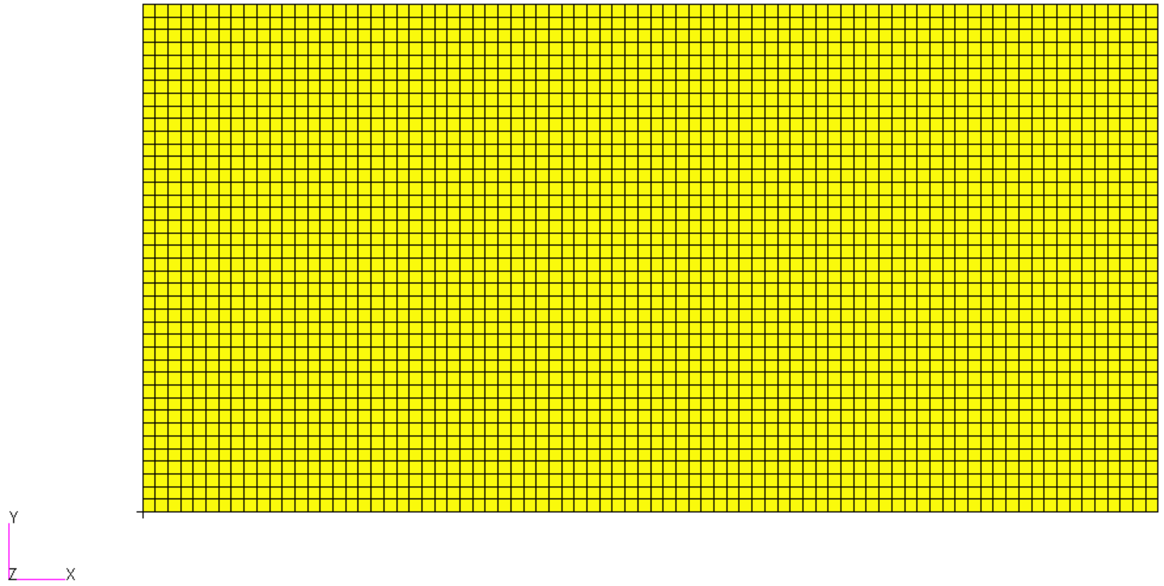
MSC Nastran Topology Optimization Mirror Symmetry Constraints

PRESENTED BY CHRISTIAN APARICIO

Goal: Use Nastran SOL 200 Optimization

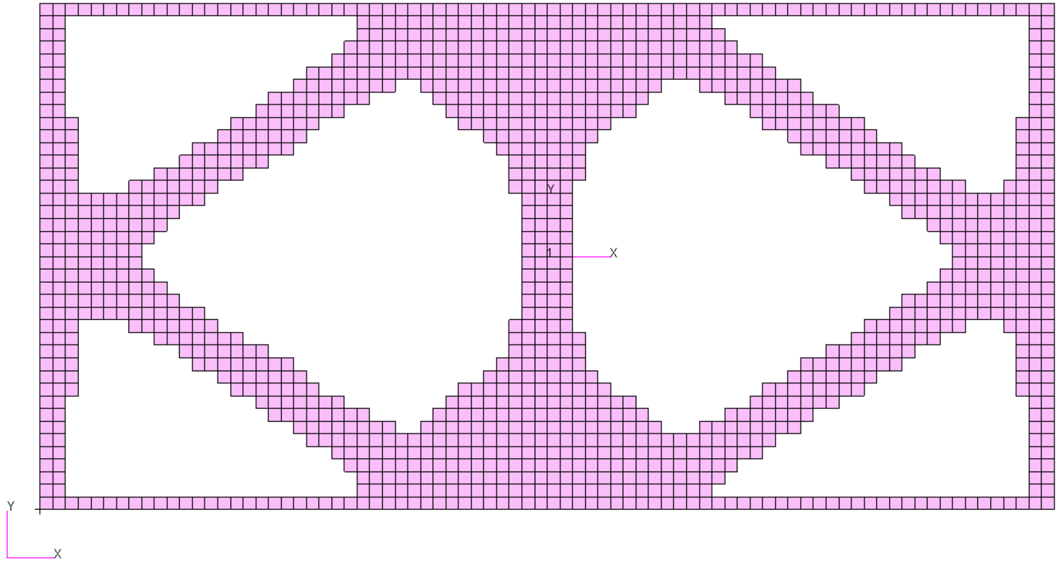
Before Optimization

- Mass: 67.



After Optimization

- Mass: 27.8 (~60% mass reduction)
- Mirror Symmetry Constraints



Agenda

Details of the structural model

Optimization Problem Statement

Steps to use Nastran SOL 200 (Optimization)
- Convert a .bdf file to SOL 200
- Create:
  - Design Regions/Variables
  - Design Objective
  - Design Constraints
- Perform optimization with Nastran SOL 200

View optimization results
- Online Plotter
- Topology Optimization and Structural Results

Contact me

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- Nastran SOL 200 questions
- Structural or mechanical optimization questions
- Access to the SOL 200 Web App

