# MSC Nastran Topology Optimization - Multidiscipline - Static Loading and Natural Frequency

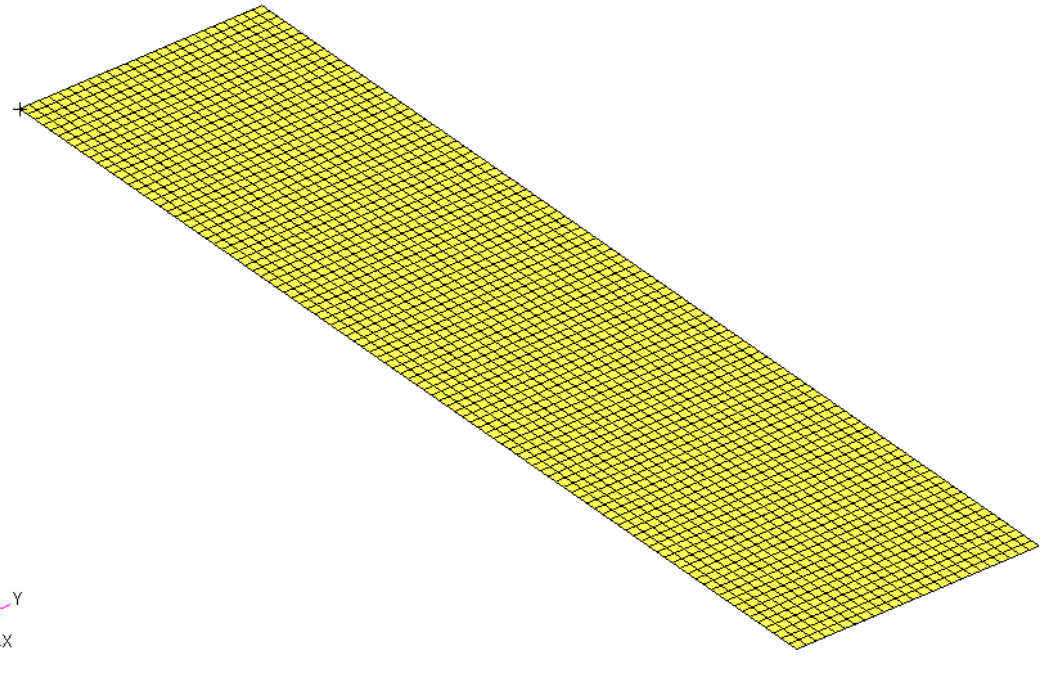
PRESENTED BY CHRISTIAN APARICIO

Questions? Email: christian@ the-engineering-lab.com

# Goal: Use Nastran SOL 200 Optimization

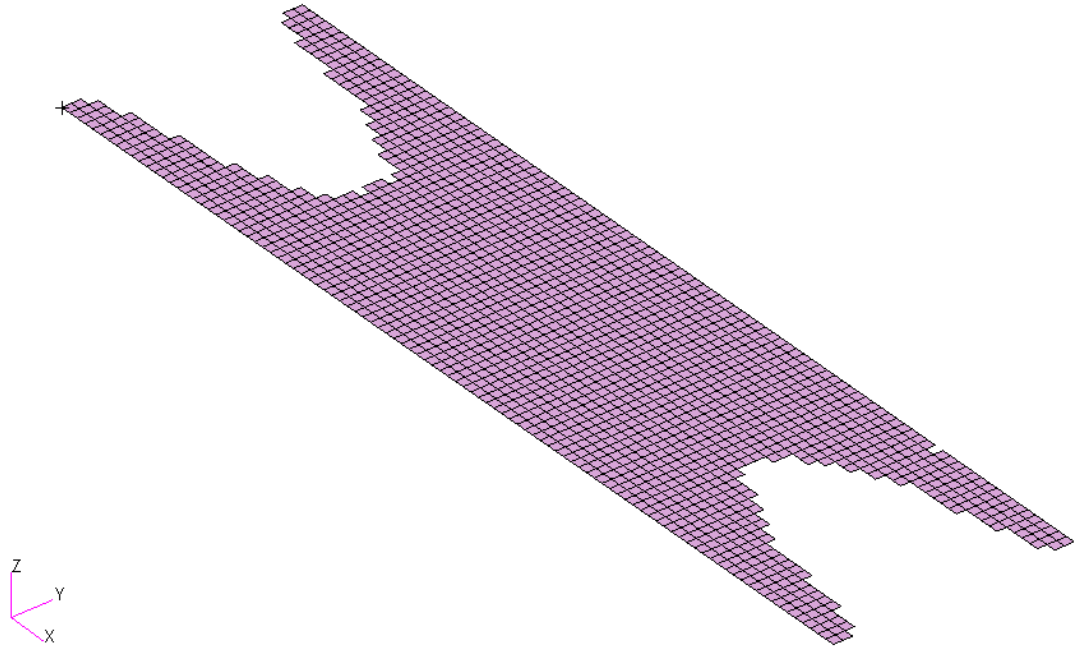
Before Optimization

- Mass:  9.73E-06




After Optimization

- Mass:  7.05E-06 (~25% mass reduction)
- Maximize stiffness
- Maximize first natural frequency



