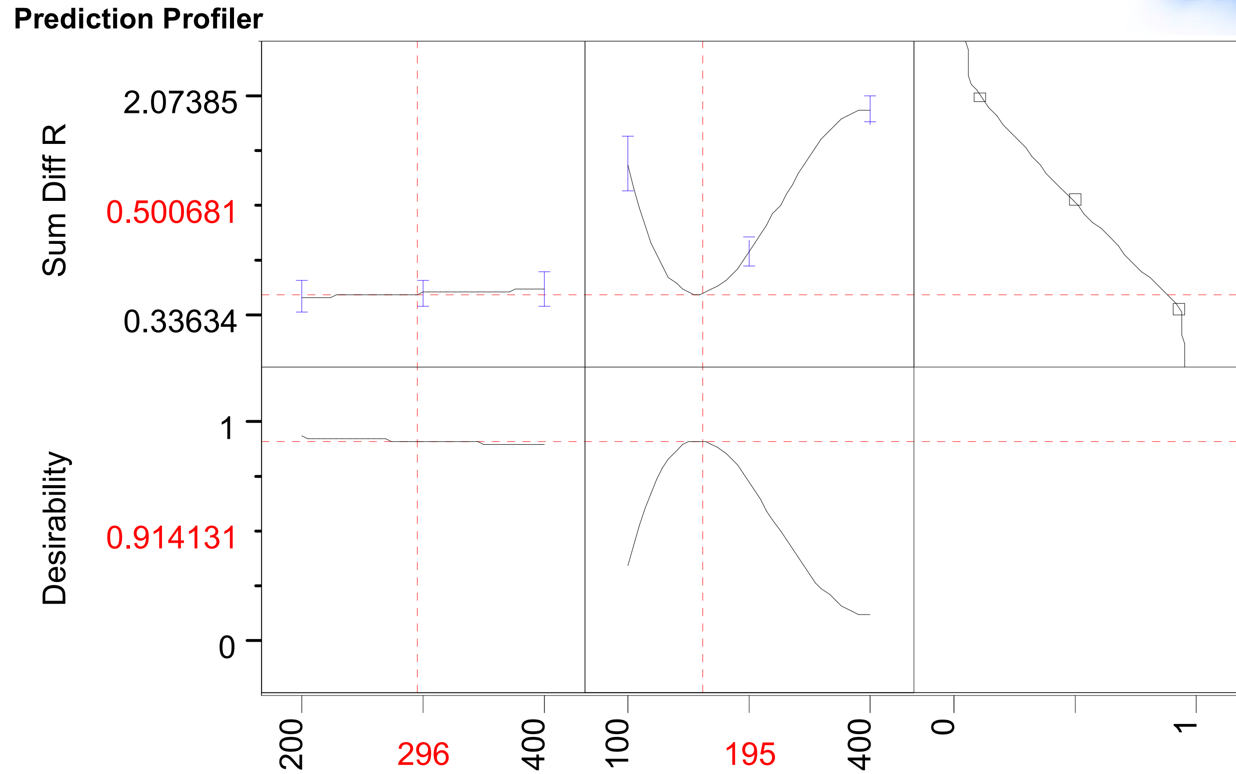
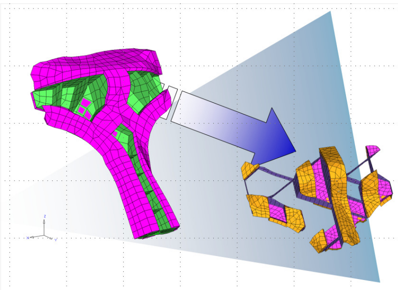
Phase 1
Material Optimization Results

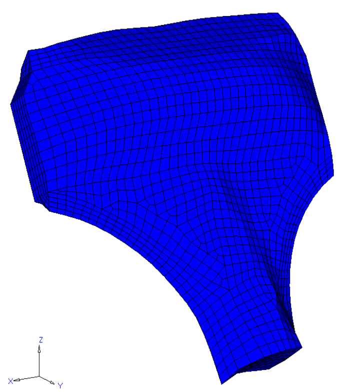


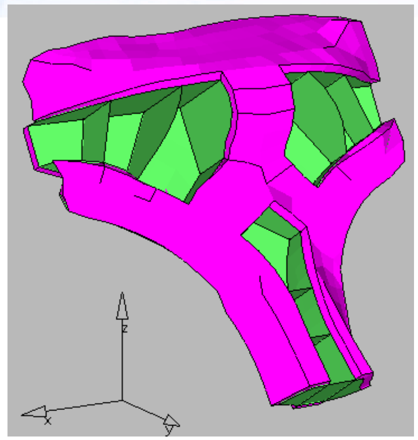


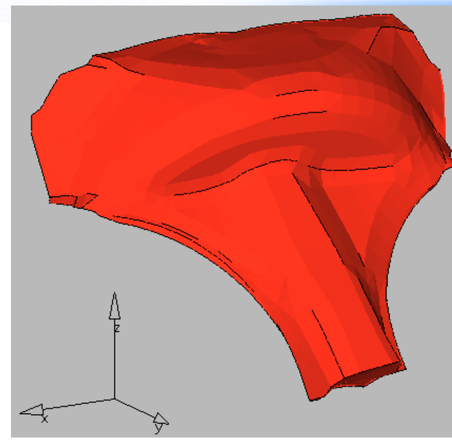
Targets are seen to be near E ≅ 300 MPa, G ≅ 200 MPa



Phase 1
Material Optimization Results







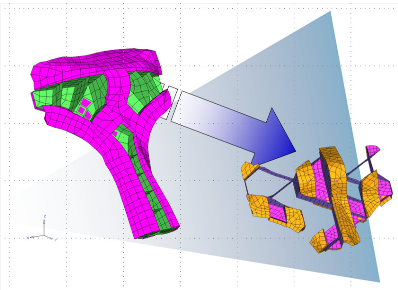
Baseline	Solid Filled
0.456 kg, 4mm thick	0.327 kg (-28.2%)
$\lvert Disp_{Force} \rvert$= 1.465 mm	$\lvert Disp_{Force} \rvert$= 1.447 mm
$\lvert Rot_{Mom} \rvert$ = 0.0124 rad	$\lvert Rot_{Mom} \rvert$ = 0.0122 rad

Name	Type	E	Rho
material.1	MAT1	207000.0	7.85e-006
Epoxy	MAT1	700.0	5e-007
nylon33	MAT1	6895.0	1.35e-006

Name	Type	E	G	Rho
material.1	MAT1	207000.0		7.85e-006
PU_foam	MAT1	300.0	200.0	4.6e-007

