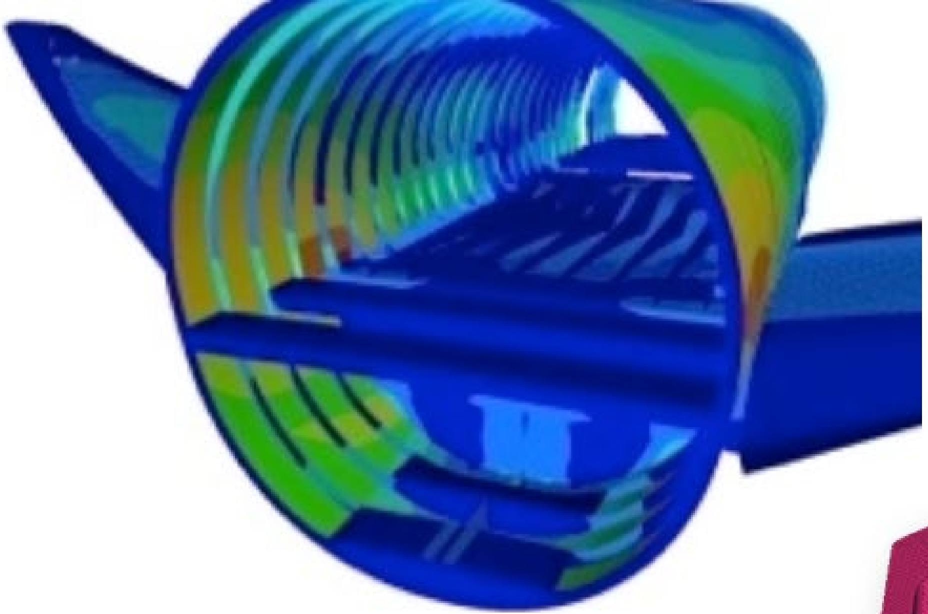
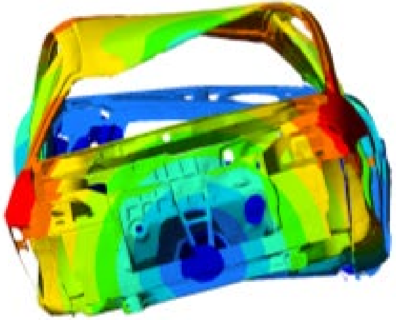
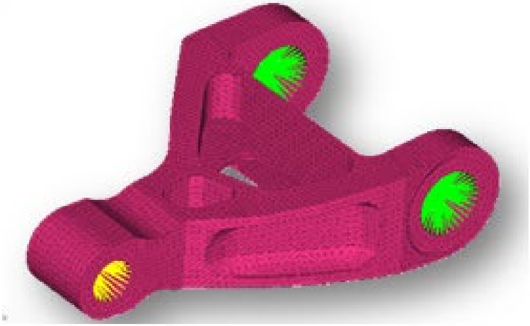






OPTISTRUCT FOR LINEAR ANALYSIS, V2019
CHAPTER 8: OPTIMIZATION IN LINEAR ANALYSIS

AGENDA

OPTIMIZATION IN LINEAR ANALYSIS: DETAILED OVERVIEW

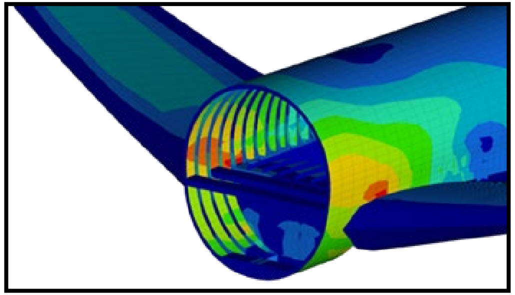
Linear Analysis Optimization

- What is OptiStruct Optimization?
- The DRCO Approach
- Setting Up Optimization
- OptiStruct Responses for Linear Analysis
- Optimization Examples and Demos
- OptiStruct Optimization Summary

WHAT IS OPTISTRUCT OPTIMIZATION?

INTRODUCTION TO OPTISTRUCT OPTIMIZATION

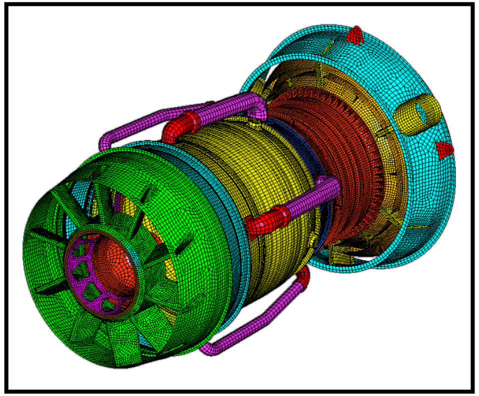
Altair OptiStruct contains a wide range of optimization methods which can be used for concept design and fine tuning



Load cases are optimization ready and only require a few additional parameters to set up and run an optimization study

Optimization methods can be used with a wide range of loading types

- Noise & vibration
  - Normal modes, Frequency response, Modal Transient, Random Response, Acoustics
- Linear static, Buckling
- Multi-Body Dynamics, Inertia relief
- Non-Linear, Heat transfer, Fatigue

