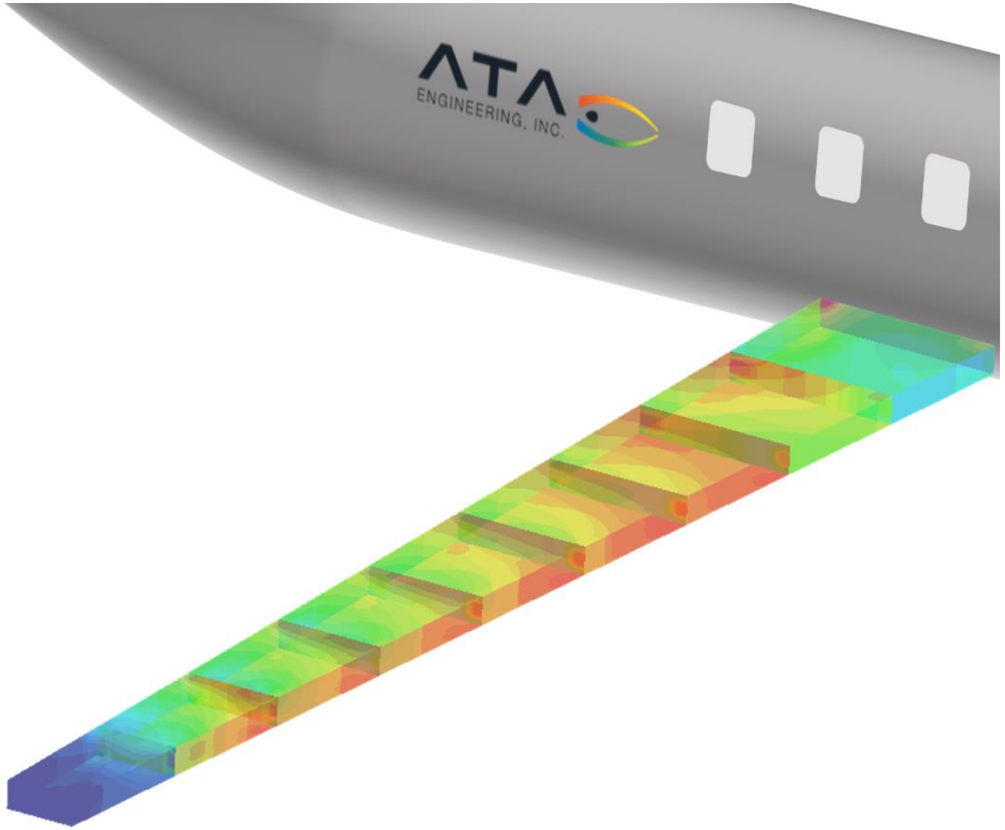

Webinar:

Design Sensitivity and Optimization with Simcenter Nastran and Femap

Anthony Ricciardi, ATA Engineering

July 23rd, 2020

13290 Evening Creek Drive S, San Diego CA 92128

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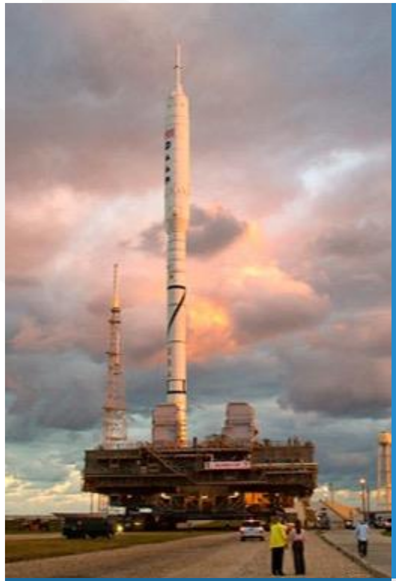

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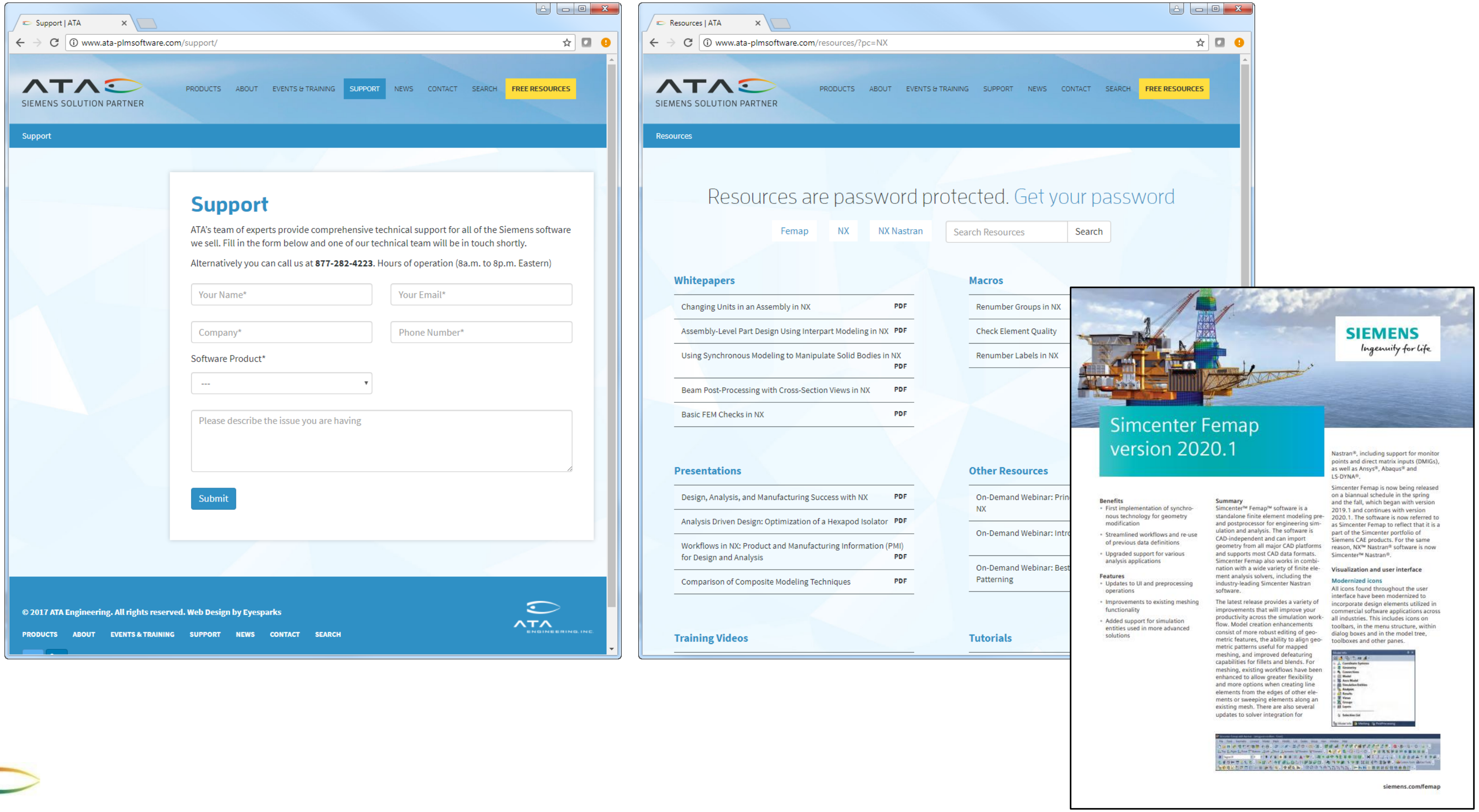