G ≈ 200 MPa

E ≈ 270 - 300 MPa



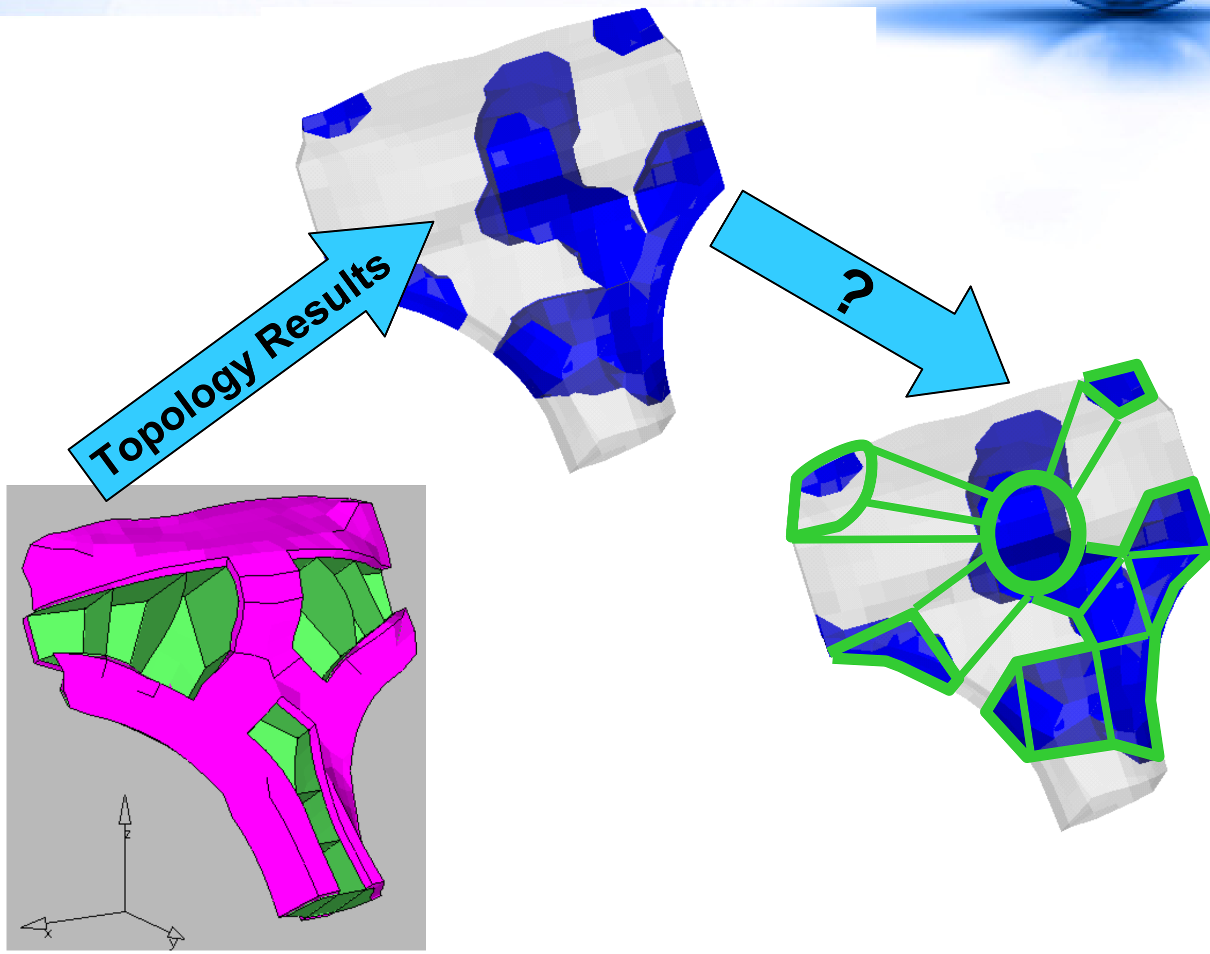
Phase 2

Optimization Assuming Typical Design & Manufacturing Practice

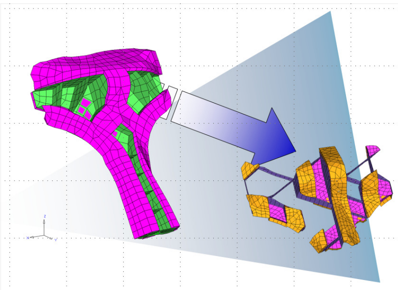
Assumptions:

- Carrier Material Properties = 33% SG Nylon
- Traditional, bonded in application
- Initial design space is equal to overall baseline design concept
- Use Existing Upper B-Pillar Steel

Goal: Minimize mass



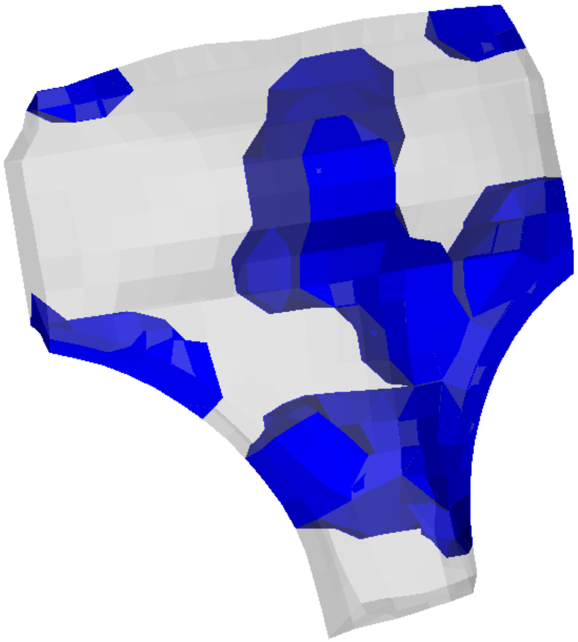
Baseline Design



Phase 2
Topology Results and Manufacturability

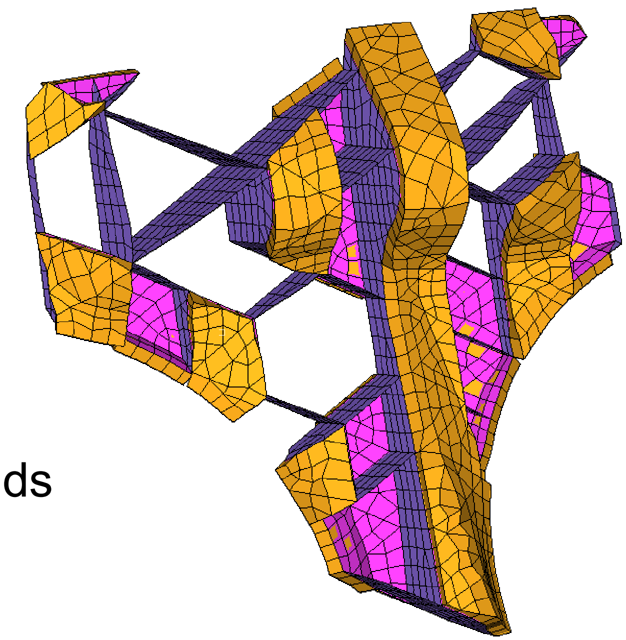
Engineers interpret the topology optimization, bringing several intrinsic assumptions into the design:

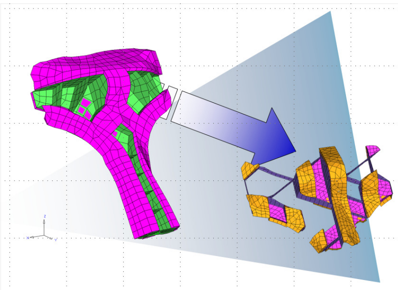
- Carrier is 33SG nylon
- Traditional adhesive bonding
- Design is *qualitative* of an injection molded, “ribbed” approach
- Ribs have certain topography



OptiStruct recommends the “true” minimum

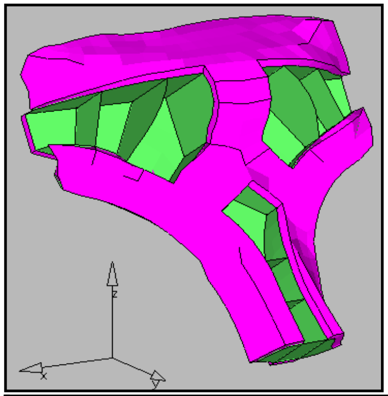
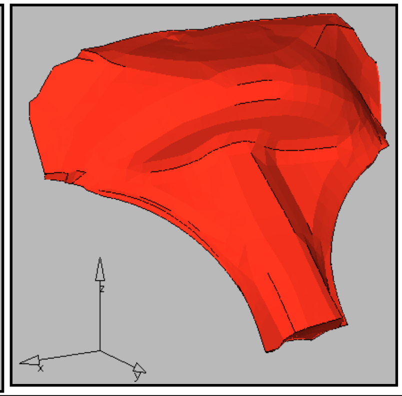
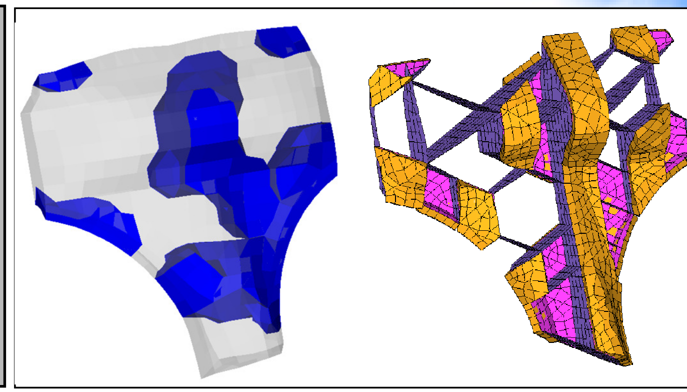
Manufacturing constraints yield …