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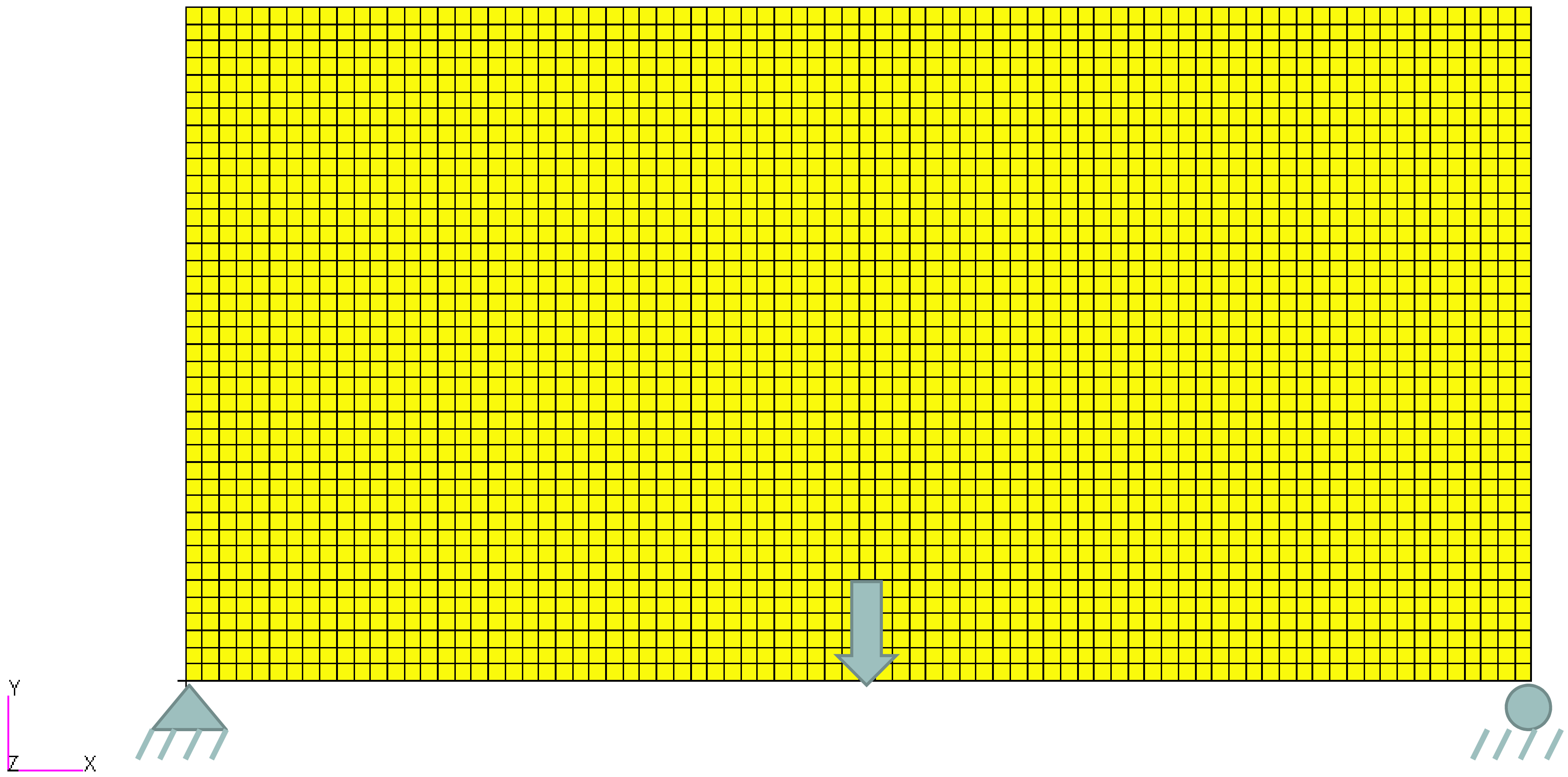
Details of the structural model

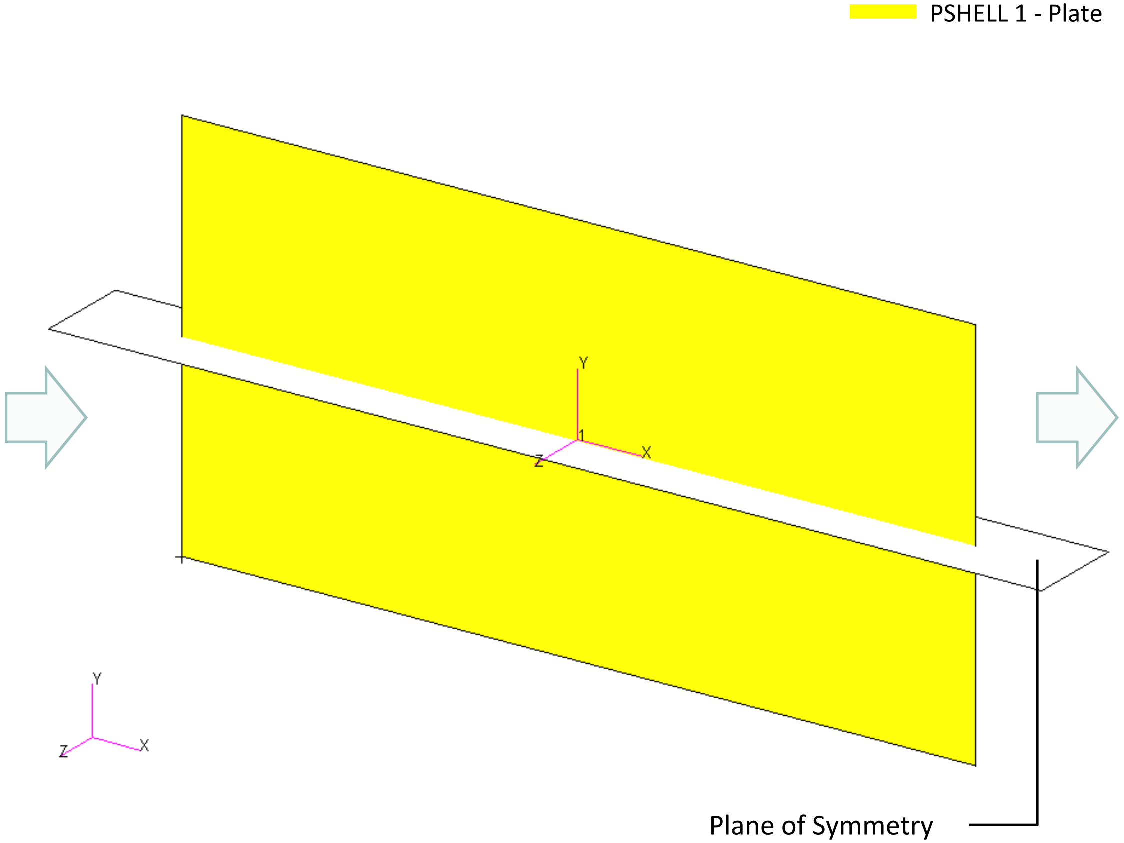


Optimization Problem Statement

Design Region/Variables

x1: PSHELL 1

Restrictions:
- Mirror Symmetry Constraints
  - Symmetry about the ZX plane of coordinate system 1