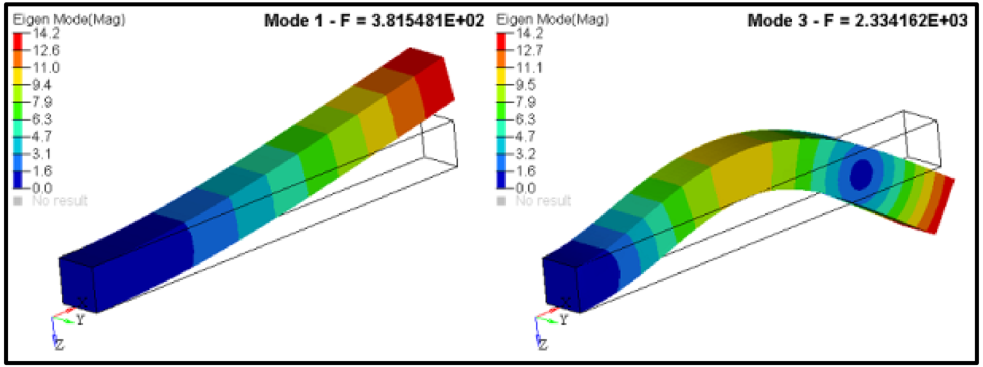


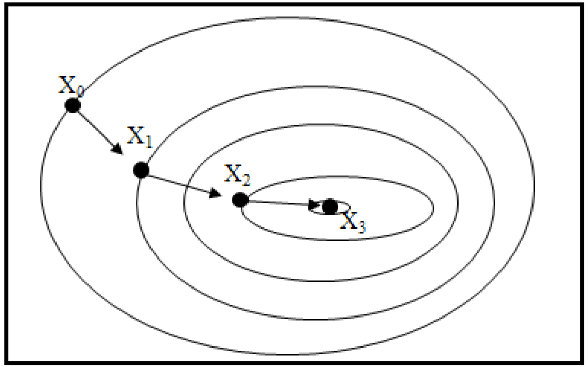
Multiple simulation types can be combined within a single optimization

WHAT IS OPTISTRUCT OPTIMIZATION?

OptiStruct optimization solves for the optimum value of an objective function based upon the response of the model to its load cases by changing model geometry and properties

- OptiStruct is a gradient-approach optimization platform
- OptiStruct can utilize any of the analysis types available in the HyperWorks suite
- OptiStruct iterates your solution based on responses from your existing model and load cases



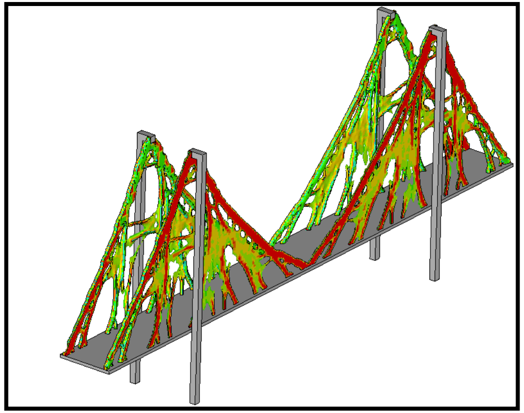


CONCEPT-LEVEL OPTIMIZATION TYPES

Topology Given a design envelope, topology optimization finds the optimum material placement within that space according to the constraints and objective

Topography Given a shell structure, topography optimization creates a bead pattern from the elements that meets the constraints and objective

Free Size Given a shell structure, free size optimization finds the optimum thickness on an element-by-element basis that meets the constraints and objective

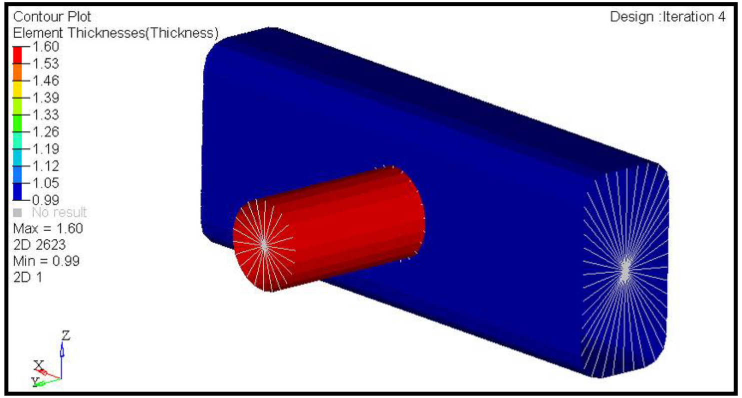


FINE-TUNING-LEVEL OPTIMIZATION TYPES

Shape Given a structure and a number of user-defined shapes, shape optimization finds the optimum fractional summation of those shapes that meets the constraints and objective.

Size/Gauge Given a structure, size optimization finds the optimum component thickness that meets the constraints and objective.

Free Shape Given a structure with features on its boundaries, free shape modifies the boundary nodes to find a more optimal structure that meets the constraints and objectives



OPTISTRUCT OPTIMIZATION OVERVIEW

Design Process

Topology

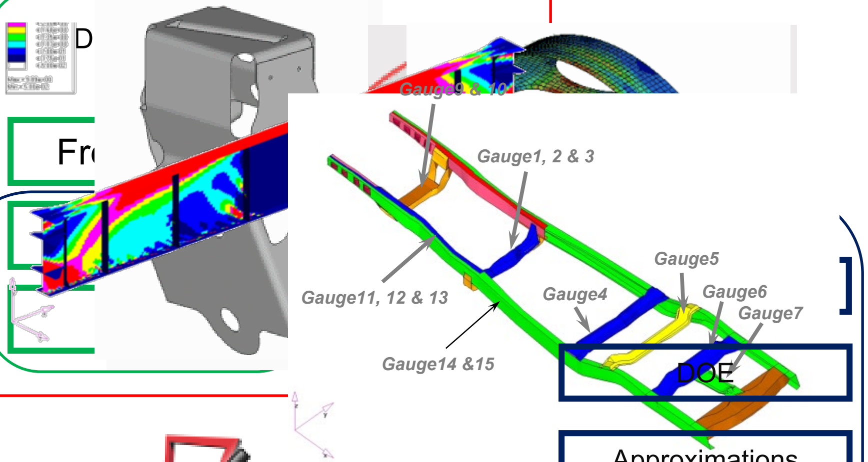
Free-size

Topography

Concept Level Design

Integrated FEA Solver

Altair OptiStruct
Optimization Driven Design



DOE

Approximations

Stochastic Studies

Altair HyperStudy
Multi-Disciplinary Design Exploration, Study and Optimization Software

THE DRCO APPROACH

THE DRCO APPROACH

Optimization in OptiStruct is based upon the “DRCO” approach

Design Variable

- The parameters, properties, or elements that OptiStruct can change to achieve different responses
- Typically either an entire part or a significant part feature

Response

- A measurement of an output characteristic of the modeled system
- Empirically sampled via sensor, oscilloscope probe, or computer imaging system

Constraint

- A numerical limit (either upper or lower limit) applied to a response
- Either specified by external guidelines (MIL-SPEC, FAA, ISO standards), internal project requirements, or computed from physical limitations and characteristics (E, ν, α, ρ, μ)