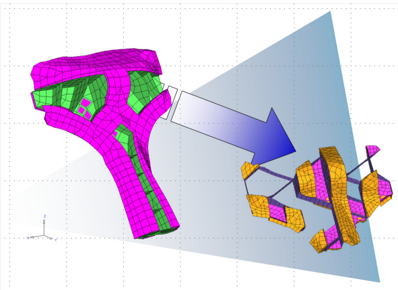


Phase 2

Shape Optimization [Ribbed Design] Results

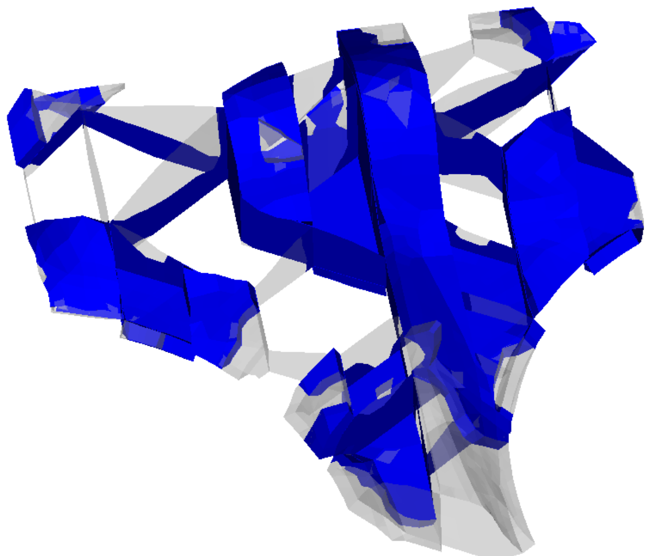
Baseline	Solid Material	Nylon Ribbed Architecture, Optimal Shape
0.456 kg, 4mm thick	0.327 kg (-28.2%)	0.3111 kg (-31.8%), 4mm thick
$\lvert Disp_{Force} \rvert$= 1.465 mm	$\lvert Disp_{Force} \rvert$= 1.447 mm	$\lvert Disp_{Force} \rvert$= <TBD>
$\lvert Rot_{Mom} \rvert$ = 0.0124 rad	$\lvert Rot_{Mom} \rvert$ = 0.0122 rad	$\lvert Rot_{Mom} \rvert$ = 0.0125 rad
	G ≈ 200 MPa E ≈ 270 - 300 MPa	



Phase 2 “B”

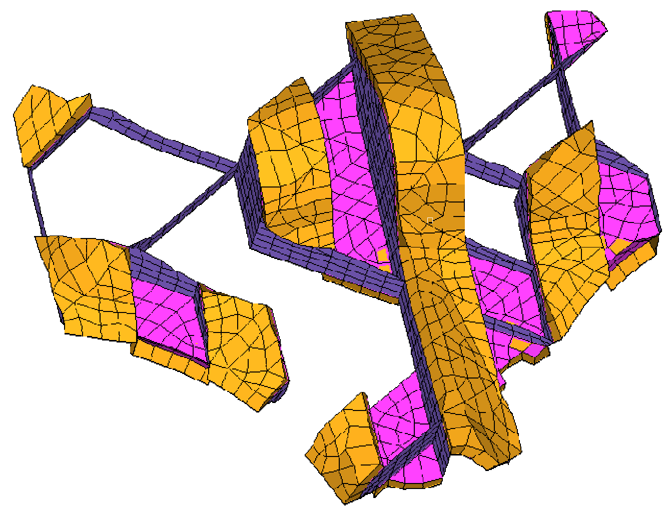
Further Optimize the Result of Phase 2 ?

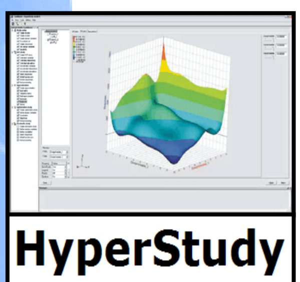
Engineers come back …

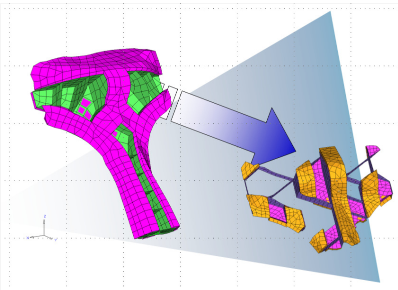


“Free Sizing of shell thicknesses yields…

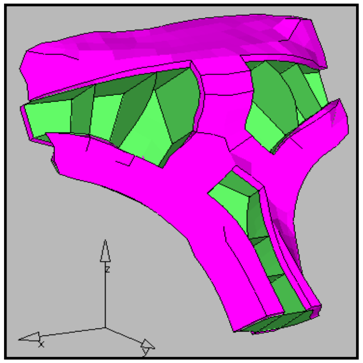
Again, manufacturing constraints yield …

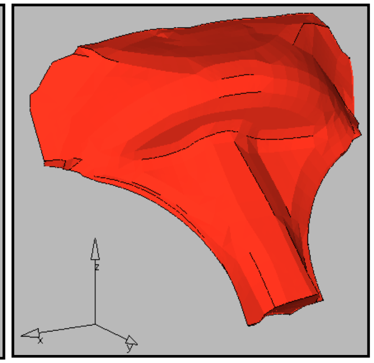


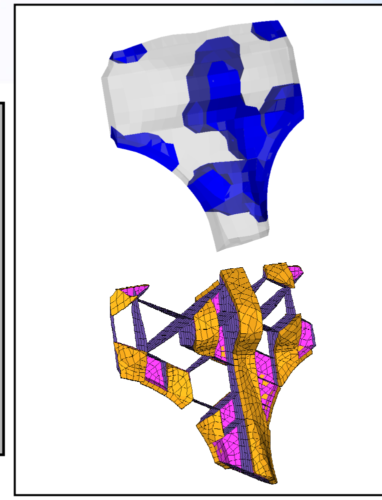


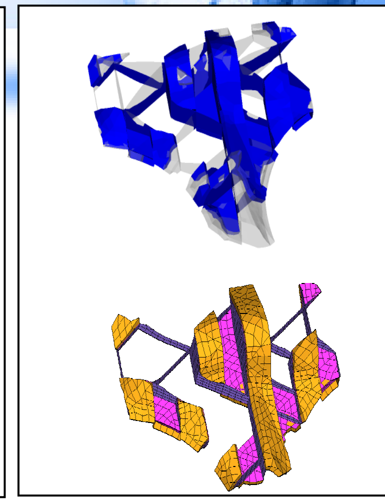


Phase 2 “B”
Additional Optimization from Free Sizing

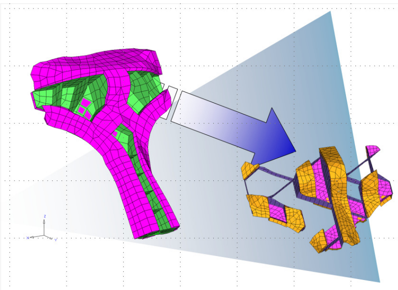








Baseline	Solid	Nylon Ribbed Architecture Optimal Shape	Nylon Ribbed Architecture Optimal Shape “B”
0.456 kg, 4mm thick	0.327 kg (-28.2%)	0.3111 kg (-31.8%) 4mm thick	0.2270 kg (-50.2%) 4mm thick
$\|Disp_{Force}\|$= 1.465 mm	$\|Disp_{Force}\|$= 1.447 mm	$\|Disp_{Force}\|$= <TBD>	$\|Disp_{Force}\|$= <TBD>
$\|Rot_{Mom}\|$ = 0.0124 rad	$\|Rot_{Mom}\|$ = 0.0122 rad	$\|Rot_{Mom}\|$ = 0.0125 rad	$\|Rot_{Mom}\|$ = 0.0130 rad
	G ≈ 200 MPa E ≈ 270 - 300 MPa		