# 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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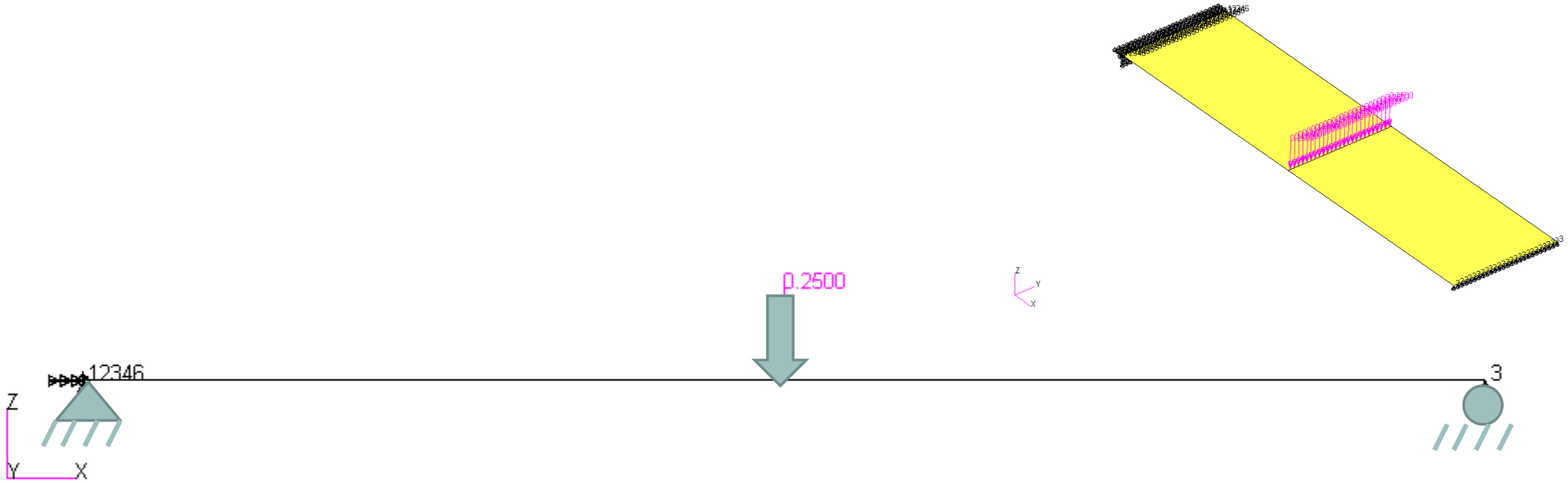
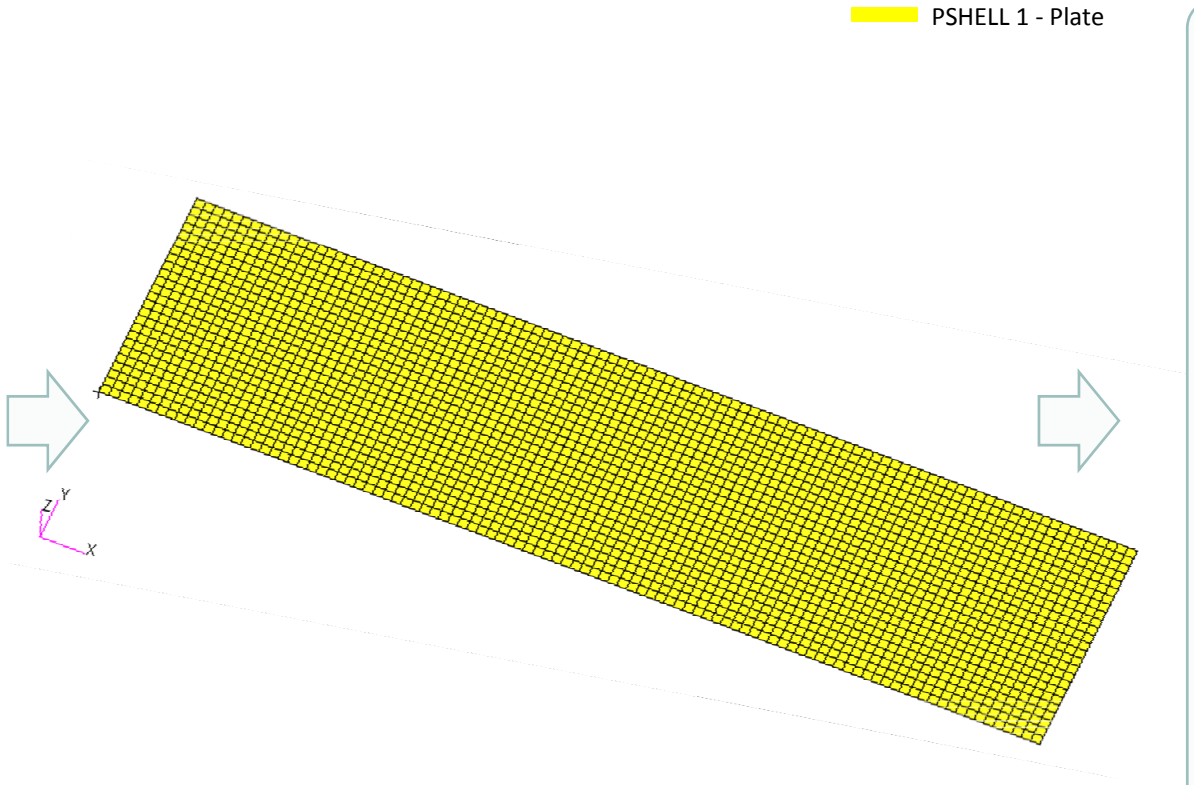
# Details of the structural model



# Optimization Problem Statement

## Design Region/Variables

x1: PSHELL 1




## Design Equation Objective

R0: Minimize the sum of normalized compliance and normalized natural frequency

$$R0 = \frac{a1}{36.7} + \frac{86.4}{a2}$$

a1: Compliance of SUBCASE 1
a2: Natural frequency of mode 1 of SUBCASE 2

## Design Constraints

r1: Fractional mass

r1 < .75 (25% mass reduction)

r2: The z component of displacement at node 714

-5.0 < r2

r3: The natural frequency of mode 1

20 < r3

# Why this Equation Constraint?

Why use this equation constraint?

- By minimizing R0,
  - The work done due to the load will be minimized => Increase in stiffness. As a1 or the work done gets larger, the term gets smaller
  - The 1st natural frequency will be maximized, as a2, the frequency, gets higher, the term becomes smaller

Why are the values normalized, i.e. dividing by the original values?

- The goal is to express the values in terms of 1.0
- Avoid the situation where the compliance is orders of magnitude larger than natural frequency

## Design Equation Objective

*R0*: Minimize the sum of normalized compliance and normalized natural frequency

$$R_0 = \frac{a_1}{36.7} + \frac{86.4}{a_2}$$

a1: Compliance of SUBCASE 1
a2: Natural frequency of mode 1 of SUBCASE 2

# Steps to use Nastran SOL 200 (Optimization)

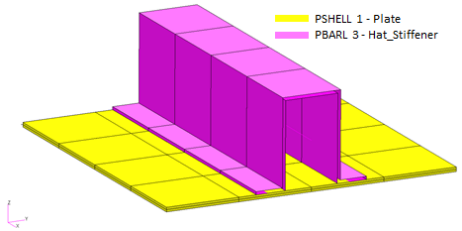
1. Start with a .bdf or .dat file
2. Use the SOL 200 Web App to:
   - Convert the .bdf file to SOL 200
     - Design Regions/Variables
     - Design Objective
     - Design Constraints
   - Perform optimization with Nastran SOL 200
3. Review optimization results
   - Online Plotter
   - Topology Optimization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