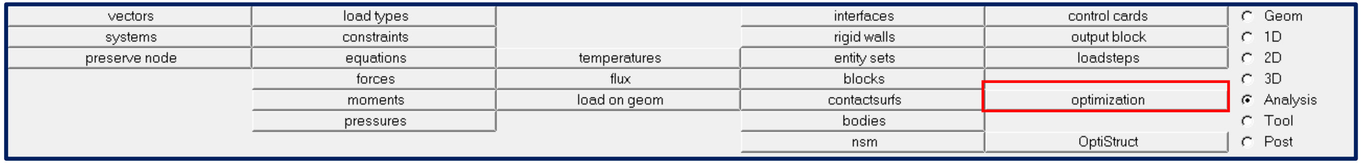
Objective

- A non-numerical indicator of the ultimate goal of the optimization
- Empirically/traditionally limited by time, monetary or manpower resources, availability of access to data/testing facilities

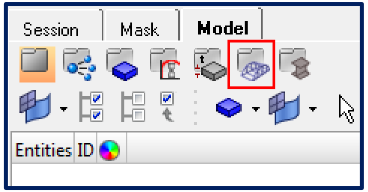
SETTING UP OPTIMIZATION

OPTIMIZATION SETUP MODULE IN HYPERMESH

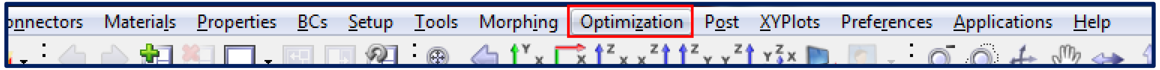
Optimization entities can be created in HyperMesh in one of three areas