Phase 3

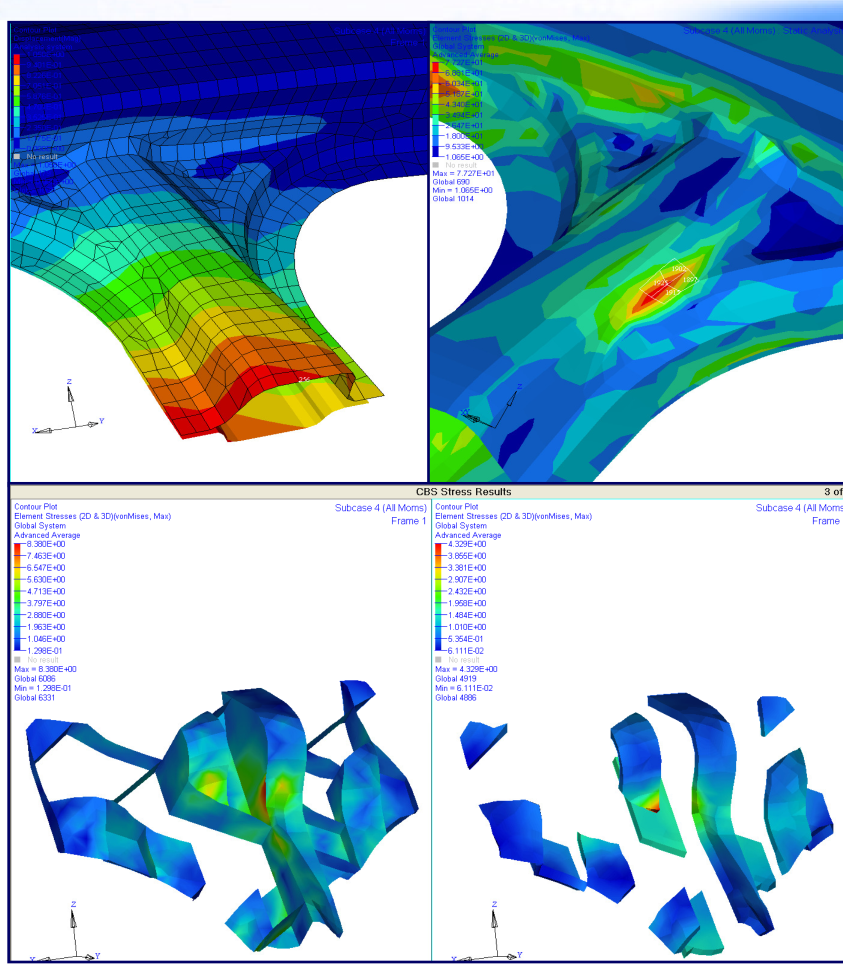
Material Innovation?

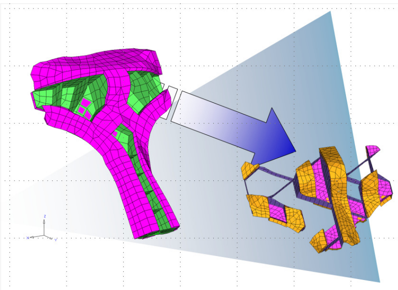
Scientists come over ….