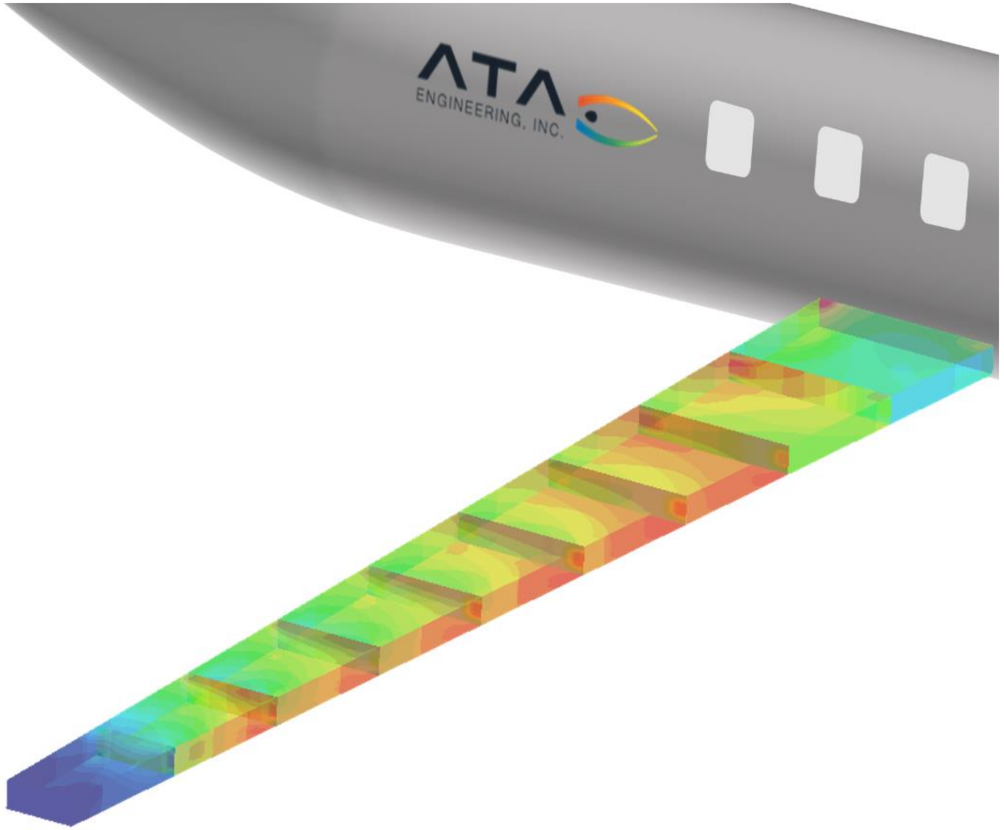

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Target Audiences and Objectives

Group	Target Audience	Objectives

(**1**)	• Experienced with Nastran
	• New to optimization
		• Introduce(**1**)/review(**2**) fundamentals of design sensitivity and optimization
		• Introduce Simcenter Nastran and Femap capabilities
		• Demonstrate Simcenter Nastran and Femap capabilities to
		  • *Reinforce your understating*
		  • *Help you get started*

(**2**)	• Experienced with legacy Nastran and optimization
	• New to recent developments (~2017-2018)
	  • *Topology optimization added to Simcenter Nastran starting with NX Nastran 12*
	  • *Improved Femap support for optimization starting with Femap 12*	

Outline

Design Sensitivity and Optimization with Simcenter Nastran and Femap

- Fundamentals
- Simcenter Nastran & Femap Capabilities
- Examples
  1. Sizing a beam cross-section
     - Graphical solution based on hand calculations
     - Femap with Simcenter Nastran solution
  2. Topology optimization of a cantilever structure
     - Sigmund 99-line topology optimization reference solution
     - Femap with Simcenter Nastran solution
  3. Sizing an aircraft wing structure using Femap with Simcenter Nastran
     - Many design variables
     - Multiple subcase types

What are Design Sensitivity and Design Optimization?