# SOL 200 Web App Capabilities

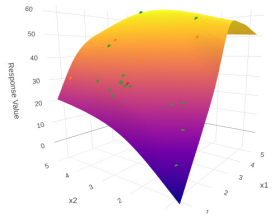
## Benefits

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

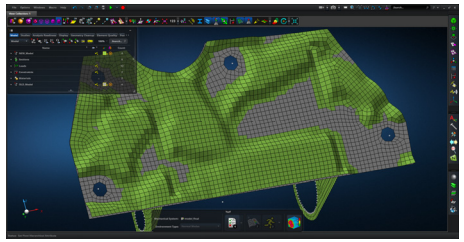
## Capabilities



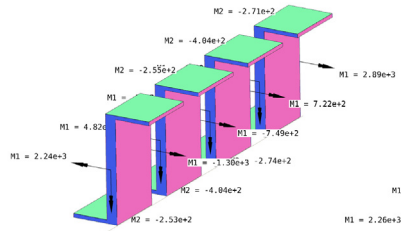

**Web Apps for SOL 200**
Pre/post for MSC Nastran SOL 200. Support for size, topology, topometry, topography and multi-model.



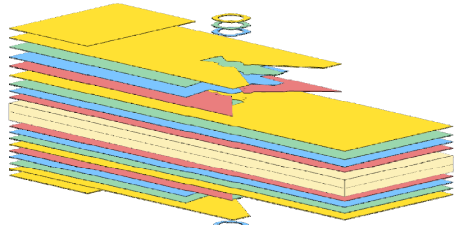
**Machine Learning Web App**
Bayesian Optimization for nonlinear response optimization (SOL 400)



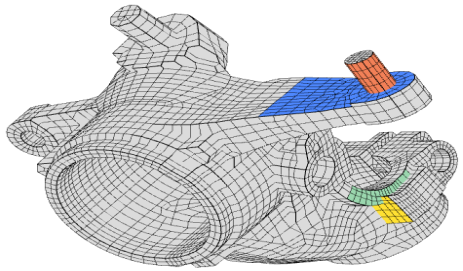
**MSC Apex Post Processing Support**
View the newly optimized model after an optimization



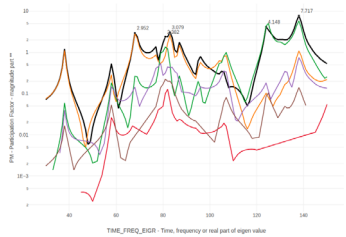
**Beams Viewer Web App**
Post process 1D element forces, including shear forces, moments, torque and axial forces



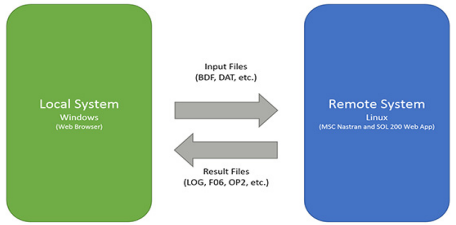
**Ply Shape Optimization Web App**
Spread plies optimally and generate new PCOMPG entries



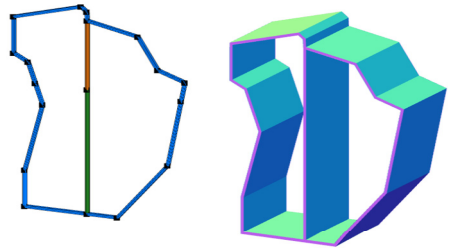
**Shape Optimization Web App**
Use a web application to configure and perform shape optimization.



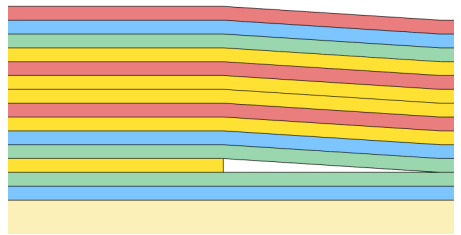
**HDF5 Explorer Web App**
Create XY plots using data from the H5 file




**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



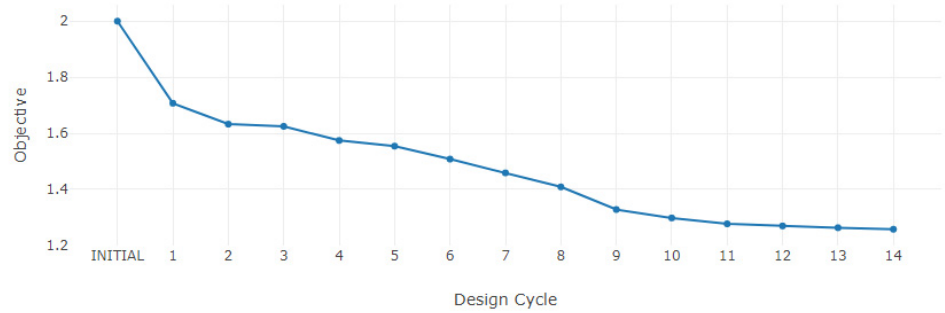
**Stacking Sequence Web App**
Optimize the stacking sequence of composite laminate plies

# View Optimization Results
## Online Plotter

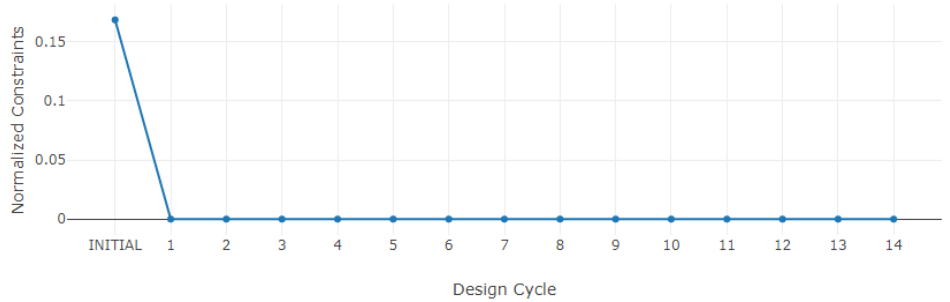
Final Message in .f06

RUN TERMINATED DUE TO HARD CONVERGENCE TO AN OPTIMUM AT CYCLE NUMBER = 14.