Optimization Panel



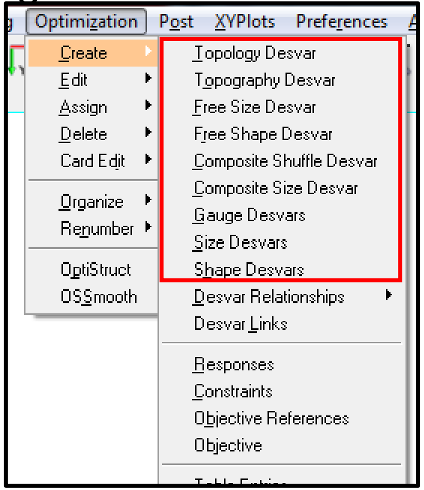
Model Browser

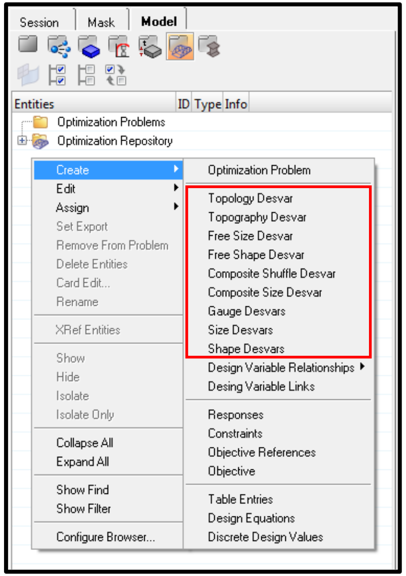


Optimization Menu

OPTIMIZATION SETUP MODULE IN HYPERMESH

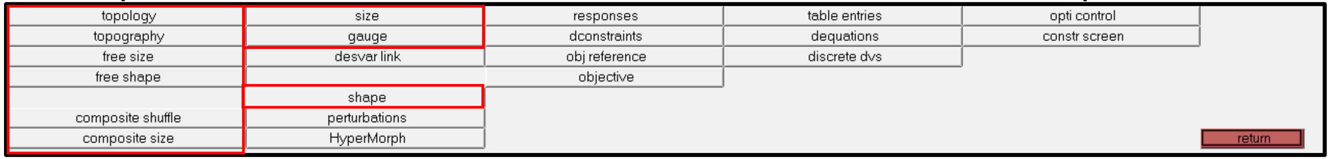
Definition of Design Variables





Optimization Menu

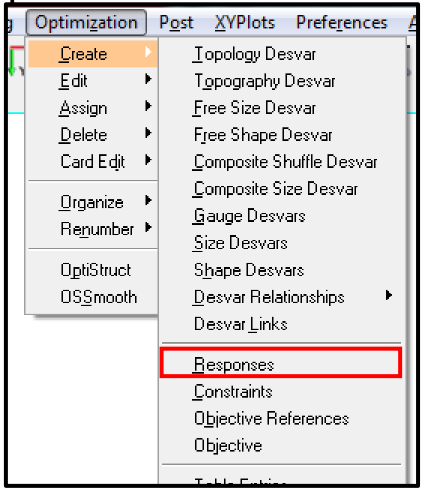
Model Browser - Optimization View



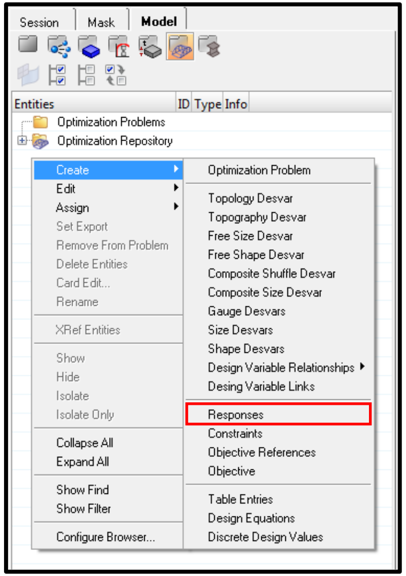
Optimization Panel

OPTIMIZATION SETUP MODULE IN HYPERMESH

Definition of Responses



Optimization Menu

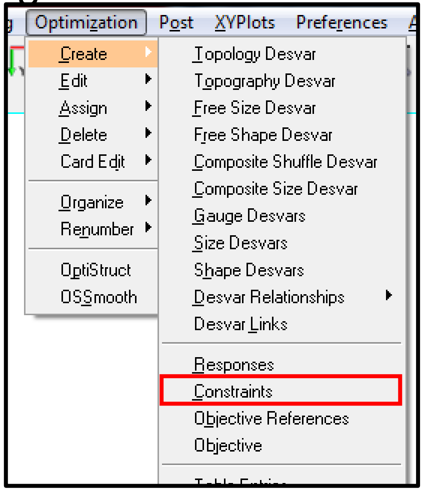


Model Browser - Optimization View

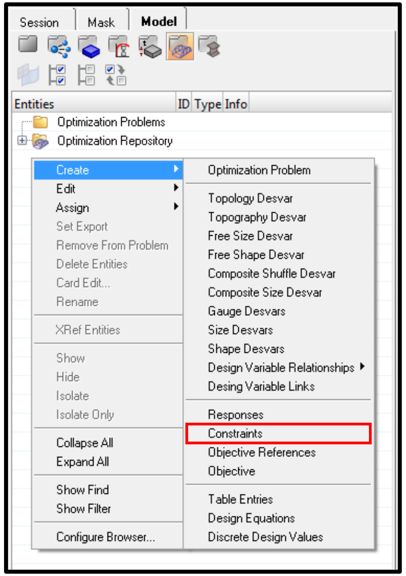
Optimization > Responses Panel

OPTIMIZATION SETUP MODULE IN HYPERMESH

Definition of Design Constraints



Optimization Menu

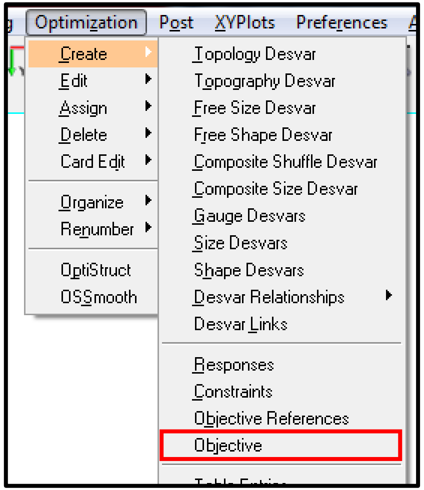


Model Browser - Optimization View

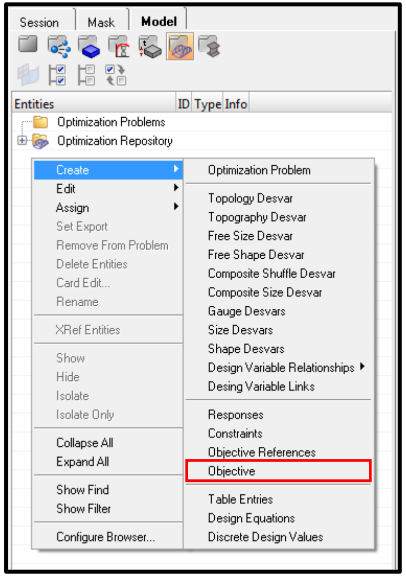
Optimization > Dconstraints Panel

OPTIMIZATION SETUP MODULE IN HYPERMESH

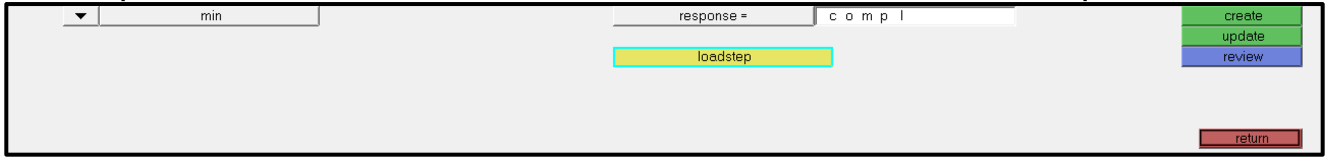
Definition of Objective



Optimization Menu



Model Browser - Optimization View



Optimization > Objective Panel

OPTISTRUCT RESPONSES FOR LINEAR ANALYSIS

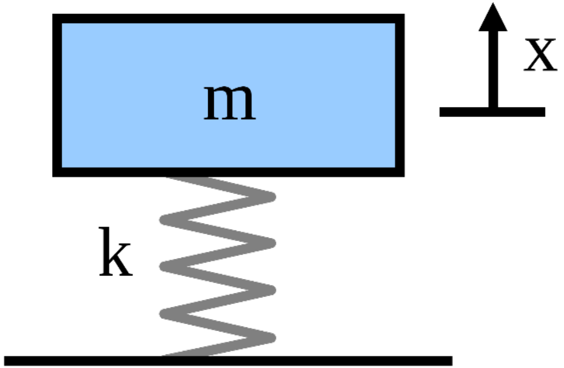
WHAT IS AN OPTIMIZATION RESPONSE?

A response is the result of a design analysis iteration

- These responses can be used as a design objective or as design constraints
- These responses are defined in OptiStruct using DRESP#(1,2,3) cards
- The extended options on the DRESP1 card are applicable to NVH responses such as frf displacement, frf acceleration etc.

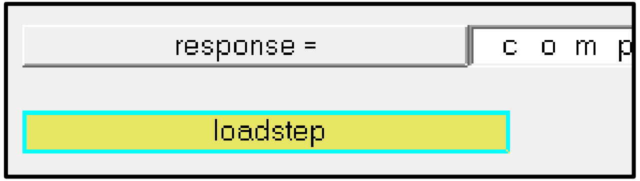
Optimization responses are a characterization of the model are often a direct function of the type of analyses specified in the model

- Frequency, by mode number
- Static displacement
- FRF acceleration
- Volume
- Mass
- User defined functions



CONSTRAINT AND OBJECTIVE LOAD CASE REFERENCE

Objective and design constraints need to be defined load case dependent if the response is a reaction to a load



Load case dependent responses include:

- Compliance, frequency, displacement, stress, strain, force, composite responses
- Functions using these responses w/o load case assignment

Load case independent (global) responses include:

- Mass, mass fraction, volume, volume fraction, center of gravity, moments of inertia, weighted compliance, weighted frequency, compliance index
- Functions using these responses
- Functions using compliance, frequency, displacement, stress, strain, force, composite responses with load case assignment

OPTIMIZATION RESPONSES

DRESP1

- Simple response definition
- Mass, mass fraction, volume, volume fraction, compliance, frequency, displacement, stress, strain, force, composite responses, weighted compliance, weighted frequency, and compliance index, frequency response analysis responses

DRESP2

- Response definition using a user defined function
- Defines responses as function of design variables, grid location, table entries, responses, and generic properties
- *Example: Average displacement of two nodes:* $$F(x_1, x_2) = \frac{x_1 + x_2}{2}$$

where x1 and x2 are nodal displacements

DRESP3

- Response definition using a user defined external function
- May be written in C (C++), Fortran, or MS Excel