- **Design sensitivity analysis** computes the rates of change of structural responses with respect to changes in design variables.
  - These design variables can be used to represent shell thicknesses, beam cross sectional dimensions, etc.
  - In civil engineering, we may be interested in how changes in the deflection of a bridge span can be affected by changes in the dimensions of the bridge sections.
  - In automotive design, we may want to investigate changes in cabin resonant frequencies given changes in panel thicknesses.
  - These rates of change (what we call *derivatives* in calculus) are called design sensitivities or design gradients.
- **Design optimization** is an automated process that uses an optimizer to generate improved designs.
  - An optimizer implements a formal algorithm to search for the *best* design.
  - Gradient-based optimization algorithms use design sensitivities to guide this search process.
  - Simcenter Nastran uses gradient-based optimization algorithms for design optimization.

Reference: *Simcenter Nastran Design Sensitivity and Optimization User's Guide*

Why Use Design Sensitivity and Optimization?

- **Design sensitivity analysis** can be used for:
  - Improving understanding of how a system response changes with respect to adjustable parameters
  - Approximate/reduced-order model creation
  - Uncertainty quantification
  - Gradient-based optimization

- **Design optimization** can be used for:
  - Producing the best design that satisfies requirements
  - Performing trade-off or feasibility studies
  - Updating models to correlate with test data

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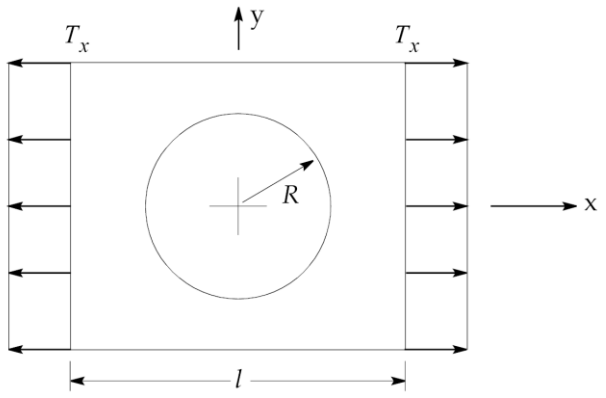
Reference: *Simcenter Nastran Design Sensitivity and Optimization User's Guide*

Engineering Analysis and Optimization

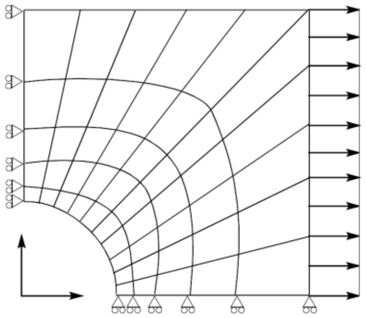
➢ Physical system and design problem

- A physical system that exists or design that will exist in reality
- Example:
  - Physical system: loaded flat plate with a hole
  - Design problem: the hole radius is to be optimized to minimize the weight of the plate while not exceeding allowable stress



➢ Analysis model

- A mathematical idealization of a physical system
- Provides response predictions
- Parametrized by design variables for optimization

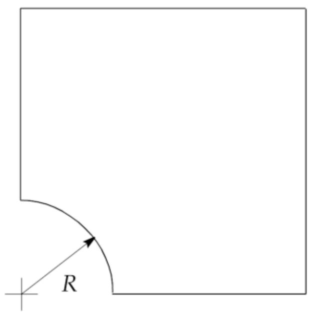


Finite element discretization of:

- Structure (Mesh).
- Loads.
- Boundary Conditions (1/4 Plate Representation).

➢ Design model

A formal statement of a the design objective, design variables, and constraints



Find R such that:

- Weight is minimized.
- Stresses do not exceed allowables.

(R is the design variable, weight is the design objective, and stresses are the design constraints.)

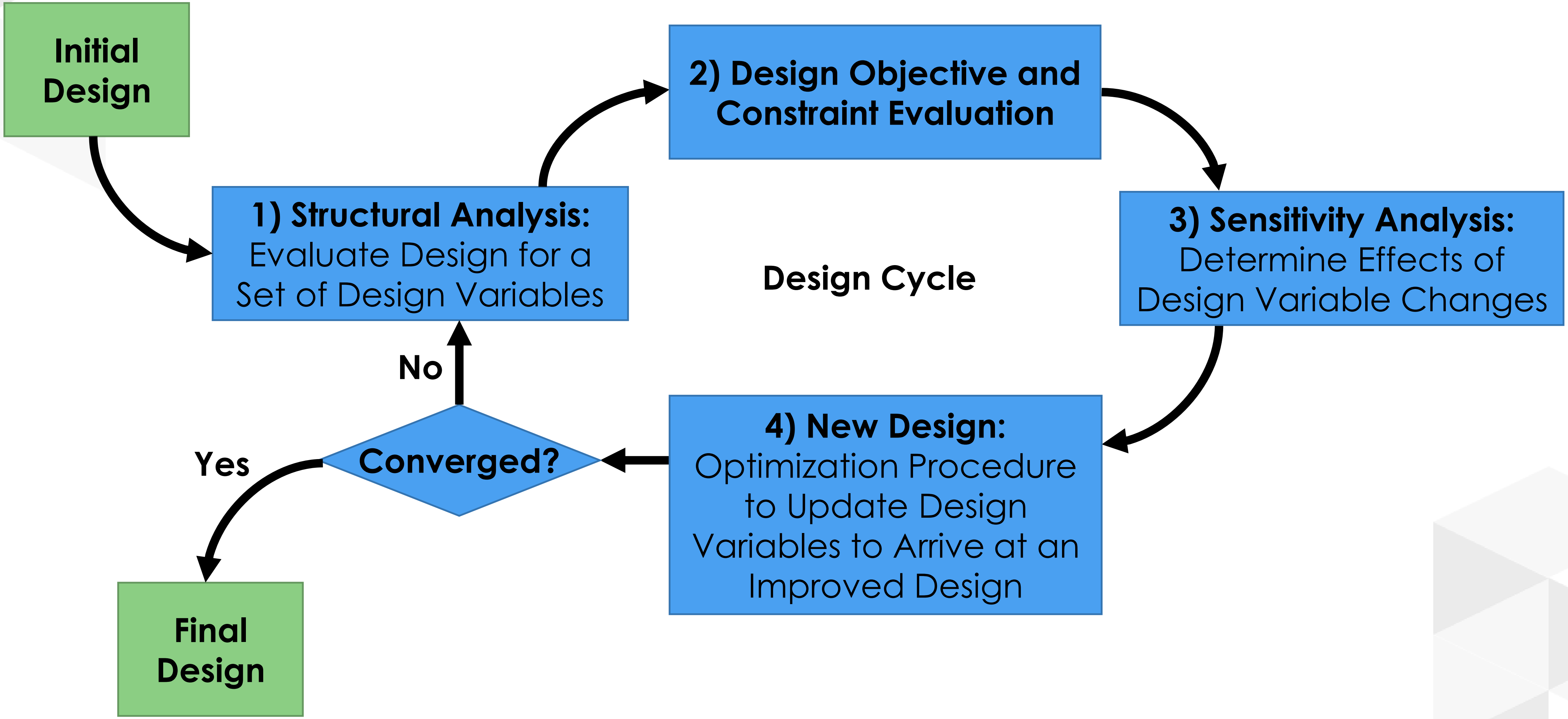
Reference: *Simcenter Nastran Design Sensitivity and Optimization User's Guide*