Design Objective

r0: Minimize compliance

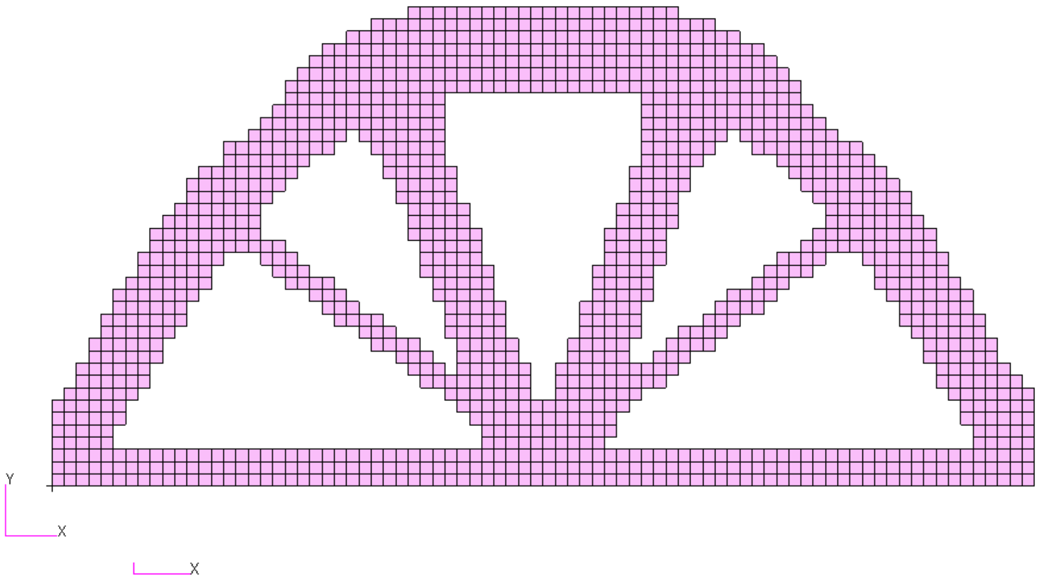
Design Constraints

r1: Fractional mass

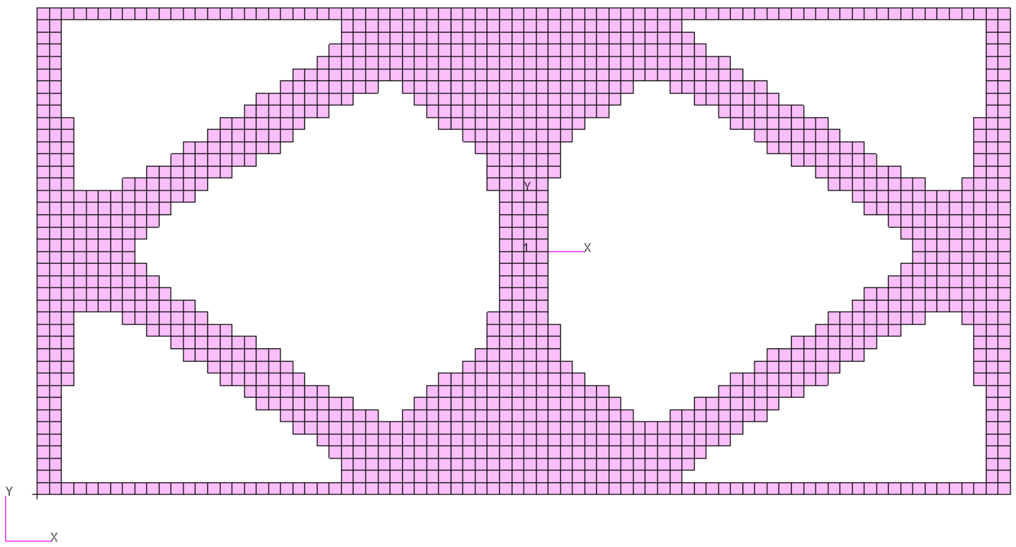
r1 < .4 (60% mass reduction)

Mirror Symmetry Constraints

Without Mirror Symmetry



With Mirror Symmetry



Steps to use Nastran SOL 200 (Optimization)

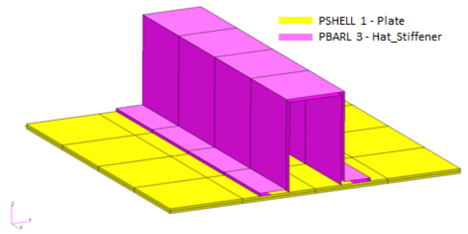
1. Start with a .bdf or .dat file
2. Use the SOL 200 Web App to:
   - Convert the .bdf file to SOL 200
     - Design Regions/Variables
     - Design Objective
     - Design Constraints
   - Perform optimization with Nastran SOL 200
3. Review optimization results
   - Online Plotter
   - Topology Optimization and Structural Results

SOL 200 Web App Capabilities

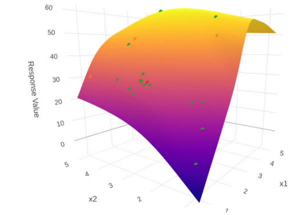
Benefits

- 200+ error validations (real time)
- Web browser accessible
- Automated creation of entries (real time)
- Automatic post-processing
- 76 tutorials

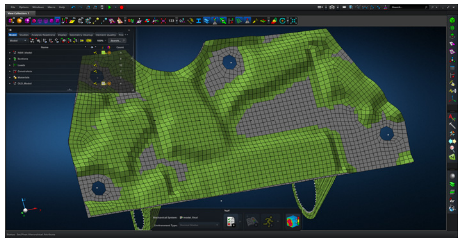
Capabilities



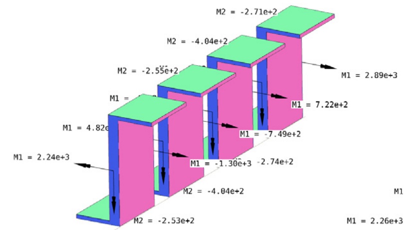
Web Apps for SOL 200
Pre/post for MSC Nastran SOL 200. Support for size, topology, topometry, topography and multi-model.