OPTIMIZATION RESPONSES

These responses are commonly used in optimization with OptiStruct:

Compliance, strain energy (COMP) – Total and Regional

$$C = \tfrac{1}{2}\, u^T f \quad \text{with} \quad Ku = f \qquad \text{or} \qquad C = \tfrac{1}{2}\, u^T K u = \tfrac{1}{2} \int \varepsilon^T \sigma \, dv$$

Weighted Compliance (WCOMP) $C_w = \sum w_i C_i = \tfrac{1}{2} \sum w_i u_i^T f_i$

Natural Frequency (FREQ) $f_i = \dfrac{\sqrt{\lambda_i}}{2\pi}$

Inverse of Weighted Eigenvalues (WFREQ) $f_w = \sum w_i / \lambda_i \quad \text{with} \quad [K - \lambda_i M]\, u_i = 0$

Combination of Weighted Compliance and Weighted Inverse Eigenvalues (COMB)

$$S = \Sigma w_i C_i + NORM \, \frac{\Sigma w_j / \lambda_j}{\Sigma w_j} \qquad NF = C_{max} \lambda_{min}$$

OPTIMIZATION RESPONSES

Subcase Independent

- Combined Compliance Index
- Weighted Reciprocal Eigenvalue (Frequency)
- Weighted Compliance
- Fraction of Mass and Fraction of Design Volume
- Bead Discreteness Fraction

Subcase Dependent

- Linear Static: Static Compliance, Displacement, Force, SPC/Grid Point Force, Stress, Strain, Failure
- Normal Modes Analysis : Frequency, Mode Shape
- Thermal Analysis: Temperature, Thermal Compliance
- Linear Buckling Analysis: Buckling Factor

OPTIMIZATION EXAMPLES AND DEMOS

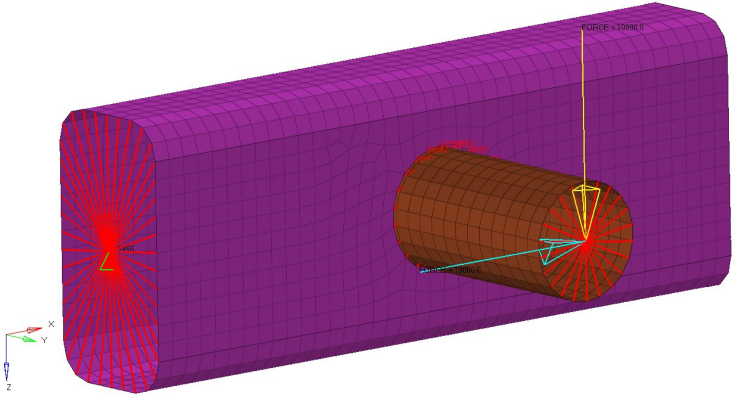
EXERCISE 8A: SIZE OPTIMIZATION OF A RAIL JOINT

File Name and Location

…\STUDENT-EXERCISE\8a_Rail_Joint\joint_size.fem

Exercise Goal

The purpose of this exercise is to set up a property parameter optimization on an automobile rail joint modeled with shell elements. The deflection at the end of the tubular cross-member should be limited. The optimal solution would use as little material as possible.



Design Variables

- *Property parameter thickness of tube1 and tube2 with initial values of 1.0, lower bounds of 0.1 and upper ones of 5.0*

Responses

- *volume*
- *U_x at load application point for load step LOAD_X*
- *U_z at load application point for load step LOAD_Z*

Objective: *min volume*

Constraints

- *$U_x < 0.9$*
- *$U_z < 1.6$*

EXERCISE 8A: SIZE OPTIMIZATION OF A RAIL JOINT

Steps

- Import the model in HyperMesh Desktop with OptiStruct user profile selected
- Review the model and check the constraints and load steps
- Run an analysis with OptiStruct and review displacements U_x and U_z according to the later constraints
- Create two size/parameter design variables with initial values of 1.0, lower bounds of 0.1 and upper ones of 5.0, empty (default) move limit and no ddval.
- Create two generic relationships to link the property parameters thickness to the according design variables
- Create a volume response
- Create a static displacement response in *x*-direction for the load application point (ID 5555), U_x
- Create a static displacement response in *z*-direction for the load application point (ID 5555), U_y
- Create a constraint for U_x response to be lower than 0.9 for load step LOAD_X
- Create a constraint for U_z response to be lower than 1.6 for load step LOAD_Z
- Define the objective function to minimize volume response
- Export and review `.fem` file wrt optimization cards
- Run optimization with OptiStruct, review `.out` file

EXERCISE 8A: SIZE OPTIMIZATION OF A RAIL JOINT

Steps with Description

- Import the model in HyperMesh Desktop with OptiStruct user profile selected
- Review the model and check the constraints and load steps
- Run an analysis with OptiStruct and review displacements U_x and U_z according to the later constraints: $U_x = 1.273$ and $U_z = 2.144$
- Create two size/parameter design variables with initial values of 1.0, lower bounds of 0.1 and upper ones of 5.0, empty (default) move limit and no ddval.
- Create two generic relationships to link the property parameters thickness to the according design variables

4

Name	Value
Solver Keyword	DESVAR
Name	dv_tube1
ID	1
Include	[Master Model]
Config	size/shape
Move Limit	
Ddval Id	<Unspecified>
Shape Id	<Unspecified>
Initial Value	1.0
Lower Bound	0.1
Upper Bound	5.0
RAND	☐
RANP	☐

4

Name	Value
Solver Keyword	DESVAR
Name	dv_tube2
ID	2
Include	[Master Model]
Config	size/shape
Move Limit	
Ddval Id	<Unspecified>
Shape Id	<Unspecified>
Initial Value	1.0
Lower Bound	0.1
Upper Bound	5.0
RAND	☐
RANP	☐

5

Name	Value
Solver Keyword	DVPREL1
Name	rel_t1
Include	[Master Model]
Config	Generic
Global Ply	☐
Property Type	PSHELL
Property Id	(1) tube1
Property Name	Thickness T
Constant	0.0
List of Design Variables	1 Designvars
Number of Design Variables	1
Desvar Coefficients	