Basic Optimization Problem Statement

- What:
  - Minimize the objective function: $f(\vec{x})$
- How:
  - Design variables: $\vec{x} = \{x_1, x_2, \dots, x_n\}$
  - Design properties: $\vec{p} = \{p_1(\vec{x}), p_2(\vec{x}), \dots, p_m(\vec{x})\}$
- Subject to:
  - Inequality constraints: $g_j(\vec{x}) \le 0 \quad j = 1, \dots, n_g$
  - Equality constraints: $h_k(\vec{x}) = 0 \quad k = 1, \dots, n_h$
  - Bounds: $x_i^l \le x_i \le x_i^u \quad i = 1, \dots, n$

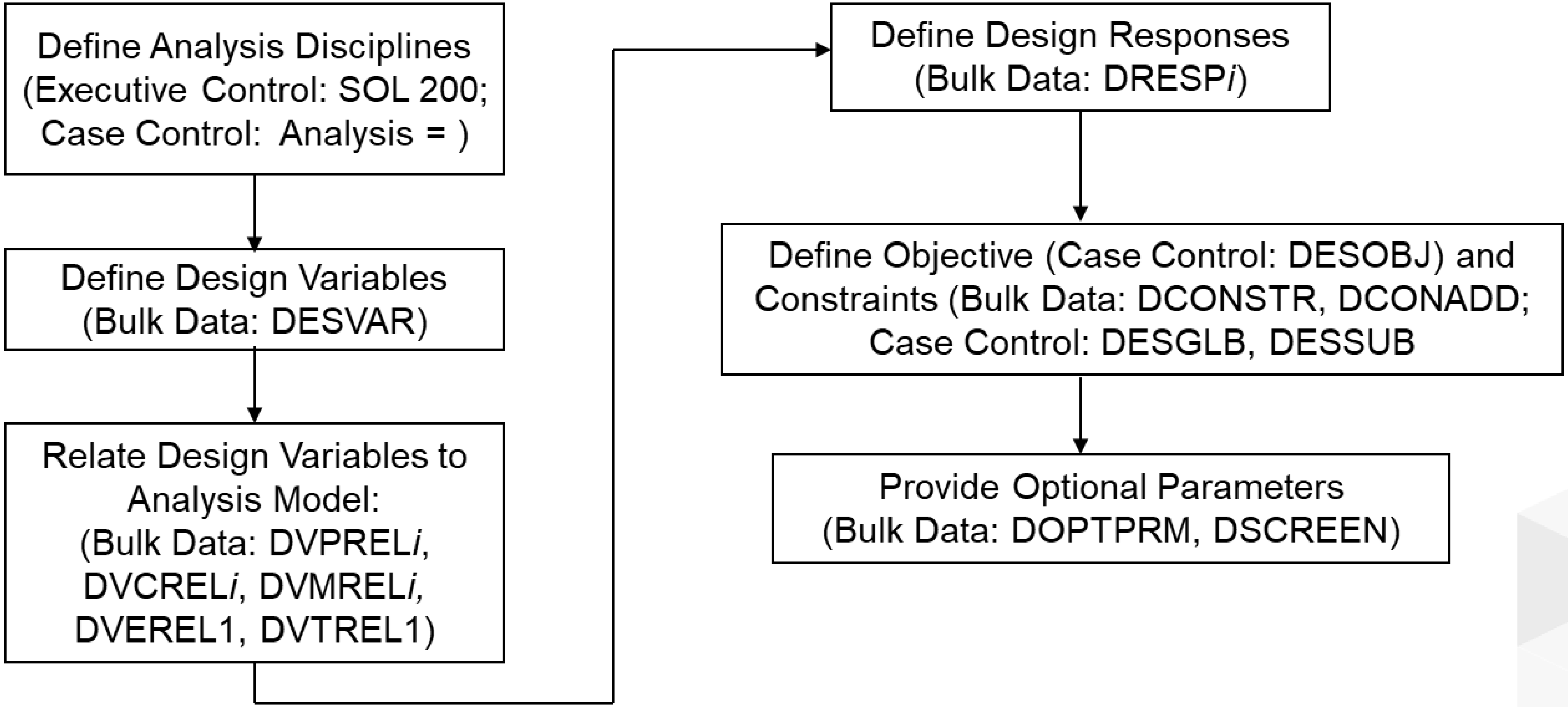
This basic optimization problem can be solved using Simcenter Nastran. Femap and Simcenter 3D support optimization preprocessing.