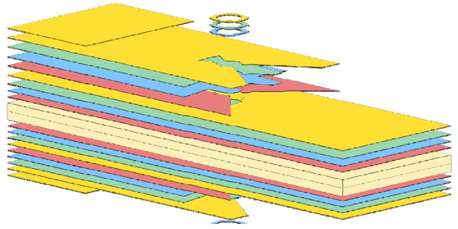
Machine Learning Web App
Bayesian Optimization for nonlinear response optimization (SOL 400)



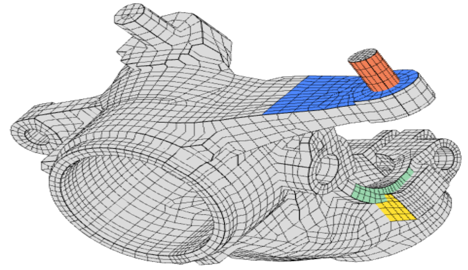
MSC Apex Post Processing Support
View the newly optimized model after an optimization



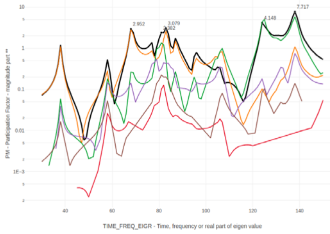
Beams Viewer Web App
Post process 1D element forces, including shear forces, moments, torque and axial forces



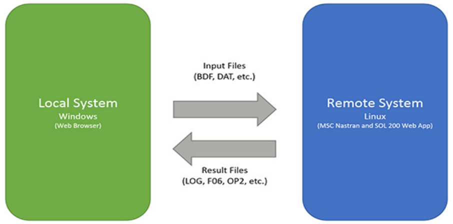
Ply Shape Optimization Web App
Spread plies optimally and generate new PCOMPG entries



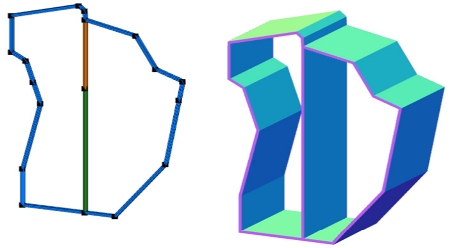
Shape Optimization Web App
Use a web application to configure and perform shape optimization.



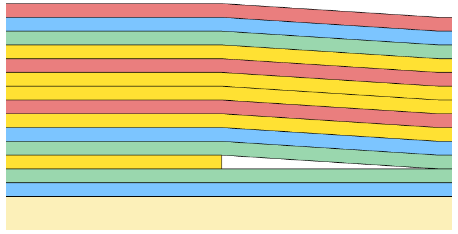
HDF5 Explorer Web App
Create XY plots using data from the H5 file



Remote Execution Web App
Run MSC Nastran jobs on remote Linux or Windows systems available on the local network



PBMSECT Web App
Generate PBMSECT and PBRSECT entries graphically



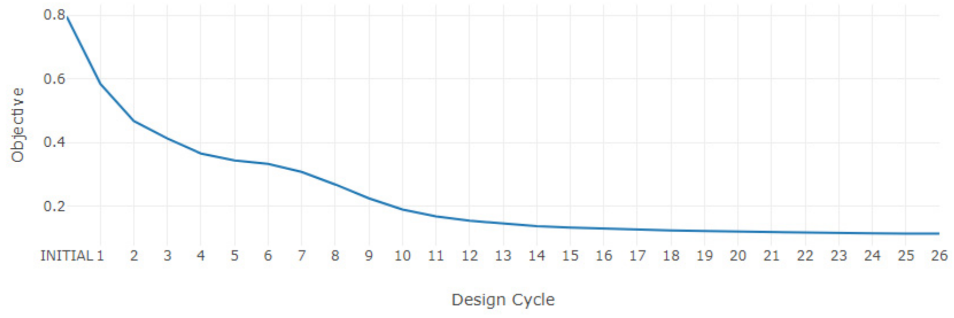
Stacking Sequence Web App
Optimize the stacking sequence of composite laminate plies

View Optimization Results
Online Plotter

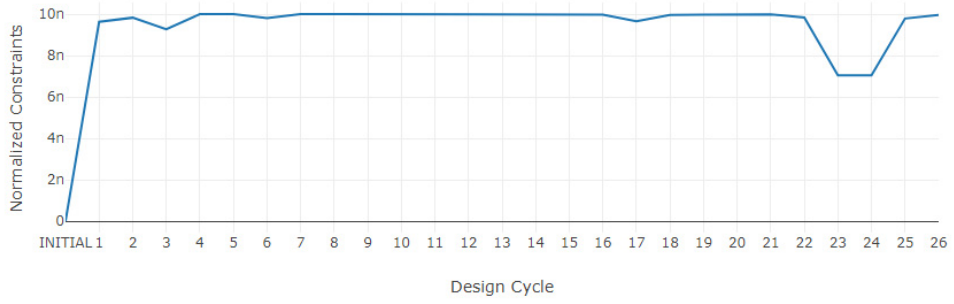
Final Message in .f06

RUN TERMINATED DUE TO HARD CONVERGENCE TO AN OPTIMUM AT CYCLE NUMBER =   26.