5

Name	Value
Solver Keyword	DVPREL1
Name	rel_t2
Include	[Master Model]
Config	Generic
Global Ply	☐
Property Type	PSHELL
Property Id	(2) tube2
Property Name	Thickness T
Constant	0.0
List of Design Variables	1 Designvars
Number of Design Variables	1
Desvar Coefficients	

EXERCISE 8A: SIZE OPTIMIZATION OF A RAIL JOINT

Steps with Description

6. Create a volume response
7. Create a static displacement response in *x*-direction
   for the load application point (ID 5555), U_x
8. Create a static displacement response in *z*-direction
   for the load application point (ID 5555), U_y
9. Create a constraint for U_x response to be lower than
   0.9 for load step LOAD_X
10. Create a constraint for U_z response to be lower than
   1.6 for load step LOAD_Z
11. Define the objective function to minimize volume response

6

Name	Value
Solver Keyword	DRESP1
Name	r_volume
ID	1
Include	[Master Model]
Response Type	volume
Property	PROP_TOTAL
Property Type	total
Region Identifier	
DREPORT	☐

7

Name	Value
Solver Keyword	DRESP1
Name	r_ux
ID	2
Include	[Master Model]
Response Type	static displacement
Property	PROP_TOTAL
List Of Nodes	1 Nodes
Region Identifier	
	$\boxed{\text{dof1}}$
COORD	☐
DREPORT	☐

8

Name	Value
Solver Keyword	DRESP1
Name	r_uz
ID	3
Include	[Master Model]
Response Type	static displacement
Property	PROP_TOTAL
List Of Nodes	1 Nodes
Region Identifier	
	$\boxed{\text{dof3}}$
COORD	☐
DREPORT	☐

9

Name	Value
Solver Keyword	DCONSTR
Name	c_ux
ID	1
Include	[Master Model]
Lower Bound	
Upper Bound	0.9
Response	(2) r_ux
List of Loadsteps	1 Loadsteps
PROB	

10

Name	Value
Solver Keyword	DCONSTR
Name	c_uz
ID	2
Include	[Master Model]
Lower Bound	
Upper Bound	1.6
Response	(3) r_uz
List of Loadsteps	1 Loadsteps
PROB	

11

Name	Value
Solver Keyword	DESOBJ(MIN)
Name	objective
ID	1
Include	[Master Model]
Objective Type	Minimize
Response Id	(1) r_volume

EXERCISE 8A: SIZE OPTIMIZATION OF A RAIL JOINT

Steps with Description

12. Export and review `.fem` file wrt optimization cards

12

```
DESOBJ(MIN)=1
SUBCASE       1
  LABEL Force_X
  SPC =         1
  LOAD =         2
  DESSUB =        3
SUBCASE       2
  LABEL Force_Z
  SPC =         1
  LOAD =         3
  DESSUB =        4
$
BEGIN BULK
DESVAR         1dv_tube11.0     0.1     5.0
DESVAR         2dv_tube21.0     0.1     5.0
DVPREL1 1       PSHELL         1       4               0.0
+       1       1.0
DVPREL1 2       PSHELL         2       4               0.0
+       2       1.0
DRESP1  1       r_volumeVOLUME
DRESP1  2       r_ux    DISP                   TX             5555
DRESP1  3       r_uz    DISP                   TZ             5555
DCONSTR        1       2        0.9
DCONSTR        2       3        1.6
DCONADD        3       1
DCONADD        4       2
[…]
PSHELL         1       11.0            1               1        0.0
PSHELL         2       10.8            1               1        0.0
```

EXERCISE 8A: SIZE OPTIMIZATION OF A RAIL JOINT

Steps with Description

13. Run optimization with OptiStruct, review `.out` file

13

```
ITERATION    4
  the 2nd satisfied convergence ratio =   2.7998E-05

Objective Function (Minimize VOLUM) =  2.28294E+05    % change =          -0.00
Maximum Constraint Violation %      =  0.92458E-01
Volume                              = 2.28294E+005    Mass      = 0.00000E+000

 Subcase    Compliance      Epsilon
       1  3.534265E+03 -1.106546E-14
       2  8.007397E+03  1.515182E-13

Note : Epsilon = Residual Strain Energy Ratio.


                           RETAINED RESPONSES TABLE
-------------------------------------------------------------------------------------
Response Type  Response     Subcase Grid/    DOF/   Response      Objective     Viol.
User-ID          Label      /RANDPS Element/ Comp    Value        Reference/     %
                            /Model  MID/PID/ /Reg                 Constraint
                            +Frqncy Mode No.                        Bound
                            /Times
-------------------------------------------------------------------------------------
      1 VOLUM r_volume           --       --  TOTL  2.283E+05 MIN
      2 DISPL r_ux                1     5555    TX  7.069E-01  <  9.000E-01    0.0
      3 DISPL r_uz                2     5555    TZ  1.601E+00  <  1.600E+00    0.1 A
-------------------------------------------------------------------------------------
```