Objective




Normalized Constraints



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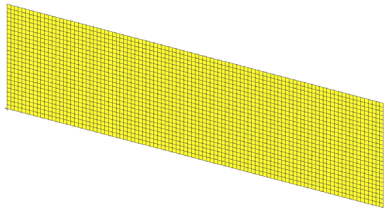
# Topology Optimization Workflows

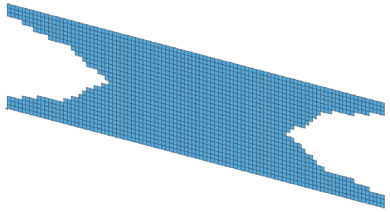
# Traditional Topology Optimization

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

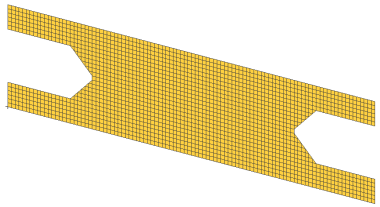
## Original Design



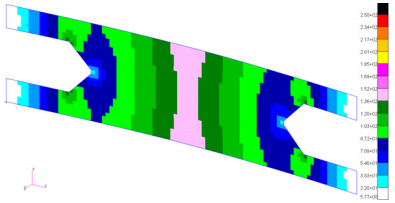
Mass: 9.737 grams



FRMASS < .75
Mass: 7.186 g
Optimization B



Mass: 7.739 g



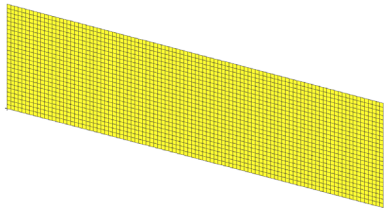
Max von Misses: 150 MPa
Max Displacement : 2.78 mm

1st natural Frequency: 111 Hz

# Traditional Topology Optimization

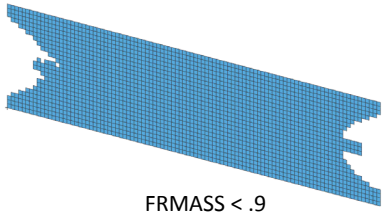
Objective: Minimize Compliance (Maximize Stiffness)
Constraint: Fractional Mass < .## (Target Mass)

## Original Design

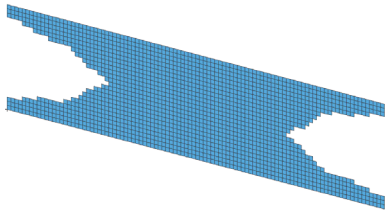


Mass: 9.737 grams

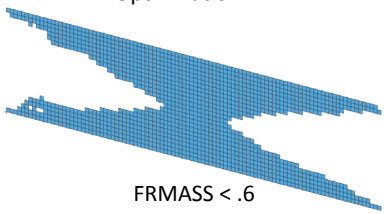
## Topology Solution



FRMASS < .9
Mass: 8.756 g
Optimization A

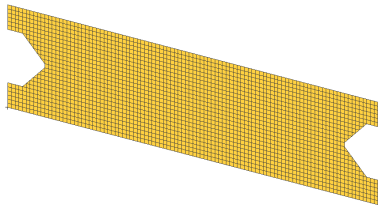


FRMASS < .75
Mass: 7.186 g
Optimization B

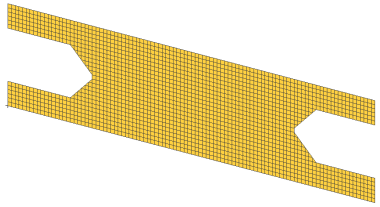


FRMASS < .6
Mass: 5.718 g
Optimization C

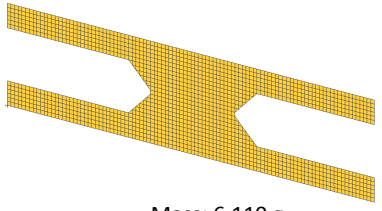
## Refined Design



Mass: 9.094 g

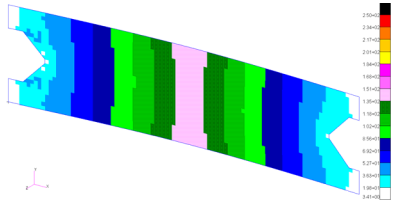


Mass: 7.739 g



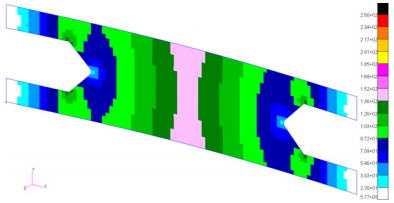
Mass: 6.119 g

## Verification



Max von Misses: 150 MPa
Max Displacement: 2.52 mm

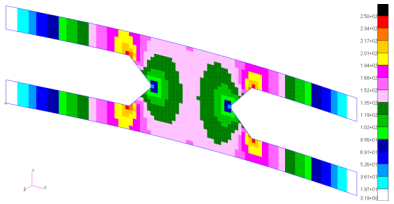
1st natural Frequency: 114 Hz



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



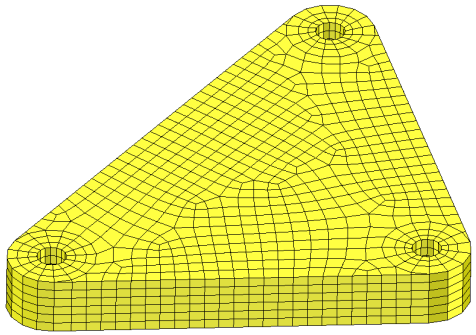
Max von Misses: 250 MPa
Max Displacement : 3.57 mm