Objective



Normalized Constraints



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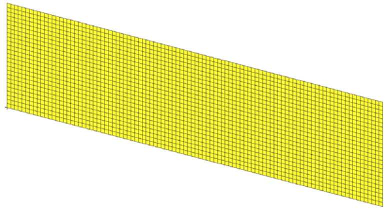
Topology Optimization Workflows

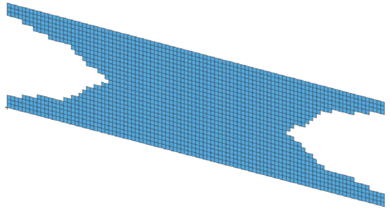
Traditional Topology Optimization

Objective: Minimize Compliance (Maximize Stiffness)
Constraint: Fractional Mass < .## (Target Mass)

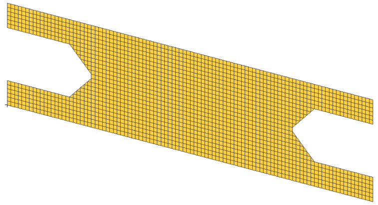
Original Design



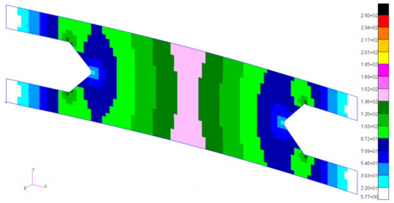
Mass: 9.737 grams



FRMASS < .75
Mass: 7.186 g
Optimization B



Mass: 7.739 g



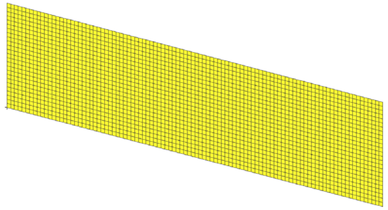
Max von Misses: 150 MPa
Max Displacement : 2.78 mm

1st natural Frequency: 111 Hz

Traditional Topology Optimization

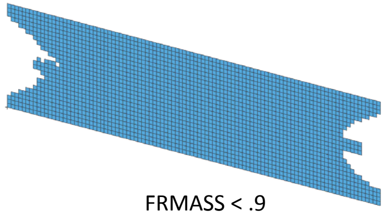
Objective: Minimize Compliance (Maximize Stiffness)
Constraint: Fractional Mass < .## (Target Mass)

Original Design

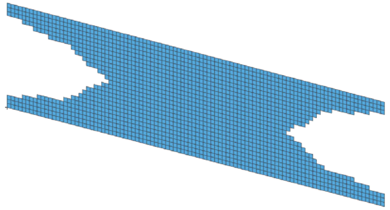


Mass: 9.737 grams

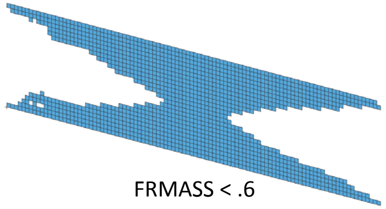
Topology Solution



FRMASS < .9
Mass: 8.756 g
Optimization A

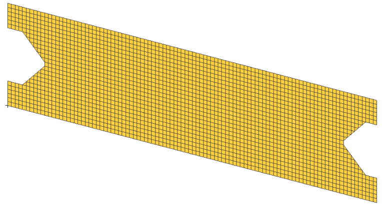


FRMASS < .75
Mass: 7.186 g
Optimization B

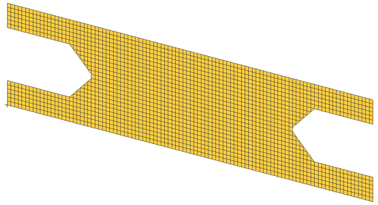


FRMASS < .6
Mass: 5.718 g
Optimization C

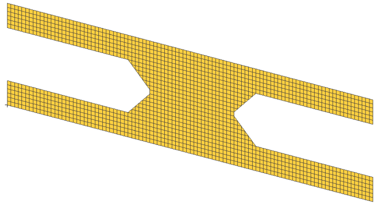
Refined Design



Mass: 9.094 g

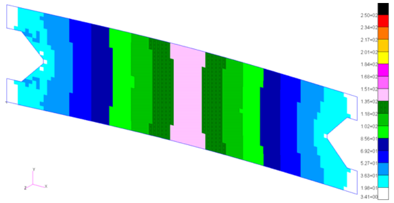


Mass: 7.739 g



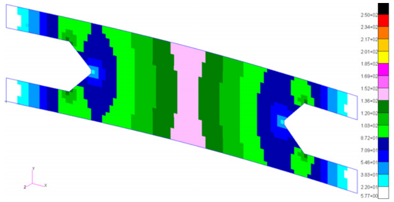
Mass: 6.119 g

Verification



Max von Misses: 150 MPa
Max Displacement: 2.52 mm

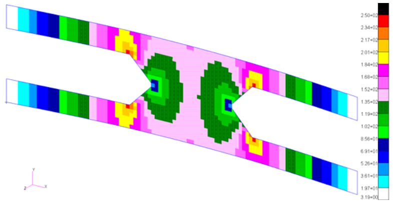
1st natural Frequency: 114 Hz



Max von Misses: 150 MPa
Max Displacement : 2.78 mm

1st natural Frequency: 111 Hz

Optimization B led to a valid and light weight design



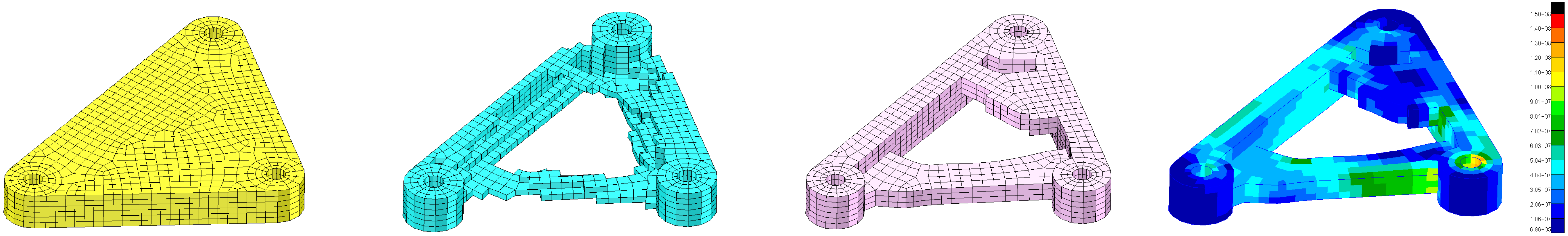
Max von Misses: 250 MPa
Max Displacement : 3.57 mm

1st natural Frequency: 109 Hz

Latest Topology Optimization

Objective: Minimize Fractional Mass (Minimize Mass)
Constraint: Stress Constraint