Simcenter Nastran Design Optimization Procedure



Simcenter Nastran Design Model Definition

(Not all capabilities shown)



Simcenter Nastran Capabilities (1)

Optimization Analysis Disciplines

Type	Meaning
STATICS+,f	Statics
MODES+,f	Normal Modes
BUCK+	Buckling
DFREQ*,f	Direct Frequency
MFREQ*,f	Modal Frequency
MTRAN+	Modal Transient
DCEIG*	Direct Complex Eigenvalue Analysis
MCEIG*	Modal Complex Eigenvalue Analysis
SAERO*	Static Aeroelasticity
DIVERGE*	Static Aeroelastic Divergence
FLUTTER*	Flutter

+ Design and topology optimization
* Design optimization only
f Native Femap support (DFREQ has native Femap support for design optimization only)

- Controlled using `ANALYSIS=TYPE` case control command.
- Can be defined at subcase level to simultaneously optimize with multiple analysis types.

Design Variables

- **DESVAR** – design variables and bounds.
- **DDVAL** – optional discrete variable values.
- **DLINK** – design variable linking.

Design-to-Model Relations

- **DVCREL*i*** – Design-Variable-Connectivity RELation
- **DVMREL*i*** – Design-Variable-Material RELation
- **DVPREL*i*** – Design-Variable-Property RELation
- Basic (or type-1 entries) support linear design variable-to-property relations.
- **DEQATN** (Design EQuATioN and type-2) entries can optionally be used for arbitrary relationships.
- **DVGRID**, **DVBSHAP**, and **DVSHAP** are used for shape optimization.
- **DVEREL1** automatically creates shell element thickness design variables.
- **DVTREL1** automatically creates design variables for topology optimization.

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Simcenter Nastran Capabilities (2)

Design Response Quantities

- **DRESP1** – supports 40 easily accessible response types:
  - CEIG, CFAILURE, CMPLNCE, CSTRAIN, CSTRESS, DISP, DWEIGHT, EIGN, ERP, ESE, FLUTTER, FORCE, FRACCL, FRDISP, FREQ, FRFORC, FRSPCF, FRSTRE, FRVELO, LAMA, PRES, PSDACCL, PSDDISP, PSDVELO, RMSACCL, RMSDISP, RMSVELO, SPCFORCE, STABDER, STRAIN, STRESS, TACCL, TDISP, TFORC, TRIM, TSPCF, TSTRE, TVELO, VOLUME, WEIGHT
  - See Simcenter Nastran Quick Reference Guide for details.
- **DRESP2** – Defines arbitrary equation responses that are used for the objective and/or design constraints, or for sensitivity analysis purposes.
- **DRESP3** – Defines arbitrary responses to be evaluated in an external user-supplied program.

Objective and Constraint Definitions

- Case control commands are used to specify a DRESPi entry that is the objective function and DCONSR or DCONADD entry that define constraints.
- **DCONSTR** defines design constraints, references DRESPi.
- **DCONADD** defines constraint set combination.
- Constraints can be subcase-specific.

Topology-Optimization-Specific Entries

- **DVTREL1** automatically creates design variables for topology optimization.
- **DMRLAW** controls the relation between material properties and the normalized mass density.
- **DMNCON** defines a manufacturing constraints for topology optimization.

Simcenter Nastran Capabilities (3)

Design Sensitivity Output

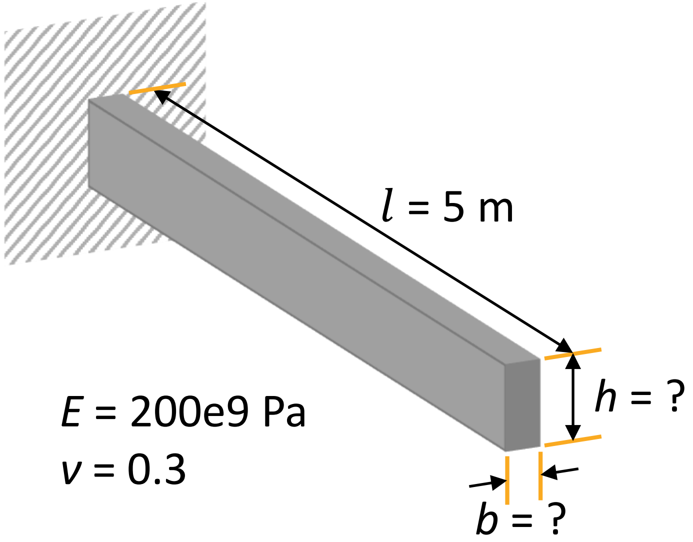
- Request output using either:
  - **`DSAPRT`** – Case control command
  - **`PARAM, OPTEXIT`** – Bulk data entry
- Various output formats supported
- Can request sensitivities only (no optimization)
  - User still needs to set up design variables and responses
  - General recommendation:
    - Define a violated constraint for each response quantity you require sensitivities for
    - Define a dummy objective function (e.g., weight)