Define the baseline performance

Structural Displacement & Stress Constraints

Adhesive Displacement & Stress Constraints

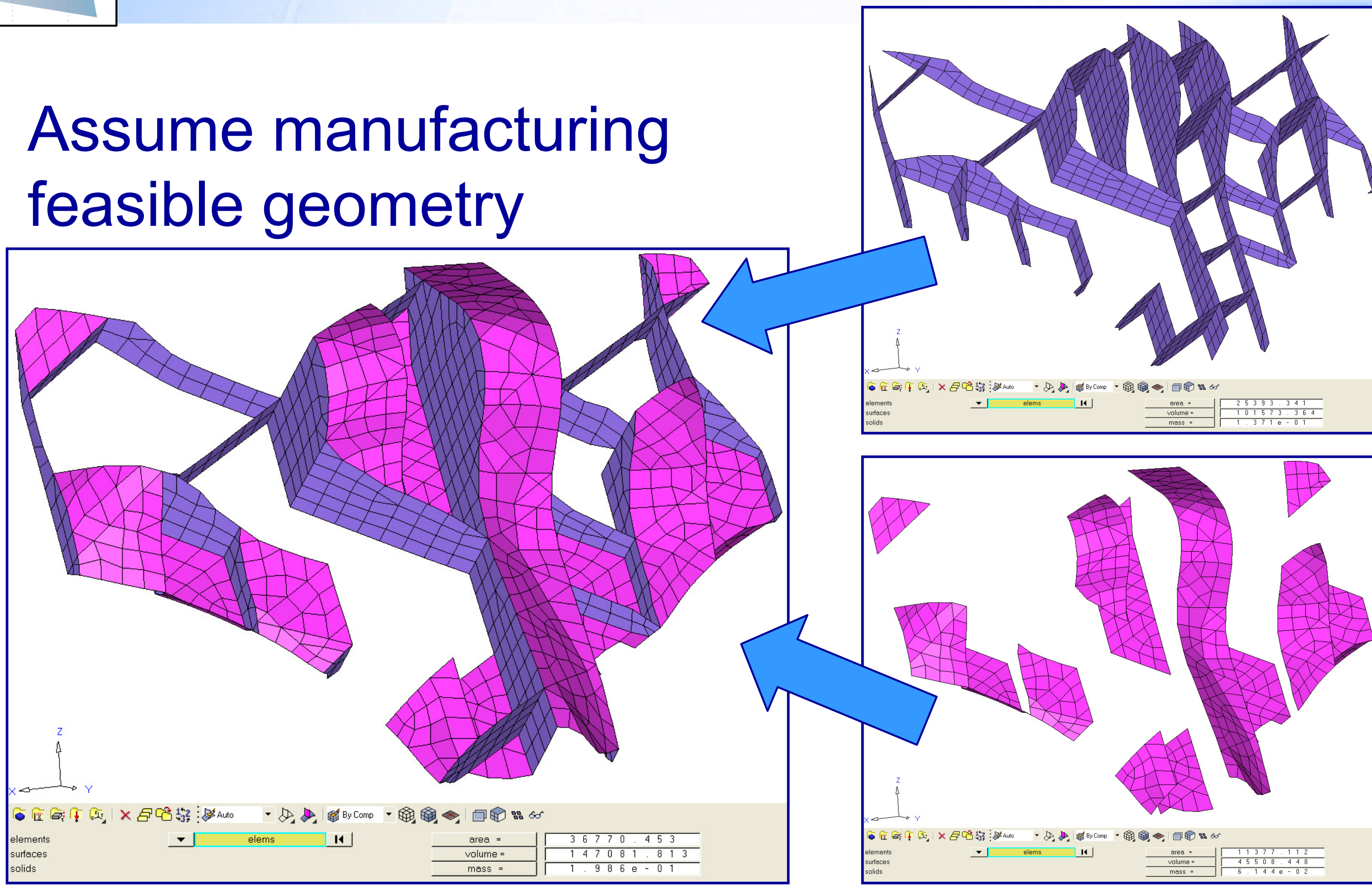


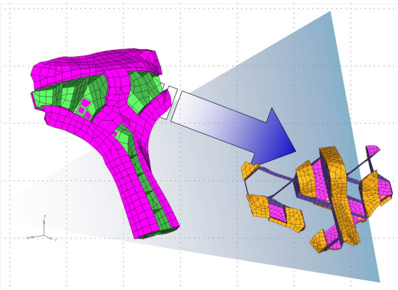


Phase 3

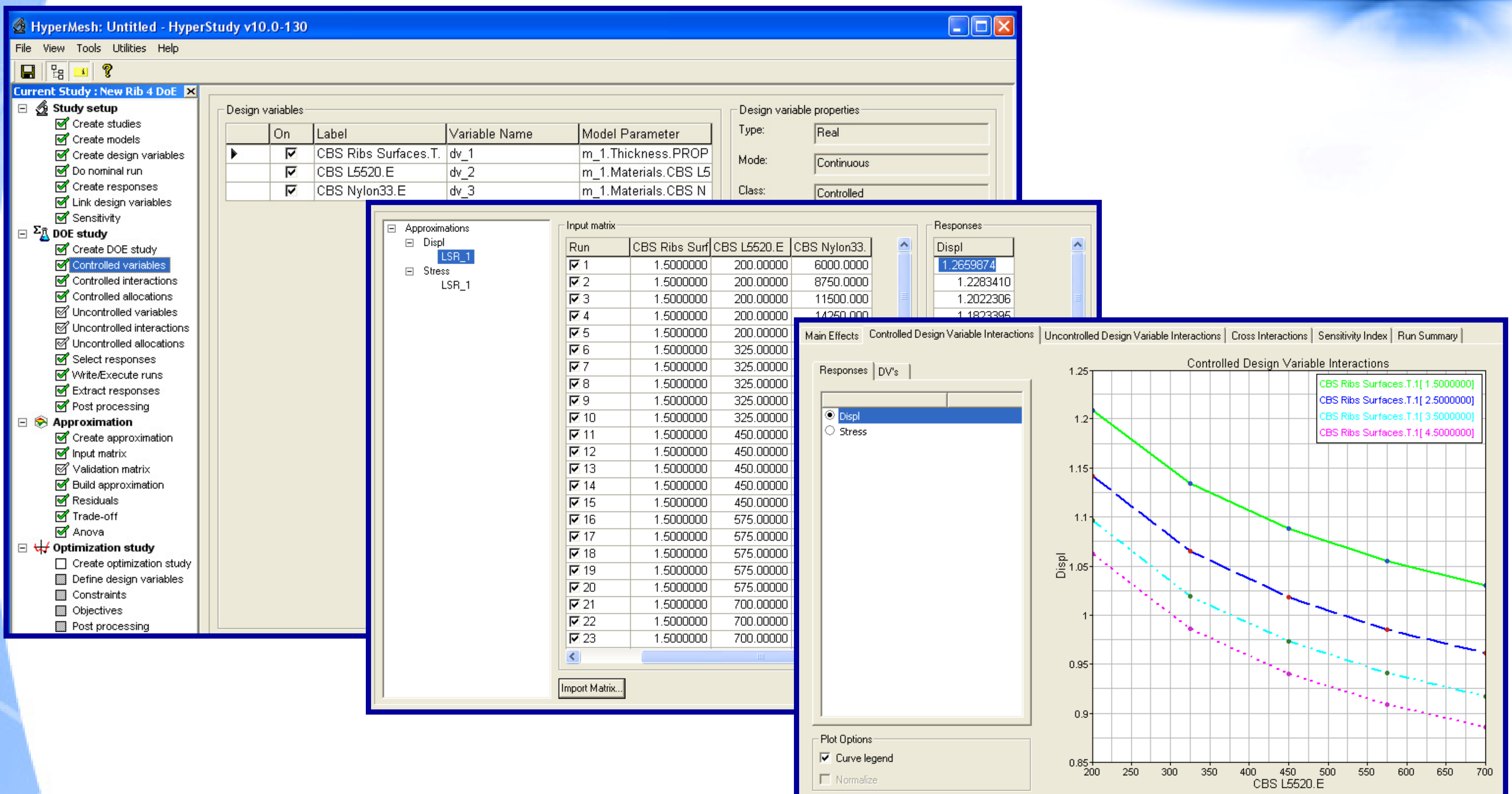
Baseline Geometry

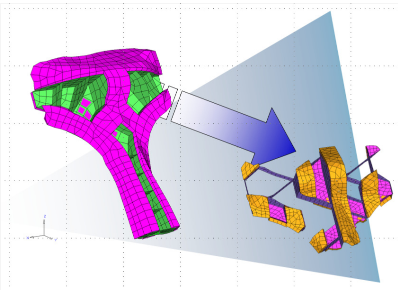
Assume manufacturing feasible geometry





Phase 3
Sensitivity Analysis & Response Surface Modeling in HyperStudy





Phase 3
Displacement RSM

Stepwise Fit

Response: Displ

Stepwise Regression Control

Prob to Enter 0.250
Prob to Leave 0.250
Direction: Mixed
Rules: Combine

Enter All | Remove All | Go | Stop | Step | Make Model

Current Estimates

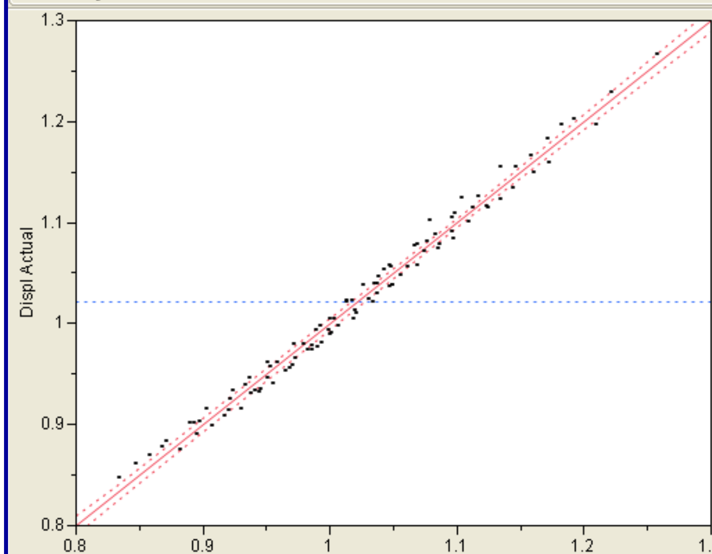
SSE	DFE	MSE	RSquare	RSquare Adj	Cp	AICc
0.0099522	93	0.000107	0.9881	0.9873	686.87938	-620.143

Lock	Entered	Parameter	Estimate	nDF	SS	"F Ratio"	"Prob>F"
☑	☑	Intercept	1.38120365	1	0	0.000	1
☐	☑	CBSRibs	-0.0484748	1	0.293726	2744.766	7.8e-71
☐	☐	(CBSRibs-3)*(CBSRibs-3)	0	1	0.008451	517.772	1.5e-39
☐	☐	(CBSRibs-3)*(CBSRibs-3)*(CBSRibs-3)	0	2	0.008635	298.282	1.1e-40
☐	☑	CBSL5520	-0.0003005	3	0.402111	1252.530	4.9e-75
☐	☑	(CBSL5520-450)*(CBSL5520-450)	5.42727e-7	2	0.02106	98.399	1.1e-23
☐	☑	(CBSL5520-450)*(CBSL5520-450)*(CBSL5520-450)	-9.173e-10	1	0.000924	8.639	0.00415
☐	☑	CBSNylon33	-9.0773e-6	2	0.128816	601.872	6.1e-54
☐	☑	(CBSNylon33-11500)*(CBSNylon33-11500)	5.1148e-10	1	0.004189	39.148	1.19e-8
☐	☐	(CBSNylon33-11500)*(CBSNylon33-11500)*(CBSNylon33-11500)	0	1	0.000158	1.487	0.22583

Step History

Step	Parameter	Action	"Sig Prob"	Seq SS	RSquare	Cp	p
1	CBSL5520	Entered	0.0000	0.381051	0.4566	35127	2
2	CBSRibs	Entered	0.0000	0.293726	0.8085	12318	3
3	(CBSNylon33-11500)*(CBSNylon33-11500)	Entered	0.0000	0.128816	0.9628	2318.4	5
4	(CBSL5520-450)*(CBSL5520-450)*(CBSL5520-450)	Entered	0.0000	0.02106	0.9881	686.88	7

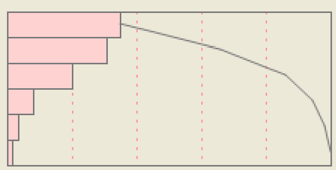
Actual by Predicted Plot



Displ Predicted P<.0001
RSq=0.99 RMSE=0.0103

Pareto Plot of Transformed Estimates

Term	Orthog Estimate
CBSL5520	-0.0617293
CBSRibs	-0.0541965
CBSNylon33	-0.0353025
(CBSL5520-450)*(CBSL5520-450)	0.0141899
(CBSNylon33-11500)*(CBSNylon33-11500)	0.0064725
(CBSL5520-450)*(CBSL5520-450)*(CBSL5520-450)	-0.0030405



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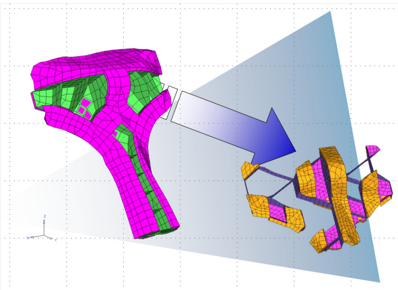


Phase 3
Stress RSM

Stepwise Fit

Response: Stress

Stepwise Regression Control

Prob to Enter 0.250
Prob to Leave 0.250
Direction: Mixed
Rules: Combine

Enter All | Remove All | Go | Stop | Step | Make Model

Current Estimates

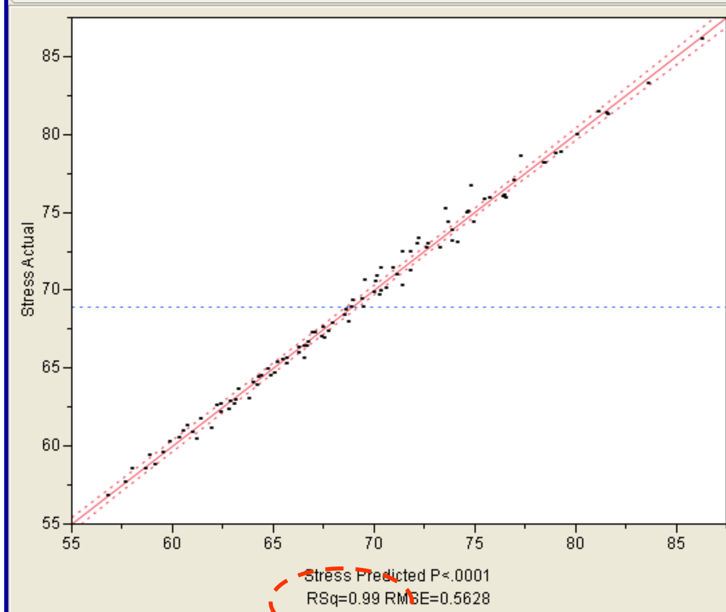
SSE	DFE	MSE	RSquare	RSquare Adj	Cp	AICc
29.452905	93	0.3166979	0.9929	0.9925	37.620252	179.1324