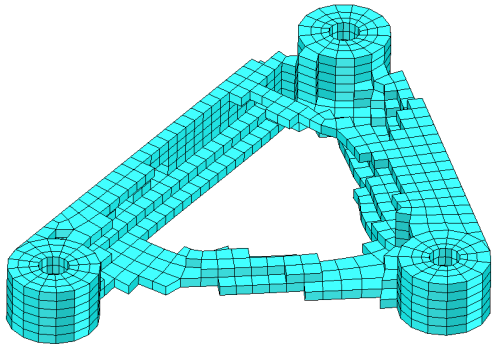
1st natural Frequency: 109 Hz

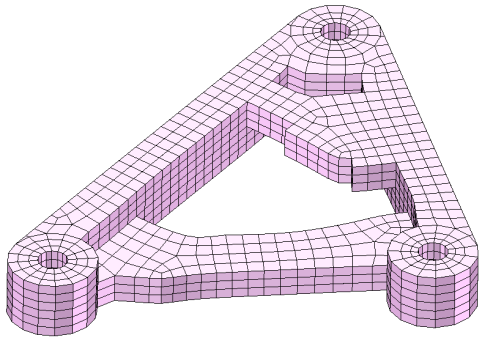
# Latest Topology Optimization

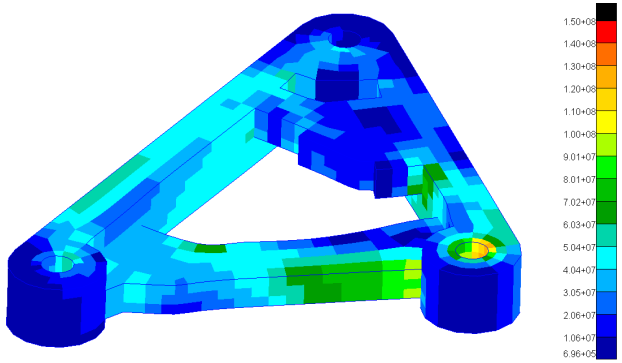
Objective: Minimize Fractional Mass (Minimize Mass)
Constraint: Stress Constraint

Original Design → Topology Solution → Refined Design → Verification





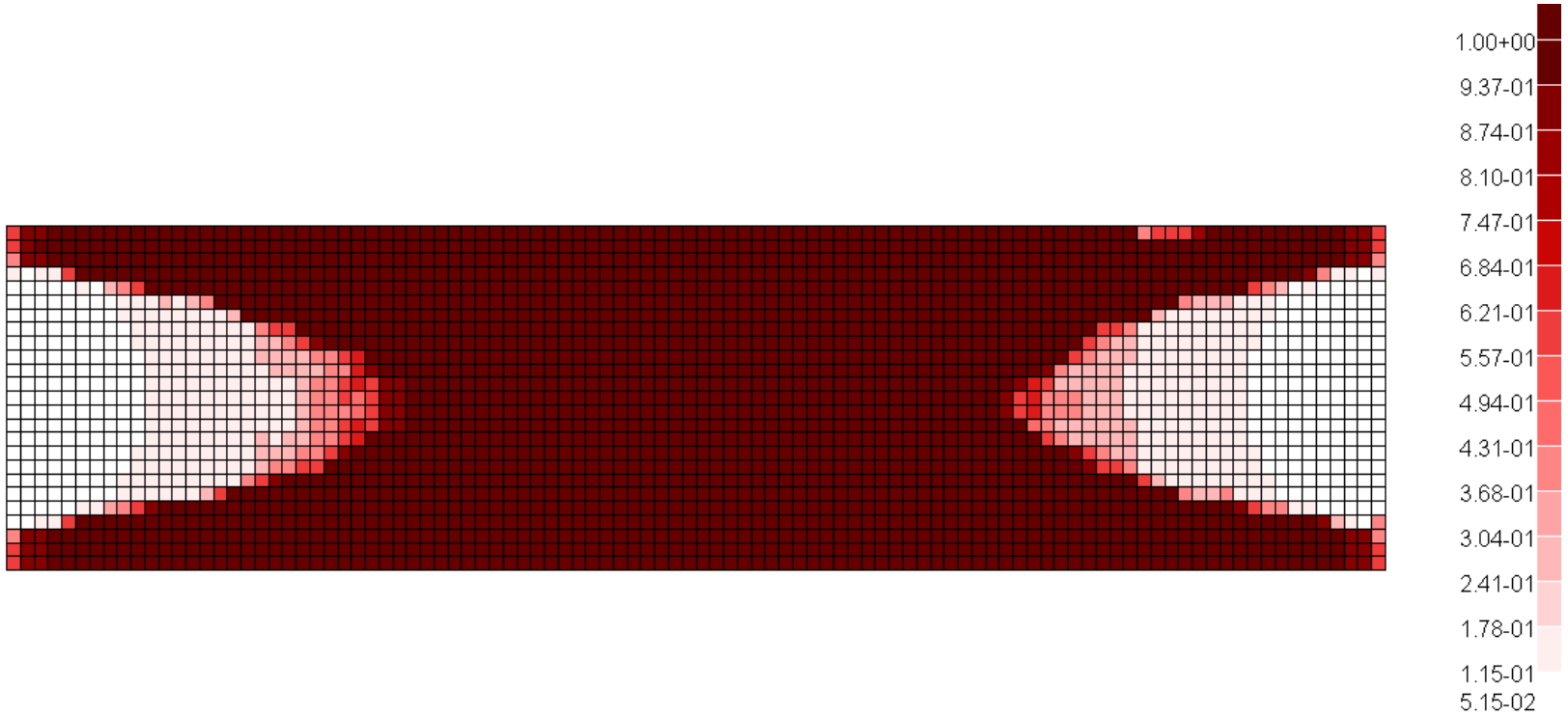




# Appendix

# 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.

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# What is compliance?

Compliance is defined in many ways

- “Compliance is simply the product of the displacement times the applied load” (MSC Nastran Design Sensitivity and Optimization User’s Guide)
- For linear elastic solids, the work is twice the total strain energy

```
                                    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      =   1.839387E+01
SUBCASE              1            * TOTAL ENERGY OF ALL ELEMENTS IN SET       -1 =   1.839387E+01

                    ELEMENT-ID          STRAIN-ENERGY          PERCENT OF

        TYPE = QUAD4     SUBTOTAL       1.839387E+01              100.0000
```

Total Strain Energy

```
                                  ********************************************
                                  *                                          *
                                  *       I N I T I A L   A N A L Y S I S    *
                                  *                                          *
                                  ********************************************


                          *******   ANALYSIS RESULTS BASED ON THE INITIAL DESIGN   *******
SC.NASTRAN JOB CREATED ON 07-SEP-17 AT 13:07:10                    SEPTEMBER   7, 2017  MSC Nastran  4/ 5/1
                                                                                                    SUBCA

                     ---------------------------------------------------------------------
                     |       R E S P O N S E S    I N    D E S I G N    M O D E L       |
                     ---------------------------------------------------------------------

                                (N/A - BOUND NOT ACTIVE OR AVAILABLE)
                              (*** VIOLATED RESPONSES MARKED WITH V ***)
                              (*** ACTIVE RESPONSES MARKED WITH A ***)

                        I N I T I A L   A N A L Y S I S   S U B C A S E =      1

                                      -----     DISPLACEMENT RESPONSES     -----

-------------------------------------------------------------------------------------------------------------------
   INTERNAL     DRESP1     RESPONSE      GRID      COMPONENT        LOWER                          UPPER
     ID           ID        LABEL         ID          NO.           BOUND          VALUE           BOUND
-------------------------------------------------------------------------------------------------------------------
          1    8000002    R2              714           3     -5.0000E+00 V    -5.8426E+00         N/A

                                      -----     COMPLIANCE RESPONSES -----

-------------------------------------------------------------------------------------------------------------------
  INTERNAL    DRESP1    RESPONSE                                          LOWER                          UPPER
    ID          ID       LABEL                                            BOUND          VALUE           BOUND
-------------------------------------------------------------------------------------------------------------------
     2  6000001        A1                                                 N/A          3.6788E+01          N/A
```