Femap and Simcenter 3D Optimization Preprocessing

Live Femap Optimization Interface Walkthrough

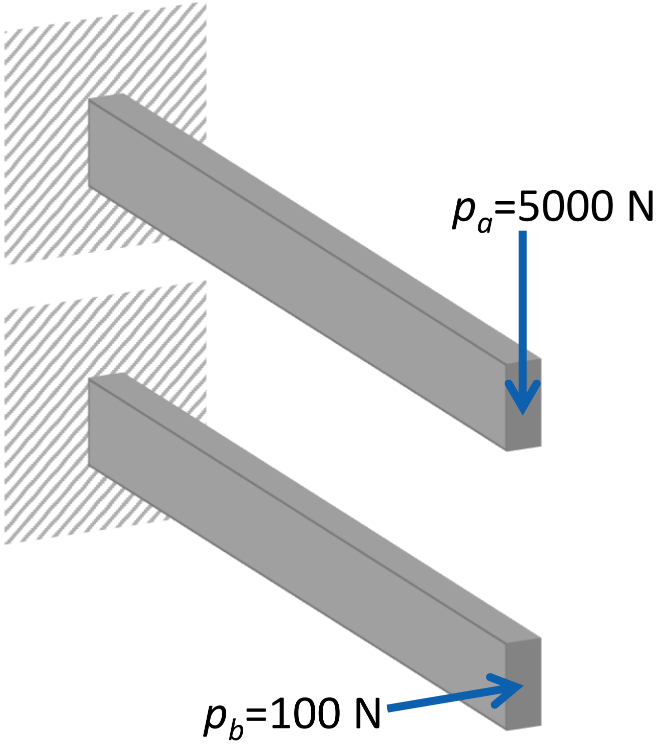
Beam Sizing Optimization

Dimensions and Properties



E = 200e9 Pa
v = 0.3

Loading Conditions



Problem Statement

Objective: Minimize volume

Design variables: *b, h*

Constraints:
$\sigma \leq$ 200e6 Pa (abs. due to bending)
$\delta \leq$ 0.1 m (abs. due do bending)

Bounds:
0.01 m $\leq b \leq$ 0.30 m
0.01 m $\leq h \leq$ 0.05 m

Response Solution Using Hand Calculations

Corner stress from beam theory

$$\sigma_a = \frac{My}{I}$$

Write in terms of design variables

$$M = p_a l$$

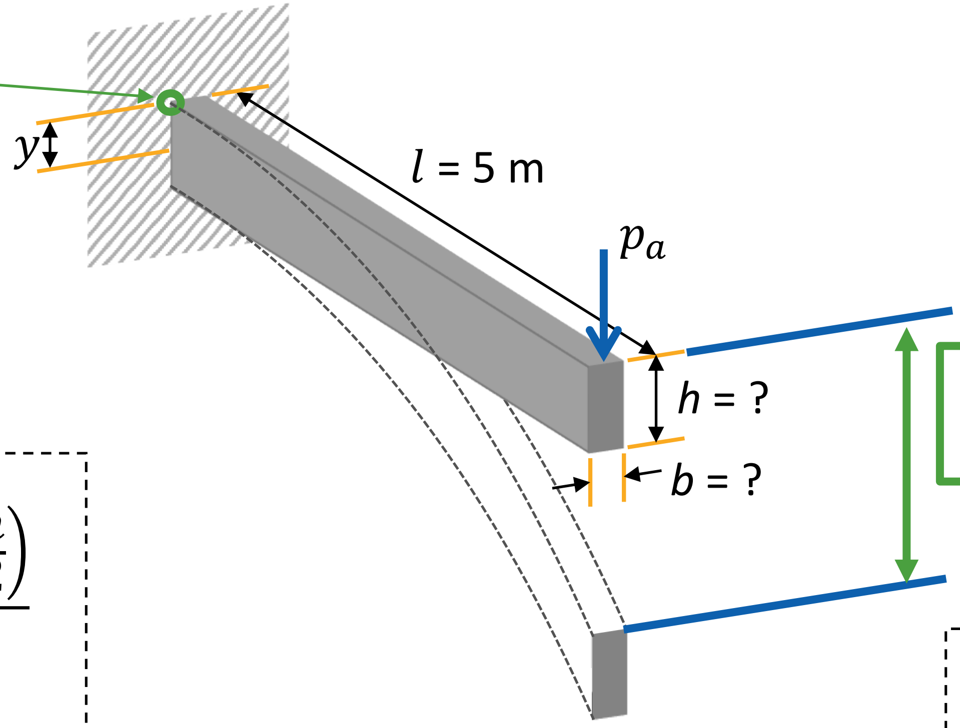
$$y = \frac{h}{2}$$

$$I = \frac{1}{12} b h^3$$

$$\sigma_a = \frac{(p_a l)\left(\frac{h}{2}\right)}{\frac{1}{12} b h^3}$$

Corner stress as a function of design variables

$$\sigma_a = 6 \frac{p_a l}{b h^2}$$



Tip displacement from beam theory

$$\delta_a = \frac{p_a l^3}{3EI}$$

Write in terms of design variables

$$\delta_a = \frac{p_a l^3}{3E\left(\frac{1}{12} b h^3\right)}$$

Tip displacement as a function of design variables

$$\delta_a = 4 \frac{p_a l^3}{E b h^3}$$

Response solution for loading condition b is analogous.