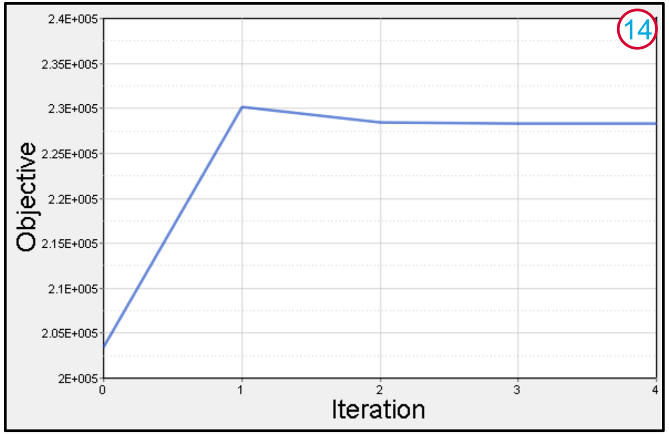
13

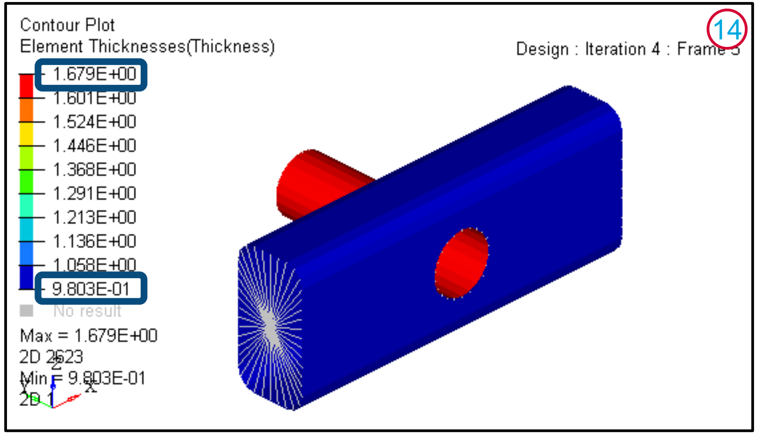
```
---------------------------------------------------------
 Design    Design      Lower       Design       Upper
Variable  Variable     Bound       Variable     Bound
   ID      Label
---------------------------------------------------------
       1  dv_tube1   1.000E-01   9.803E-01   5.000E+00
       2  dv_tube2   1.000E-01   1.679E+00   5.000E+00
---------------------------------------------------------


                DESIGNED PROPERTY ITEMS TABLE
--------------------------------------------------------------
 DVPREL1/2  USER-ID  PROP-TYPE  PROP-ID  ITEM-CODE  PROP-VALUE
--------------------------------------------------------------
 DVPREL1          1   PSHELL          1   T          9.803E-01
 DVPREL1          2   PSHELL          2   T          1.679E+00
--------------------------------------------------------------

************************************************************************

 OPTIMIZATION HAS CONVERGED.

 FEASIBLE DESIGN (ALL CONSTRAINTS SATISFIED).
```

EXERCISE 8A: SIZE OPTIMIZATION OF A RAIL JOINT

Steps with Description

14. Review results of `hist.mvw` and `.mvw` files





15

```
$ ----------------------------------------
$ PROPERTIES AND MATERIALS AT ITERATION
$ ----------------------------------------
PSHELL, 1, 1, .98030871461  1, 1.0, 1,, 0.0
PSHELL, 2, 1, 1.6789640958  1, 1.0, 1,, 0.0
```

15. Import `.prop` file in HyperMesh Desktop

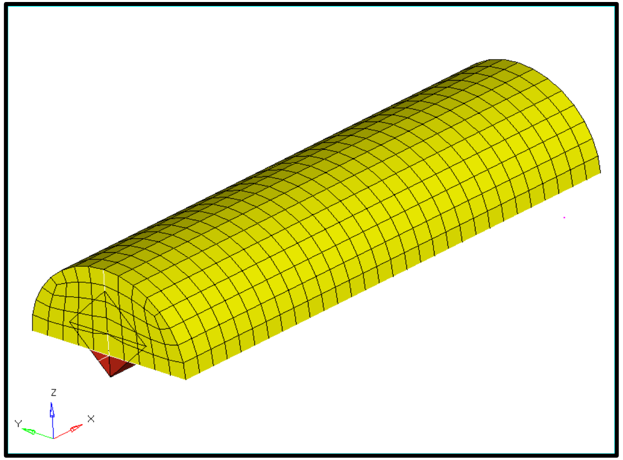
EXERCISE 8B: SIZE OPTIMIZATION OF A SHREDDER

File Name and Location:

`../8b_Modal_Size_Opti/shredder.hm`

Exercise Goal

The purpose of this exercise is to set up a property parameter optimization on a shredder. The deflection at the end of the tubular cross-member should be limited. The optimal solution would use as little material as possible.



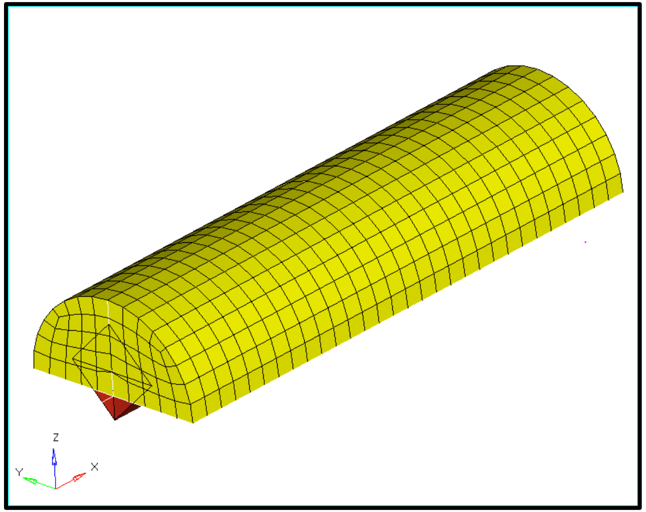
Design Variables
- *Property parameter thickness of shredder components*

Responses
- *3^{rd} mode frequency*
- *4^{th} mode frequency*
- *mass*

Objective: *max 3^{rd} mode*

Constraints
- *mass < 1.4*
- *4^{th} freq > 6 Hz*

EXERCISE 8B: SIZE OPTIMIZATION OF A SHREDDER



Exercise 8b:

Size Optimization of a Shredder

File Name and Location:

`../8b_Modal_Size_Opti/shredder.hm`

Objectives:

- Open the model in **HyperMesh Desktop**
- Switch the Model Browser to Optimization View
- Create the size design variables for the shredder components
- Create relationships between the design variables and properties
- Create responses for the total mass, third natural frequency mode, and fourth natural frequency mode
- Create a mass upper bound constraint of **`1.8`** and a 4th mode frequency lower bound of **`6`** Hz
- Create an objective to maximize the third mode frequency response for the **`ld1`** loadstep
- Run the analysis in **OptiStruct** & review the **`*.prop`** and **`*.out`** files for the optimized property values

EXERCISE 8B: SIZE OPTIMIZATION OF A SHREDDER

Exercise Results:

Files: **`shredder.prop`**

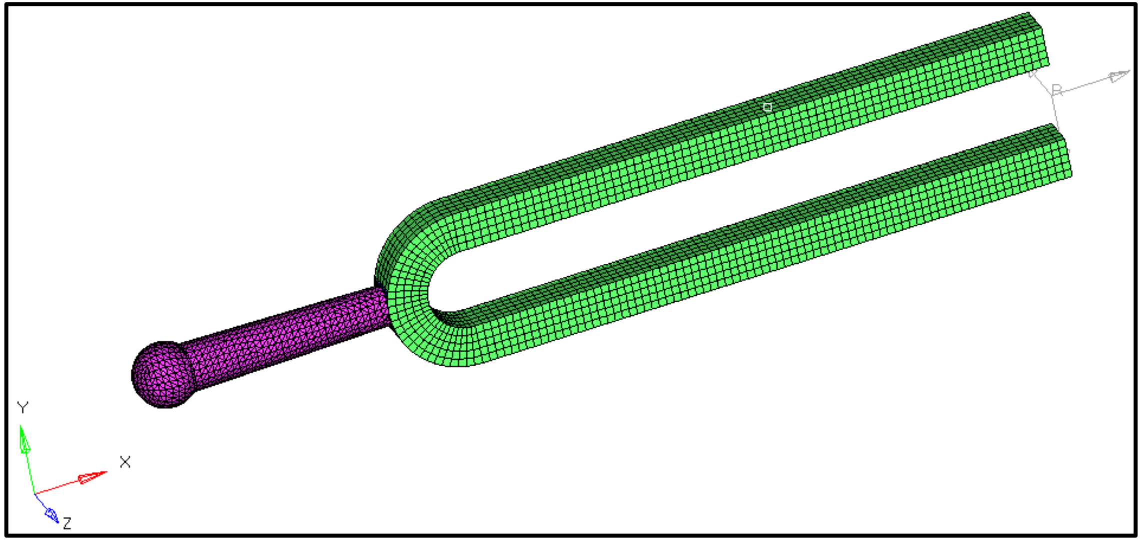
```
$ PROPERTIES AND MATERIALS AT ITERATION    7
$ -----------------------------------------
$
$HMNAME PROP                       1"frame2" 3
$HWCOLOR PROP                      1       38
PBARL   1              1         HAT
+, 125.0, 11.525224906, 80.0, 40.0, 0.0
$ A=4459.681 I1=8799222. I2=7028952. I12=     0.0 J=197461.0 K1=.5269398 K2=.3539209
$ C1~F2 = +       65.87983    40.0-59.1202    80.0-59.1202    -80.065.87983    -40.0
$M1A~N2B= +            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
$HMNAME PROP                       2"cover" 4
$HWCOLOR PROP                      2       3
PSHELL, 2, 1, .63122871619, 1, 1.0, 1, .833333, 0.0
```

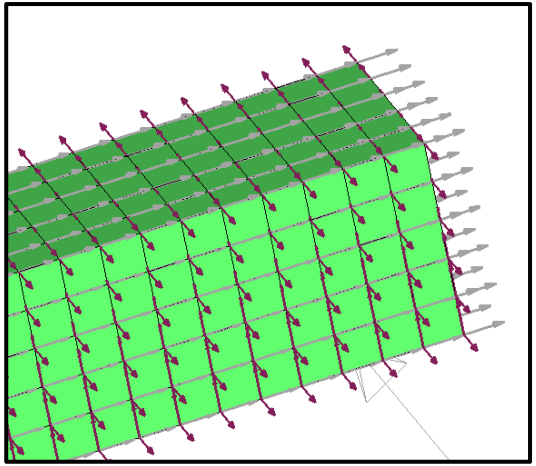
```
 DVPREL1/2  USER-ID  PROP-TYPE  PROP-ID  ITEM-CODE  PROP-VALUE
-------------------------------------------------------------
 DVPREL1          1   PSHELL          2   T          6.312E-01
 DVPREL1          2   PBAR            1   DIM1       1.250E+02
 DVPREL1          3   PBAR            1   DIM2       1.153E+01
 DVPREL1          4   PBAR            1   DIM3       8.000E+01
 DVPREL1          5   PBAR            1   DIM4       4.000E+01
-------------------------------------------------------------


ITERATION    7
  TRACKED OBJECTIVE FUNCTION/CONSTRAINT MODE #  4 GOES OUT OF BOUND,
  RETURNED TO THE PREVIOUS GOOD DESIGN.

Objective Function (Maximize FREQ )  =  6.34153E+00   % change =        0.00
Maximum Constraint Violation %       =  0.00000E+00
Volume                               = 2.33075E+008   Mass     = 1.79468E+000

 Subcase Mode   Order     Weight      Frequency     Eigenvalue    Weight/Eigen
       1    1      1   1.000E+00   1.031023E+00   4.196590E+01   2.382887E-02
       1    2      2   0.000E+00   1.534846E+00   9.300133E+01   0.000000E+00
       1    3      3   0.000E+00   6.341527E+00   1.587623E+03   0.000000E+00
       1    4     10   0.000E+00   8.145025E+00   2.619055E+03   0.000000E+00
       1    5      4   0.000E+00   7.358200E+00   2.137484E+03   0.000000E+00
       1    6      5   0.000E+00   7.358540E+00   2.137682E+03   0.000000E+00
       1    7      6   0.000E+00   7.359955E+00   2.138504E+03   0.000000E+00
       1    8      7   0.000E+00   7.361666E+00   2.139498E+03   0.000000E+00
       1    9      8   0.000E+00   7.363115E+00   2.140341E+03   0.000000E+00
       1   10      9   0.000E+00   7.423498E+00   2.175590E+03   0.000000E+00
--------------------------------------------------------------------------------
~ implies mode is ambiguously tracked    * implies mode cannot be tracked.
```

DEMO: SHAPE OPTIMIZATION OF A TUNING FORK

Model: `diapson_02.fem`

- Shape optimization can be used to modify the first flexible mode of a tuning fork
- How do we set the target frequency?
- What responses are used to control the optimization constraints?





OPTISTRUCT OPTIMIZATION SUMMARY

OPTISTRUCT OPTIMIZATION SUMMARY

OptiStruct Optimization can be set up in HyperWorks using D-R-C-O:

- Design Variable
- Response
- Constraint
- Objective

The choice of optimization type (concept or fine-tuning) will influence the type of optimization. This, in turn, will determine the type of design variable and the manufacturing and design constraints which need to be applied.

For more information on OptiStruct Optimization using HyperWorks, ask your Altair professional about the OptiStruct for Optimization Training Course.

CHAPTER 9: QUESTION & ANSWER