Compliance

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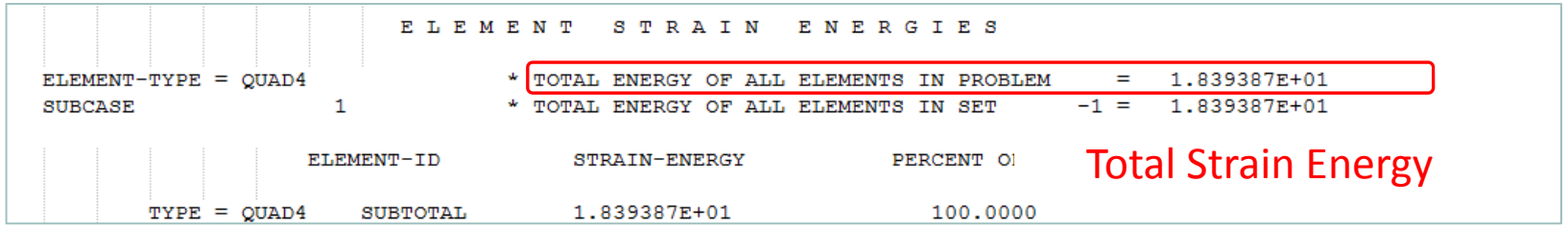
The SOL 200 Web App is now available through MSC**One**XT.
Contact your Hexagon sales representative for access.

# 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=.90)=ALL*
2. Search the .f06 file for the initial design's
    1. *ELEMENT STRAIN ENERGIES*
3. *Note the value of TOTAL ENERGY OF ALL ELEMENTS IN PROBLEM*
4. *Search the .f06 for the*
    1. SUMMARY OF DESIGN CYCLE HISTORY
5. Note the value for OBJECTIVE FROM EXACT ANALYSIS for the INITIAL cycle number
6. The Compliance of 36.78 is twice the TOTAL STRAIN ENERGY of 18.39.



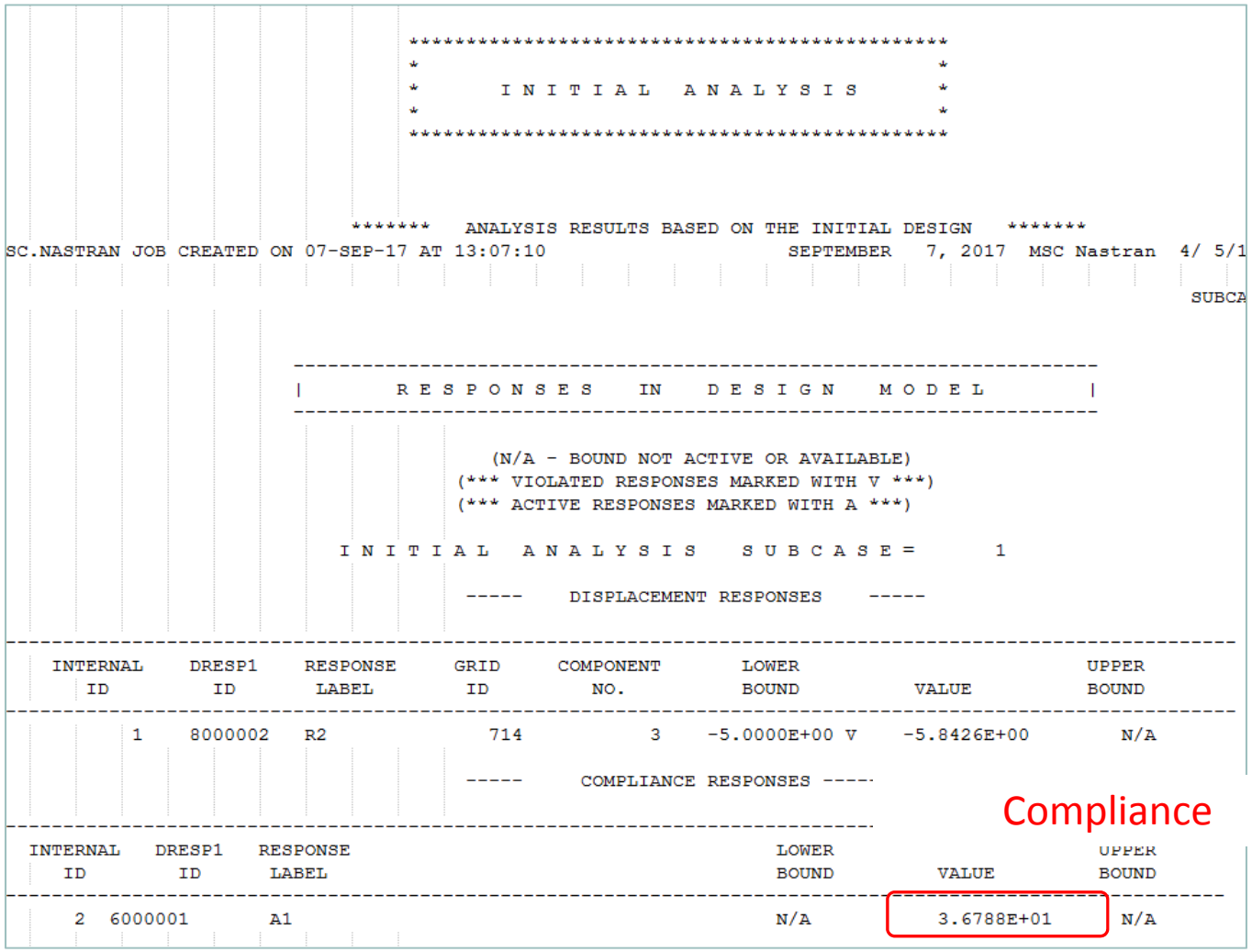
```
                                E L E M E N T   S T R A I N   E N E R G I E S

ELEMENT-TYPE = QUAD4              * TOTAL ENERGY OF ALL ELEMENTS IN PROBLEM      =   1.839387E+01
SUBCASE              1            * TOTAL ENERGY OF ALL ELEMENTS IN SET       -1 =   1.839387E+01

                  ELEMENT-ID          STRAIN-ENERGY          PERCENT OF

       TYPE = QUAD4     SUBTOTAL        1.839387E+01              100.0000
```