Graphical Solution for Beam Sizing Optimization Using Hand Calculations

Objective: minimize volume = lbh

Constraints

$$\sigma_a = 6\frac{p_a l}{bh^2} \leq 200e6 \text{ Pa}$$

$$\sigma_b = 6\frac{p_b l}{hb^2} \leq 200e6 \text{ Pa}$$

$$\delta_a = 4\frac{p_a l^3}{Ebh^3} \leq 0.1 \text{ m}$$

$$\delta_b = 4\frac{p_b l^3}{Ehb^3} \leq 0.1 \text{ m}$$

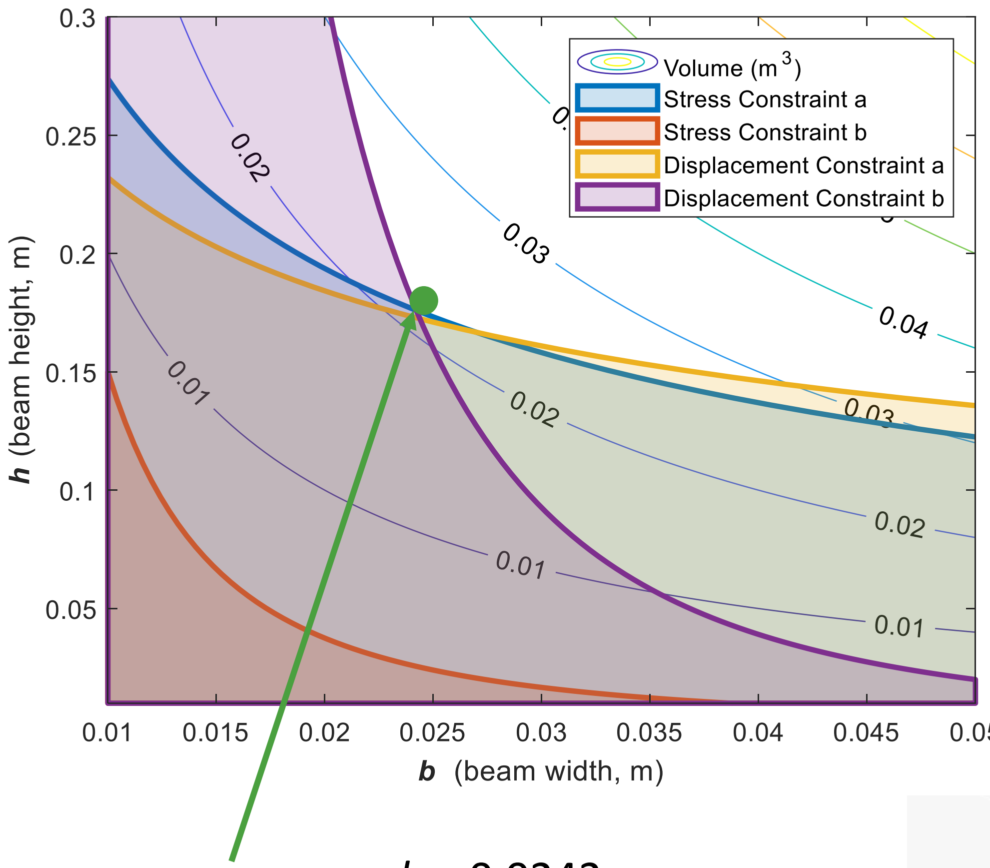
Constraints Curves

$$h \geq \sqrt{6\frac{p_a l}{200e6\, b}}$$

$$h \geq 6\frac{p_b l}{200e6\, b^2}$$

$$h \geq \left(4\frac{p_a l^3}{0.1Eb}\right)^{1/3}$$

$$h \geq 4\frac{p_b l^3}{0.1Eb^3}$$



Optimum

b = 0.0242 m
h = 0.1760 m
volume = 0.0213 m^3

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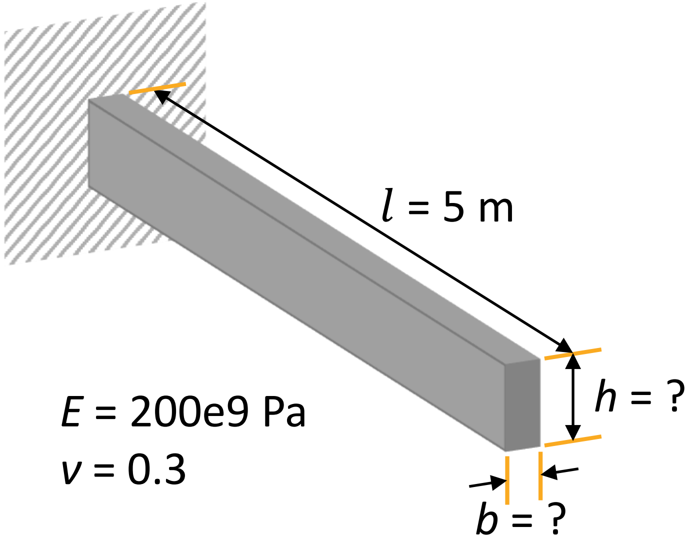
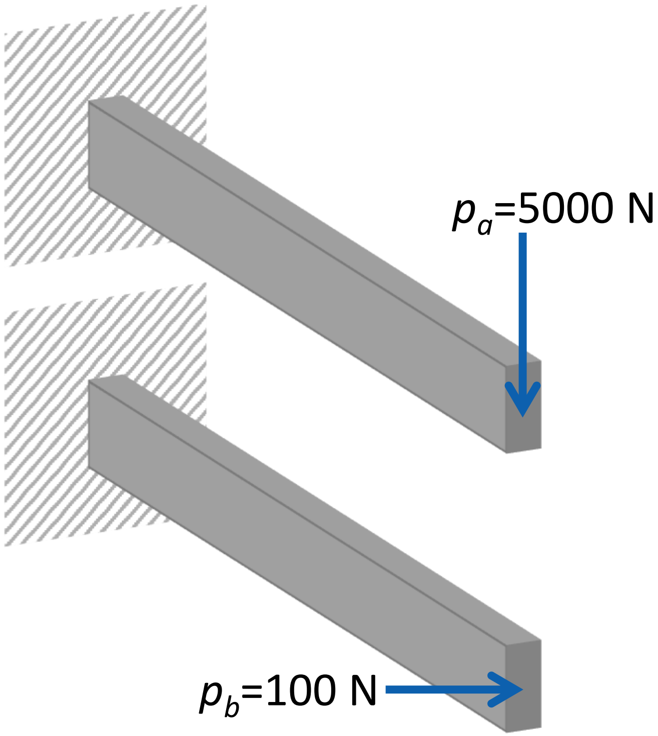
Beam Sizing Optimization using Femap and Simcenter Nastran