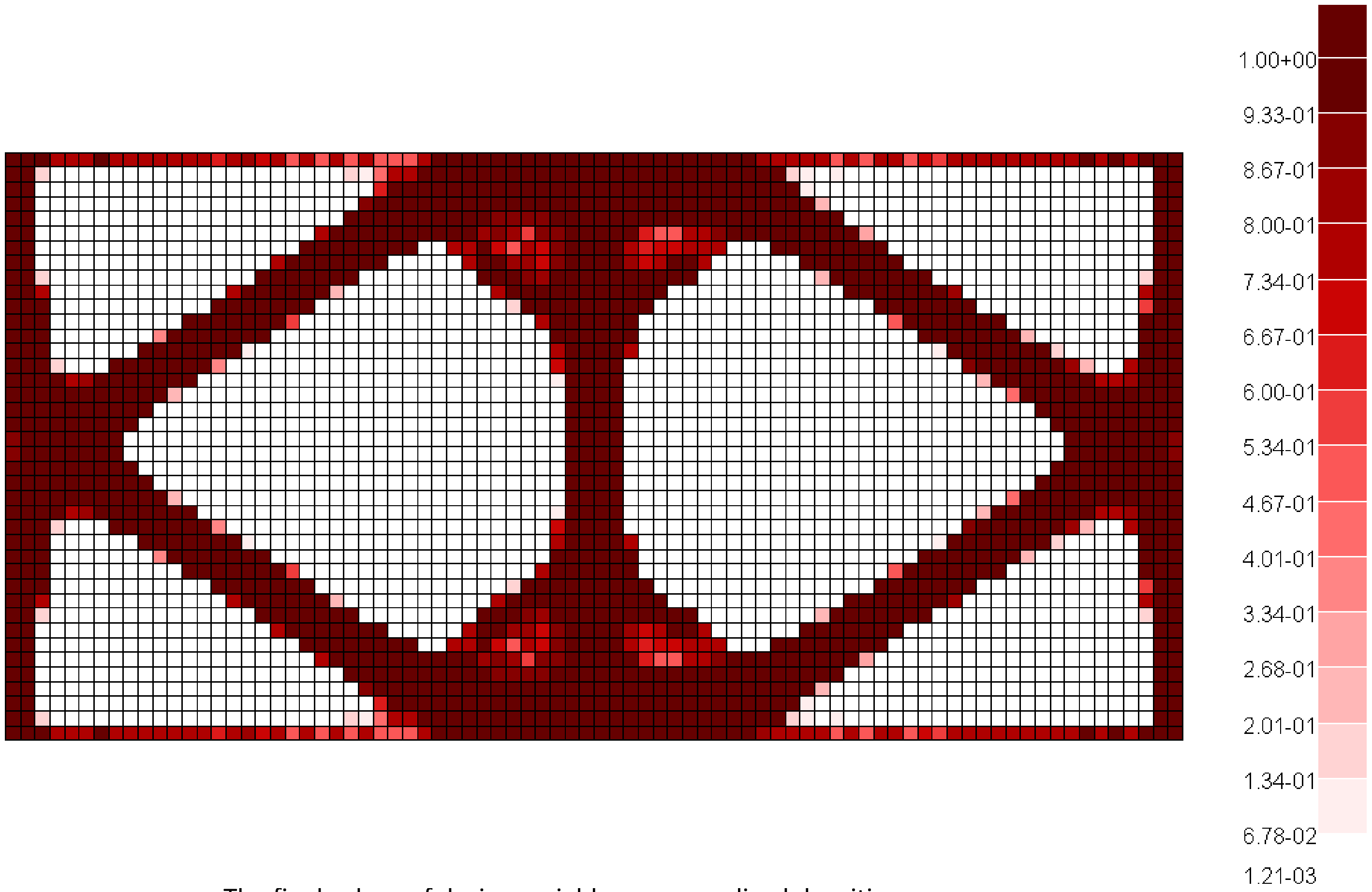
Original Design → Topology Solution → Refined Design → Verification



Appendix

What are the design variables in Topology Optimization?

- Each element that is within a design region is given a design variable that represents a *normalized material density*
  - 0 - Normalized density values close to 0 are not critical to the design
  - 1 - Normalized density values close to 1 are critical to the design



The final values of design variables or normalized densities are plotted for each element.

What is compliance?

Compliance is defined in many ways

- *“Compliance is defined as the dot product of the load times the displacement.”* (MSC Nastran Design Sensitivity and Optimization User’s Guide)
- “Compliance is simply the product of the displacement times the applied load” (MSC Nastran Design Sensitivity and Optimization User’s Guide)
- For the example shown on the right, the work done or compliance is equal to the product of load and displacement. See eq. 8.2.1.
- The work done and total strain energy are related. Note that the work done is twice the value of strain energy. See eq. 8.2.2.

```
                        E L E M E N T   S T R A I N   E N E R G I E S

ELEMENT-TYPE = QUAD4                * TOTAL ENERGY OF ALL ELEMENTS IN PROBLEM     =   3.975871E-01
SUBCASE               1             * TOTAL ENERGY OF ALL ELEMENTS IN SET      -1 =   3.975871E-01

                ELEMENT-ID        STRAIN-ENERGY        PERCENT OF T                    'Y
                        1         2.566443E-02              6.4550
                        2         9.840468E-03              2.4750                3.936195E-01
                        3         4.652526E-03              1.1702                1.861014E-01
                     1561         2.380879E-02              5.9883                9.523516E-01
                     1562         4.874675E-03              1.2261                1.949870E-01
                     1601         2.380879E-02              5.9883                9.523516E-01
```

Total Strain Energy

```
                   ******************************************************************
                   S U M M A R Y   O F   D E S I G N   C Y C L E   H I S T O R Y
                   ******************************************************************

                                (HARD CONVERGENCE ACHIEVED)

                   NUMBER OF FINITE ELEMENT ANALYSES COMPLETED          27
                   NUMBER OF OPTIMIZATIONS W.R.T. APPROXIMATE MODELS    26

                           OBJECTIVE AND MAXIMUM CONSTRAINT HISTORY
```