Total Strain Energy



```
                                  ********************************************
                                  *                                          *
                                  *      I N I T I A L   A N A L Y S I S     *
                                  *                                          *
                                  ********************************************


                              *******   ANALYSIS RESULTS BASED ON THE INITIAL DESIGN   *******
SC.NASTRAN JOB CREATED ON 07-SEP-17 AT 13:07:10                    SEPTEMBER   7, 2017  MSC Nastran  4/ 5/1
                                                                                                    SUBCA

                        ---------------------------------------------------------------------
                        |       R E S P O N S E S    I N    D E S I G N    M O D E L       |
                        ---------------------------------------------------------------------

                                    (N/A - BOUND NOT ACTIVE OR AVAILABLE)
                                  (*** VIOLATED RESPONSES MARKED WITH V ***)
                                  (*** ACTIVE RESPONSES MARKED WITH A ***)

                           I N I T I A L   A N A L Y S I S   S U B C A S E =      1

                                        -----    DISPLACEMENT RESPONSES    -----

-------------------------------------------------------------------------------------------------------------------
   INTERNAL     DRESP1     RESPONSE      GRID      COMPONENT       LOWER                          UPPER
      ID          ID        LABEL         ID         NO.          BOUND          VALUE           BOUND
-------------------------------------------------------------------------------------------------------------------
         1     8000002    R2              714           3     -5.0000E+00 V    -5.8426E+00        N/A

                                        -----    COMPLIANCE RESPONSES -----

-------------------------------------------------------------------------------------------------------------------
  INTERNAL    DRESP1    RESPONSE                                          LOWER                          UPPER
     ID         ID       LABEL                                           BOUND          VALUE           BOUND
-------------------------------------------------------------------------------------------------------------------
     2  6000001       A1                                                N/A          3.6788E+01        N/A
```

Compliance

Do you have questions? Email me:
christian@ the-engineering-lab.com

The SOL 200 Web App is now available through MSC**One**XT.
Contact your Hexagon sales representative for access.

# 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

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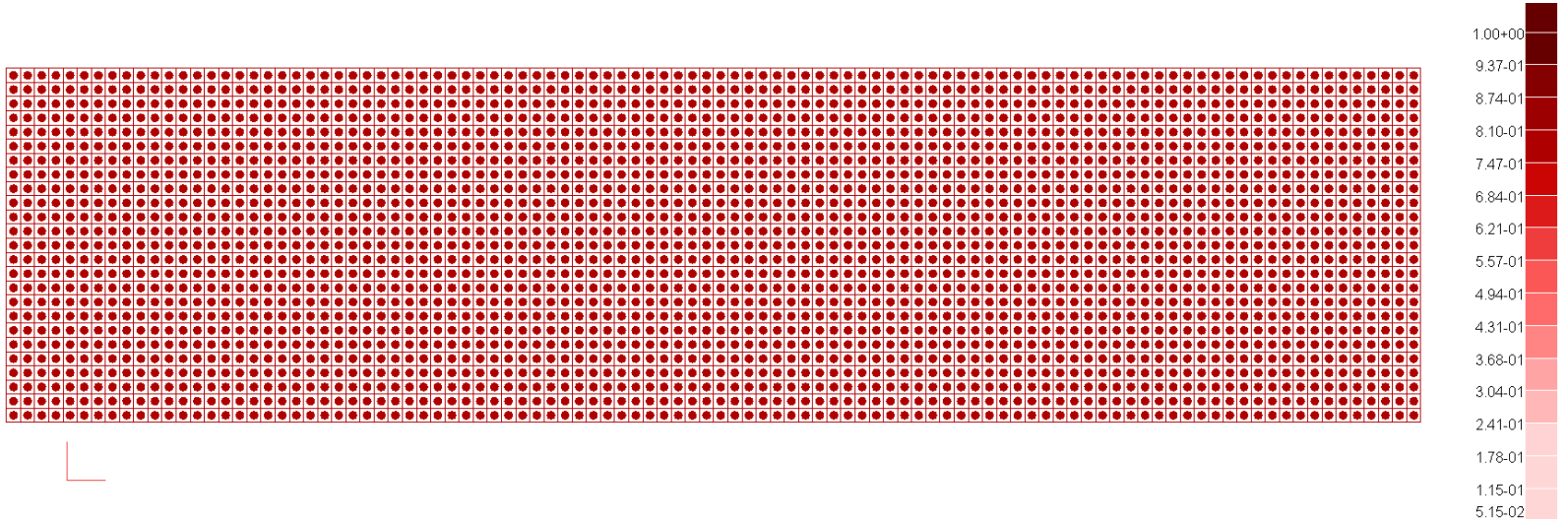
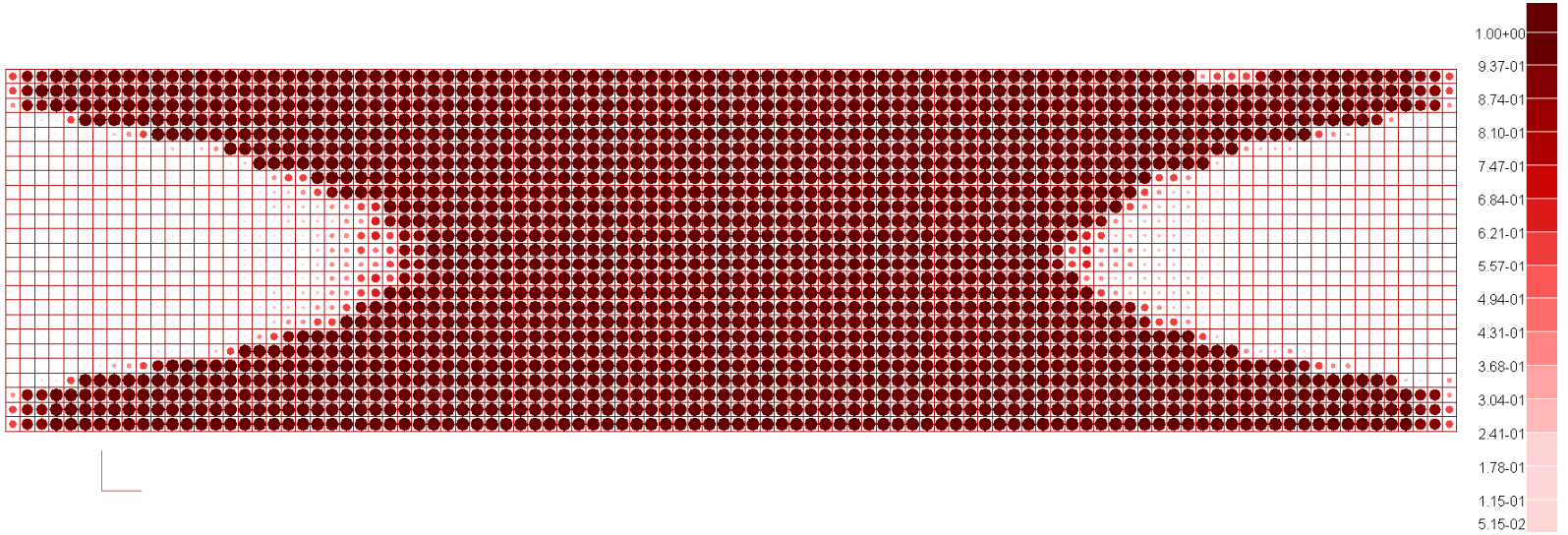
# How is it possible to increase the stiffness?