Lock	Entered	Parameter	Estimate	nDF	SS	"F Ratio"	"Prob>F"
☑	☑	Intercept	94.6908758	1	0	0.000	1
☐	☑	CBSRibs	-3.2503372	2	1368.228	2160.146	1.1e-78
☐	☑	(CBSRibs-3)*(CBSRibs-3)	0.69022594	1	47.64118	150.431	3.9e-21
☐	☐	(CBSRibs-3)*(CBSRibs-3)*(CBSRibs-3)	0	1	1.2551	4.095	0.04591
☐	☑	CBSL5520	-0.0254123	2	2138.43	3376.135	1.5e-87
☐	☑	(CBSL5520-450)*(CBSL5520-450)	0.00004196	1	120.356	380.034	1.3e-34
☐	☐	(CBSL5520-450)*(CBSL5520-450)*(CBSL5520-450)	0	1	5.788376	22.503	7.65e-6
☐	☑	CBSNylon33	-0.0006378	2	640.8019	1011.693	7.8e-64
☐	☑	(CBSNylon33-11500)*(CBSNylon33-11500)	3.99801e-8	1	25.59626	80.822	2.8e-14
☐	☐	(CBSNylon33-11500)*(CBSNylon33-11500)*(CBSNylon33-11500)	0	1	0.966652	3.122	0.08056

Step History

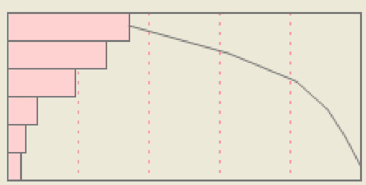
Step	Parameter	Action	"Sig Prob"	Seq SS	RSquare	Cp	p
1	(CBSL5520-450)*(CBSL5520-450)	Entered	0.0000	2138.43	0.5120	8462	3
2	(CBSRibs-3)*(CBSRibs-3)	Entered	0.0000	1368.228	0.8395	2723.2	5
3	(CBSNylon33-11500)*(CBSNylon33-11500)	Entered	0.0000	640.8019	0.9929	37.62	7

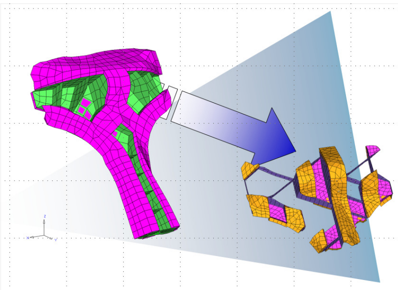
Actual by Predicted Plot



Pareto Plot of Estimates

Term	t Ratio
CBSL5520	-79.82629
CBSRibs	-64.57447
CBSNylon33	-44.07452
(CBSL5520-450)*(CBSL5520-450)	19.49446
(CBSRibs-3)*(CBSRibs-3)	12.26503
(CBSNylon33-11500)*(CBSNylon33-11500)	8.99012





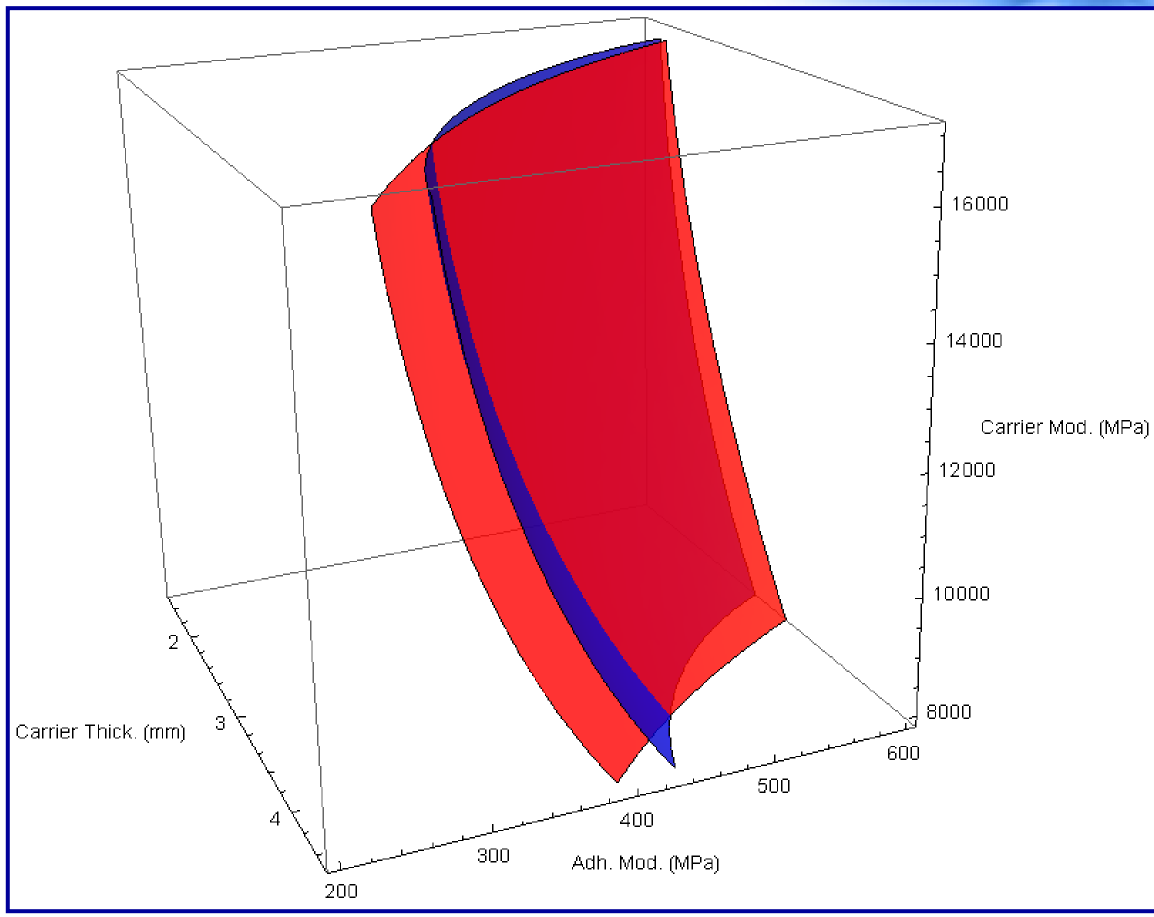
Phase 3

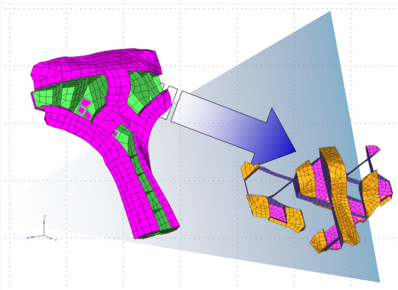
Displacement & Stress Response Surfaces Isoclines

Within the:

- **carrier thickness**
- **carrier modulus**
- **adhesive modulus**

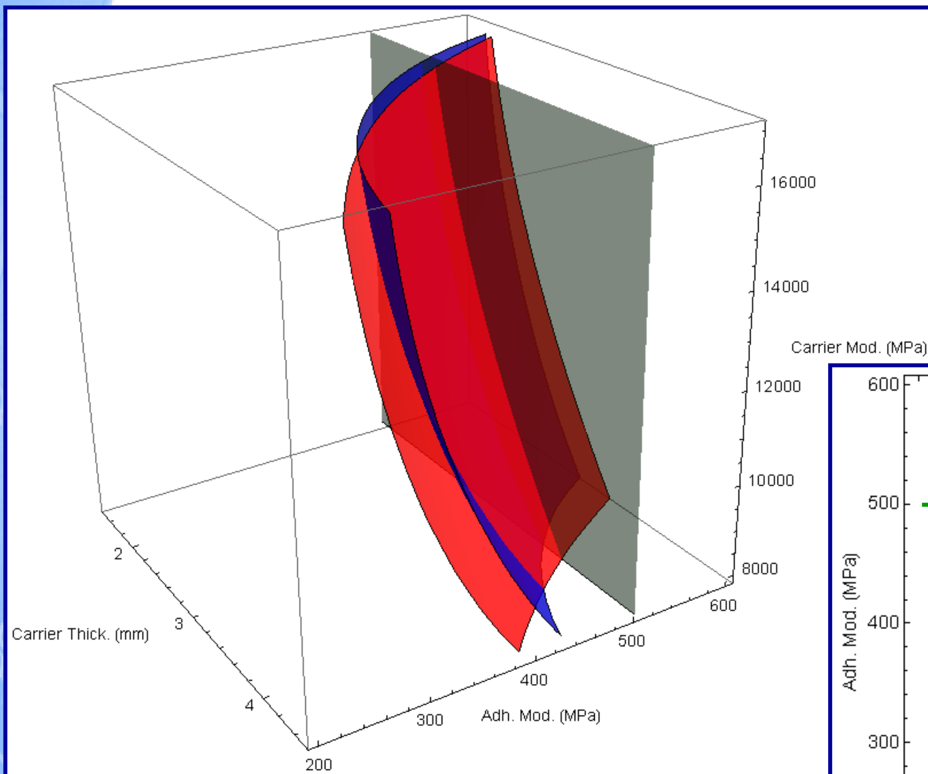
space, what points satisfy the baseline performance?