CYCLE NUMBER	OBJECTIVE FROM APPROXIMATE OPTIMIZATION	OBJECTIVE FROM EXACT ANALYSIS	FRACTIONAL ERROR OF APPROXIMATION	MAXIMUM VALUE OF CONSTRAINT
INITIAL		7.951742E-01		-2.234324E-14
1	3.554465E-01	5.847678E-01	-3.921578E-01	9.627482E-09
2	2.969779E-01	4.67	3.643395E-01	9.820965E-09
3	2.743056E-01	4.123281E-01	-3.347396E-01	9.511386E-09
4	2.502092E-01	3.647719E-01	-3.140666E-01	9.883022E-09

Compliance

What is compliance? Continued

The .f06 file reports the value of compliance and strain energy. **The following applies if and only if minimizing the compliance is the design objective.**

1. Make sure this statement is in the Case Control Section of the .bdf file.
    1. *ESE(THRESH=.99)=ALL*
2. Search the .f06 file for the initial design’s
    1. *E L E M E N T S T R A I N E N E R G I E S*
3. *Note the value of TOTAL ENERGY OF ALL ELEMENTS IN PROBLEM*
4. *Search the .f06 for the*
    1. S U M M A R Y O F D E S I G N C Y C L E H I S T O R Y
5. Note the value for OBJECTIVE FROM EXACT ANALYSIS for the INITIAL cycle number
6. The Compliance of 7.95E-01 is twice the TOTAL STRAIN ENERGY of 3.97E-01.

```
                        E L E M E N T   S T R A I N   E N E R G I E S

ELEMENT-TYPE = QUAD4               * TOTAL ENERGY OF ALL ELEMENTS IN PROBLEM     =    3.975871E-01
SUBCASE            1               * TOTAL ENERGY OF ALL ELEMENTS IN SET      -1 =    3.975871E-01

               ELEMENT-ID          STRAIN-ENERGY           PERCENT OF T                         Y
                        1          2.566443E-02                6.4550
                        2          9.840468E-03                2.4750              3.936195E-01
                        3          4.652526E-03                1.1702              1.861014E-01
                     1561          2.380879E-02                5.9883              9.523516E-01
                     1562          4.874675E-03                1.2261              1.949870E-01
                     1601          2.380879E-02                5.9883              9.523516E-01
```

Total Strain Energy

```
          ******************************************************************
          S U M M A R Y   O F   D E S I G N   C Y C L E   H I S T O R Y
          ******************************************************************

                        (HARD CONVERGENCE ACHIEVED)

     NUMBER OF FINITE ELEMENT ANALYSES COMPLETED           27
     NUMBER OF OPTIMIZATIONS W.R.T. APPROXIMATE MODELS     26

                  OBJECTIVE AND MAXIMUM CONSTRAINT HISTORY
---------------------------------------------------------------------------------------------
               OBJECTIVE FROM        OBJECTIVE FROM     FRACTIONAL ERROR      MAXIMUM VALUE
 CYCLE           APPROXIMATE             EXACT                OF                   OF
 NUMBER          OPTIMIZATION           ANALYSIS         APPROXIMATION         CONSTRAINT
---------------------------------------------------------------------------------------------

 INITIAL                              7.951742E-01                             -2.234324E-14

      1         3.554465E-01          5.847678E-01        -3.921578E-01         9.627482E-09

      2         2.969779E-01          4.67                 3.643395E-01         9.820965E-09

      3         2.743056E-01          4.123281E-01        -3.347396E-01         9.511386E-09

      4         2.502092E-01          3.647719E-01        -3.140666E-01         9.883022E-09
```

Compliance

What is FRMASS or Fractional Mass?

- At the start of the optimization, the INITIAL design has its material densities reduced.
- During the optimization, each normalized material density is varied in order to minimize the compliance of the entire structure (increase the stiffness)
- IMPORTANT: Always use decimal points when specifying FRMASS

Total: 6

1.0	1.0	1.0
1.0	1.0	1.0

1) INITIAL design
- FRMASS = 1.0
- Original density

Total: 1.8

.3	.3	.3
.3	.3	.3

2) Reduction (Start of Optimization)
- FRMASS = .3
- All densities are set to .3 (30%) of the original density