- 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 .75 of the original density, the mass is 75% 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 75% of the original
  - The compliance or work done has been minimized



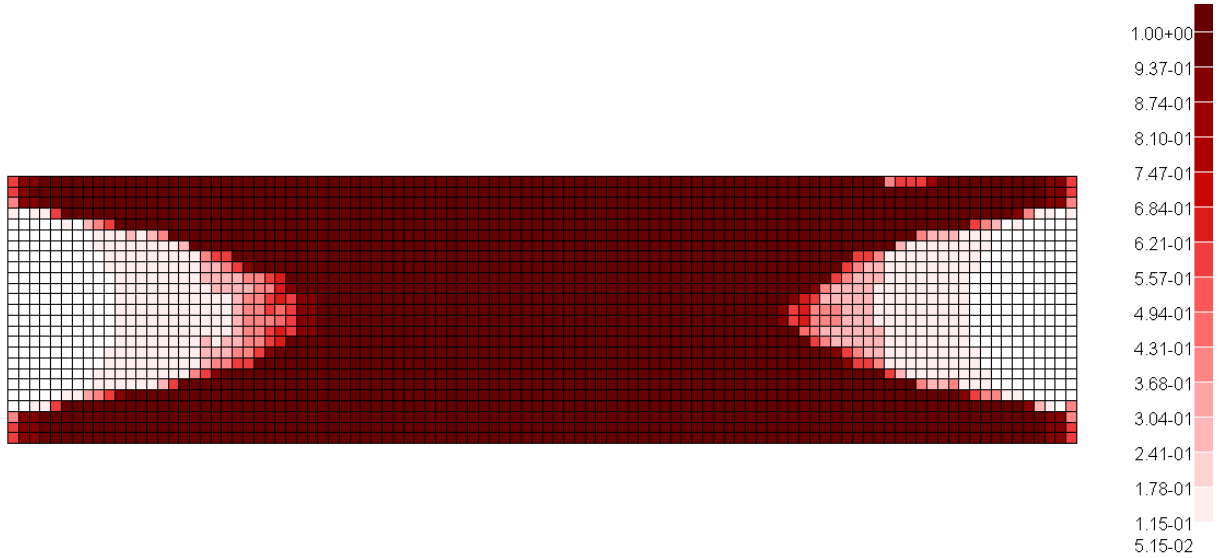

For the initial design, the normalized densities start at a value of .75. The initial design satisfies the design constraint where FRMASS is less than .75.



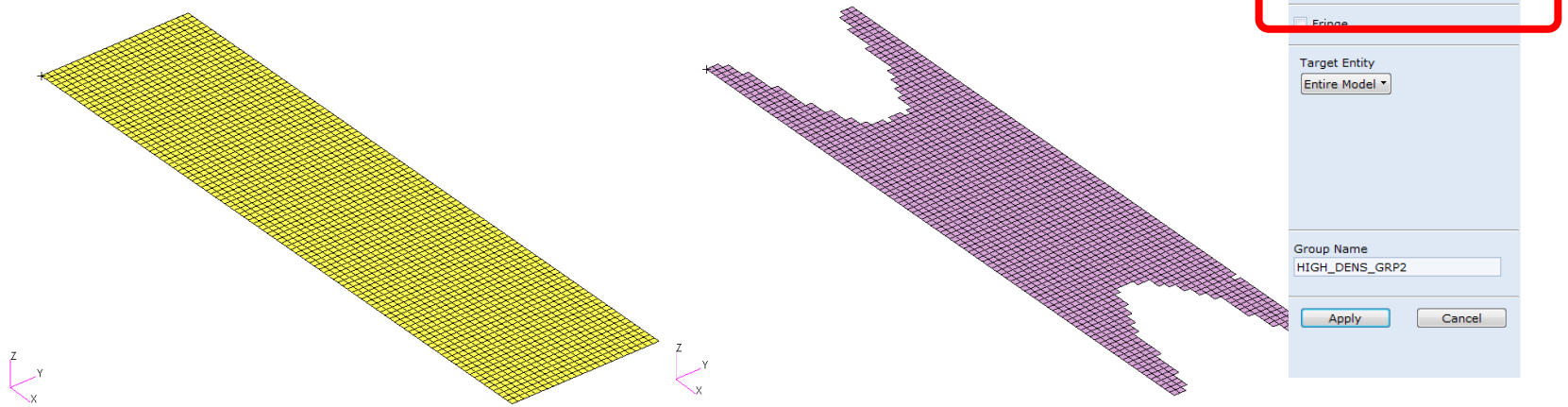

At the end of the optimization, each element has a different normalized density. The total mass of this design still satisfies the design constraint, FRMASS is less than .75.

# 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.

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