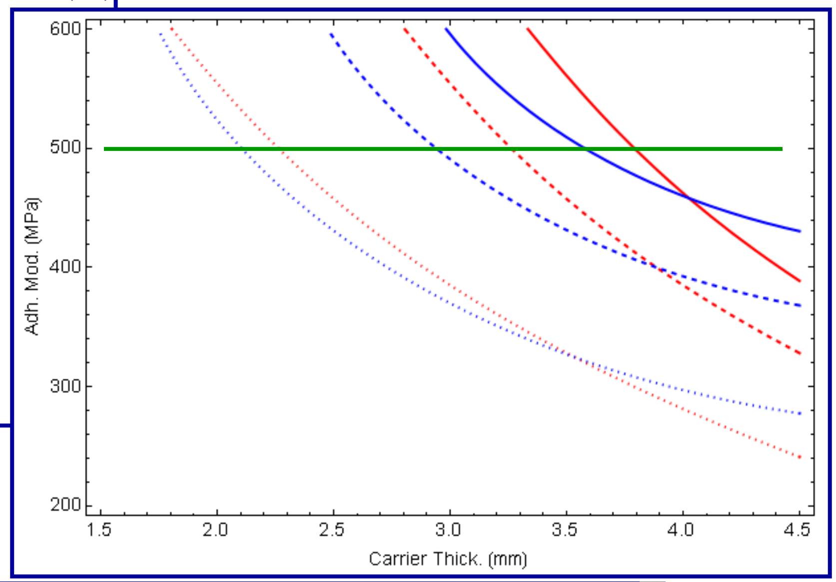


Phase 3

Displacement & Stress Response Surfaces



	Displacement Constrained	Stress Constrained
Nylon66, 33%sgf		
Nylon66, 43%sgf		
BMC (304)		



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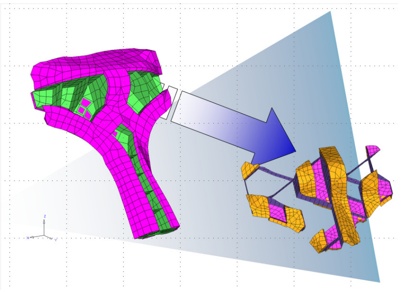
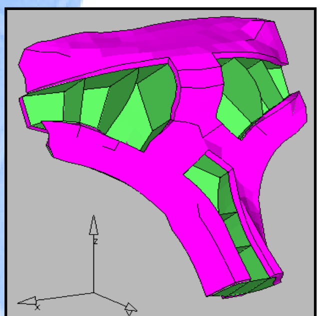
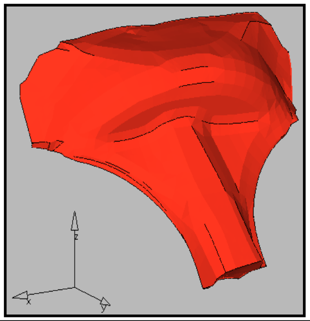
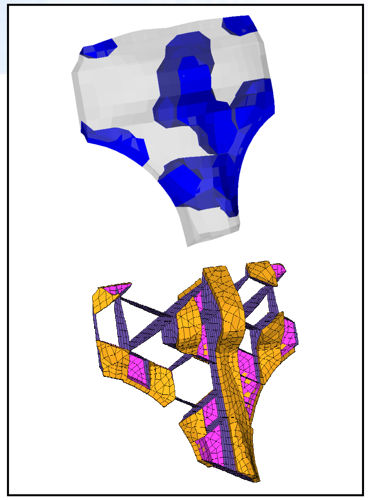


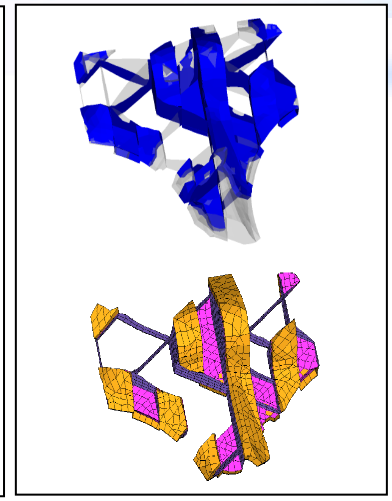
Phase 3

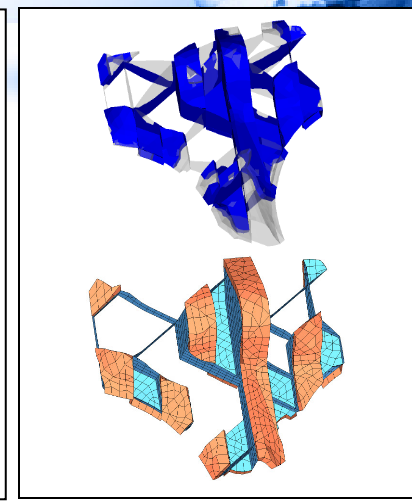
Additional Value from Material Optimization