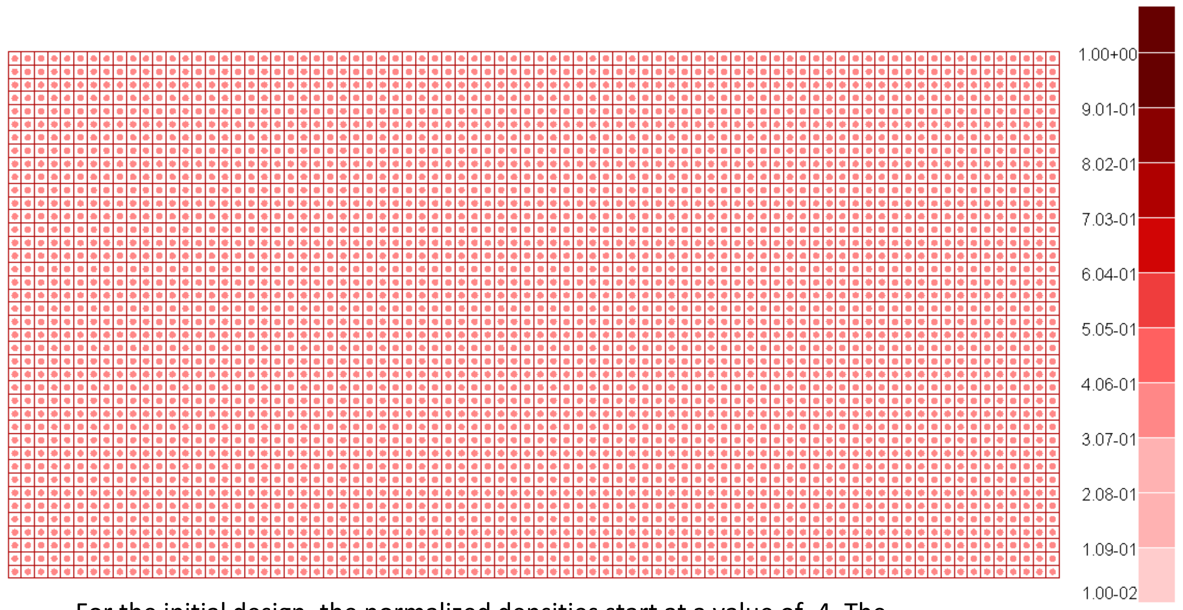
Total: 1.8

.1	.1	1.0
.1	.1	.4

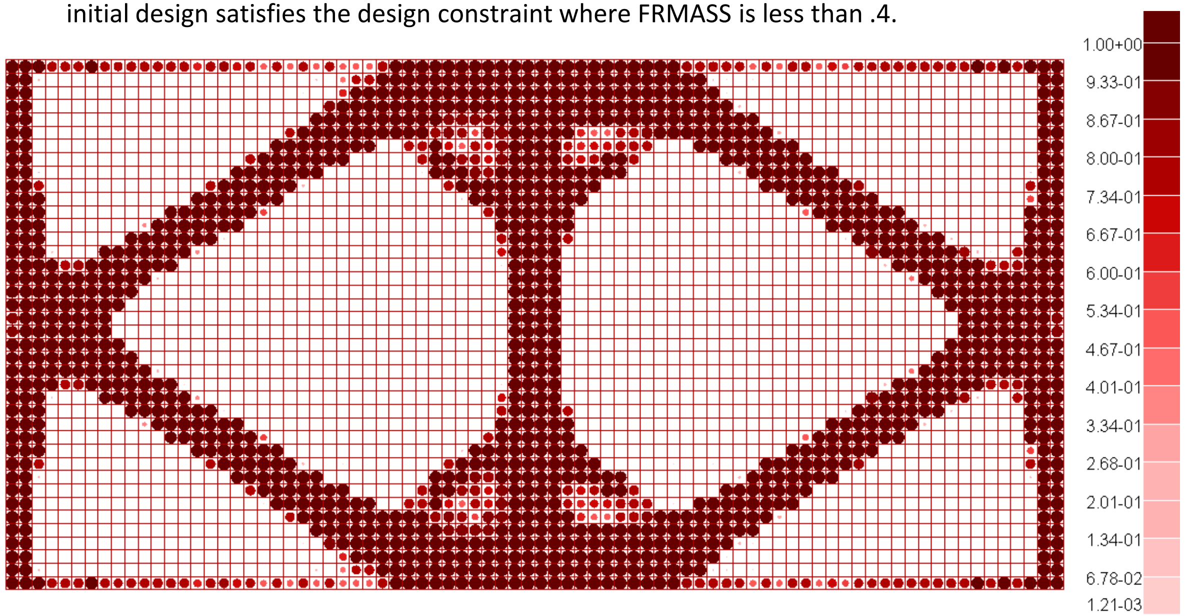
3) Optimization
- FRMASS < .3
- Normalized Densities are varied

How is it possible to increase the stiffness?

- The initial design (Top) has the following characteristics:
  - The optimizer will set each initial normalized material density to the FRMASS specified.
  - Since each element's density is .4 of the original density, the mass is 40% of the original
  - As a result, the compliance or work done has been increased
- During the Topology Optimization, the optimizer will vary the normalized material densities while minimizing the Compliance
- The final design (Bottom) has the following characteristics:
  - The normalized densities have been varied, but the total mass remains 40% of the original
  - The compliance or work done has been minimized



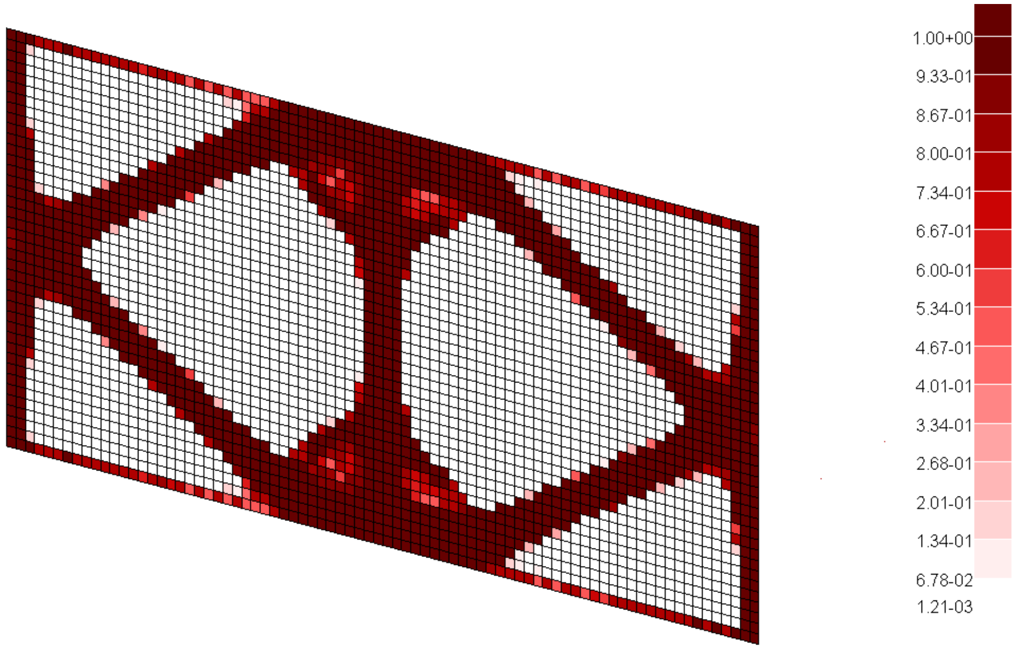
For the initial design, the normalized densities start at a value of .4. The initial design satisfies the design constraint where FRMASS is less than .4.



At the end of the optimization, each element has a different normalized density. The total mass of this design still satisfies the design constraint, FRMASS is less than .4.

How can non-critical elements be removed from the design?

- Use the threshold to suppress non-critical elements
- The threshold means: *'Keep every element that has a normalized density greater than the threshold'*
- Recall from before:
    - 0 - Normalized density values close to 0 are not critical to the design
    - 1 - Normalized density values close to 1 are critical to the design



The normalized densities are plotted for each element. Note that all the elements are present.