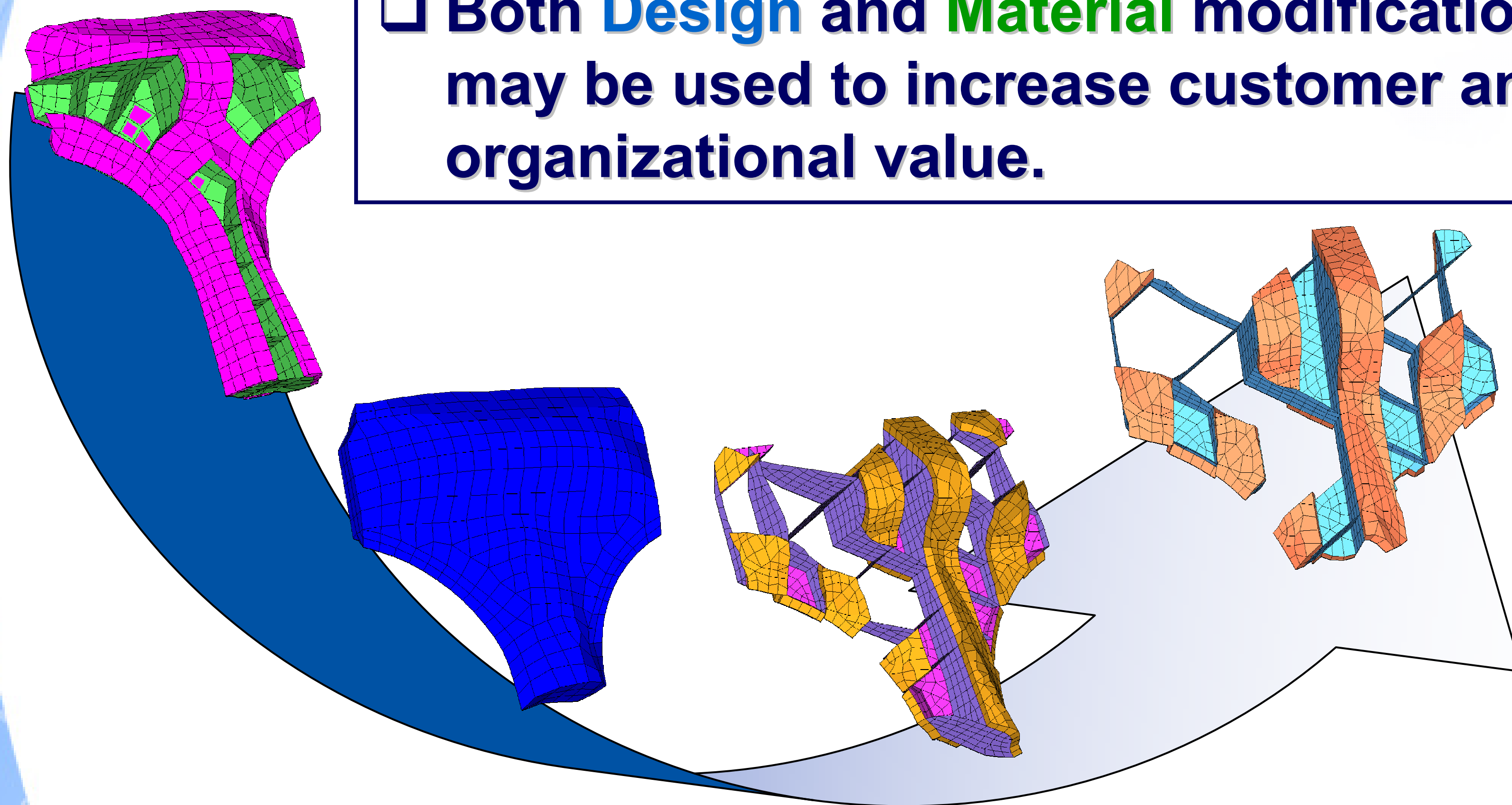


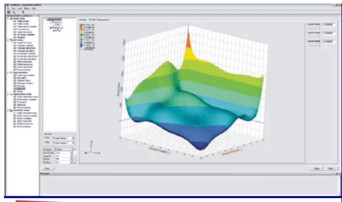


Baseline	Solid	Nylon Ribbed Architecture Optimal Shape	Nylon Ribbed Architecture Optimal Shape “B”	Nylon Ribbed Architecture Alternative Materials
0.456 kg, 4mm thick	0.327 kg (-28.2%)	0.311 kg (-31.8%) 4mm thick	0.227 kg (-50.2%) 4mm thick	0.197 kg (-56.8%) 3.3mm thick Nylon43 OR 0.167 kg (-63.4%) 2.3mm thick BMC
$\lvert \text{Disp}_{\text{Force}} \rvert$= 1.465 mm	$\lvert \text{Disp}_{\text{Force}} \rvert$= 1.447 mm	$\lvert \text{Disp}_{\text{Force}} \rvert$= 1.45 mm	$\lvert \text{Disp}_{\text{Force}} \rvert$= 1.47 mm	$\lvert \text{Disp}_{\text{Force}} \rvert$= 1.47 mm
$\lvert \text{Rot}_{\text{Mom}} \rvert$ = 0.0124 rad	$\lvert \text{Rot}_{\text{Mom}} \rvert$ = 0.0122 rad	$\lvert \text{Rot}_{\text{Mom}} \rvert$ = 0.0125 rad	$\lvert \text{Rot}_{\text{Mom}} \rvert$ = 0.0130 rad	$\lvert \text{Rot}_{\text{Mom}} \rvert$ = 0.0132 rad

Conclusions

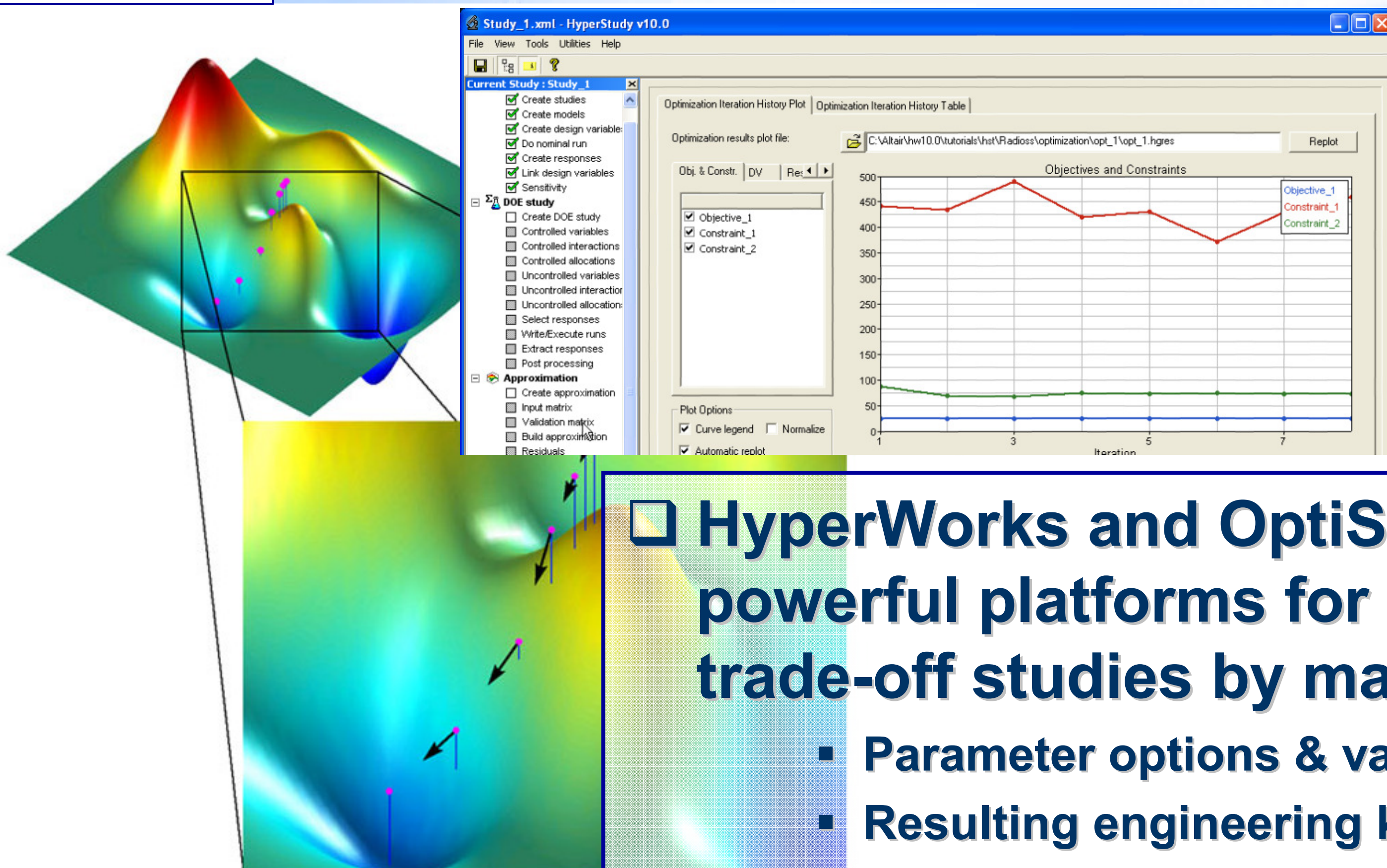
- ❑ **Both Design and Material modifications may be used to increase customer and organizational value.**





HyperWorks®

Conclusions



- ❑ **HyperWorks and OptiStruct provide powerful platforms for design trade-off studies by managing:**
  - **Parameter options & variability**
  - **Resulting engineering knowledge**
  - **Process repeatability**

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Conclusions

- ❑ **Profitability insight and guidelines for innovation in enterprise market space.**

Thank you ….

Tack

Vielen Dank

Obrigado

Merci

ありがとうございます

Bedankt

Takk

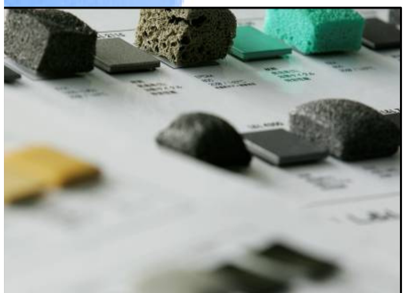
感謝您

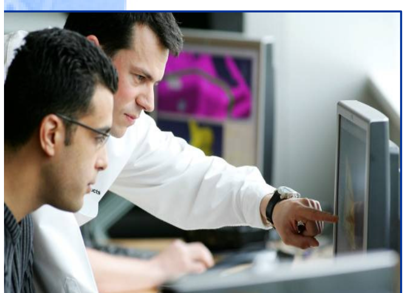
Terima Kasih

谢谢

Grazie

ขอบคุณ





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