Dimensions and Properties



Loading Conditions



Problem Statement

Objective: Minimize volume

Design variables: *b, h*

Constraints:
$\sigma \leq$ 200e6 Pa (abs. due to bending)
$\delta \leq$ 0.1 m (abs. due do bending)

Bounds:
0.01 m $\leq b \leq$ 0.05 m
0.01 m $\leq h \leq$ 0.30 m

Live Femap Demonstration

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Topology Optimization Example

Sigmund Cantilever Beam

Ole Sigmund. "A 99 line topology optimization code written in MATLAB." **Structural and Multidisciplinary Optimization 21(2), 2001, pp. 120-127).**

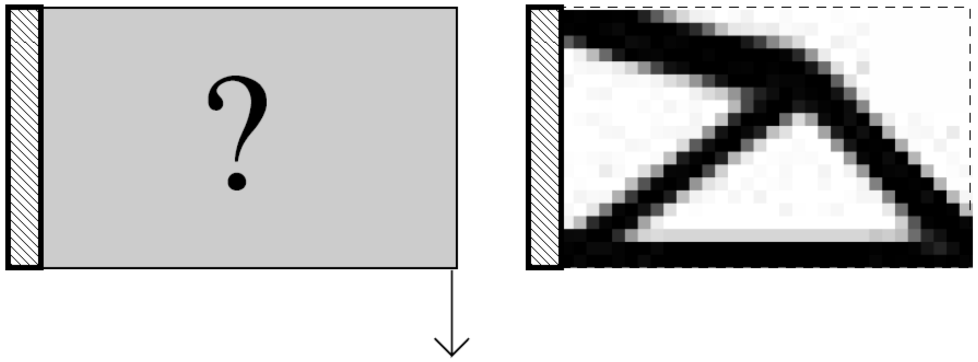
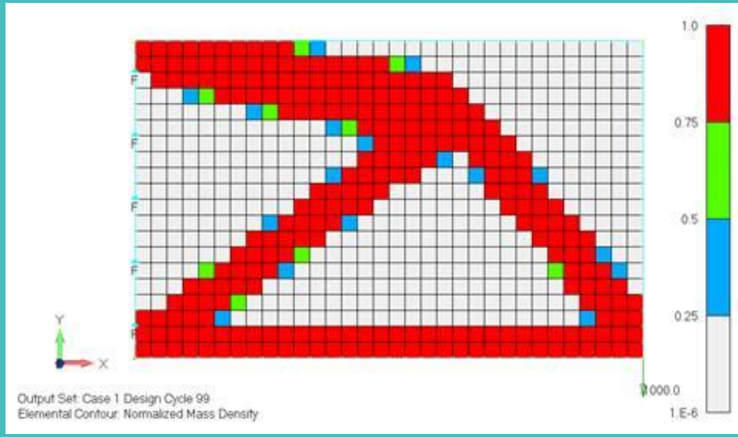


Fig. 2 Topology optimization of a cantilever beam. Left: design domain and right: topology optimized beam

```
nelx    = 32; % number of elements in the horizontal direction
nely    = 20; % number of elements in the horizontal direction
volfrac = 0.4;% volume fraction
top(nelx,nely,volfrac,3.0,1.5)
```

Live Femap Demonstration



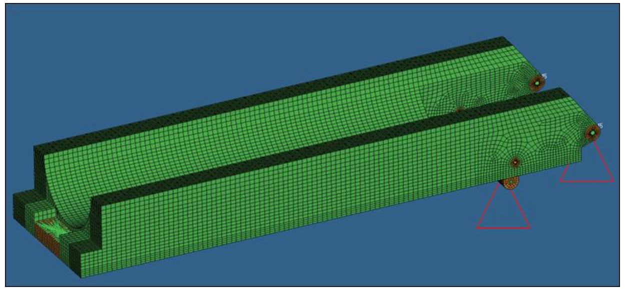
Topology Optimization Case Study

Transporter/Erector/Launcher (TEL) system for the Antares

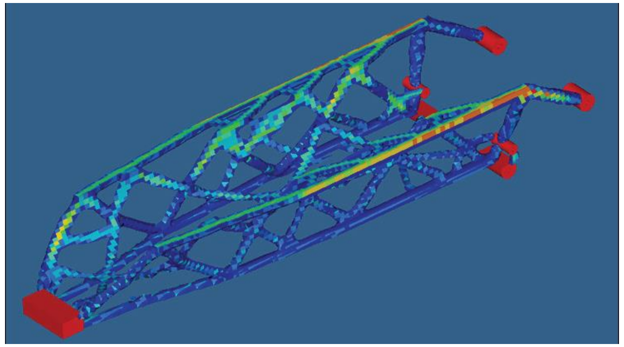
Background

- ATA Engineering and its engineering and manufacturing partner, Martinez & Turek, were selected to design, engineer, manufacture, install, and test the TEL.
- Topology optimization was used to rapidly explore topologies.

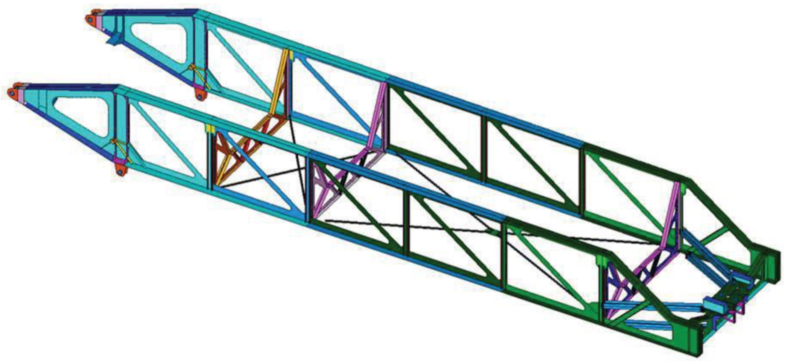
Meshed design space of strongback



Topology optimization results

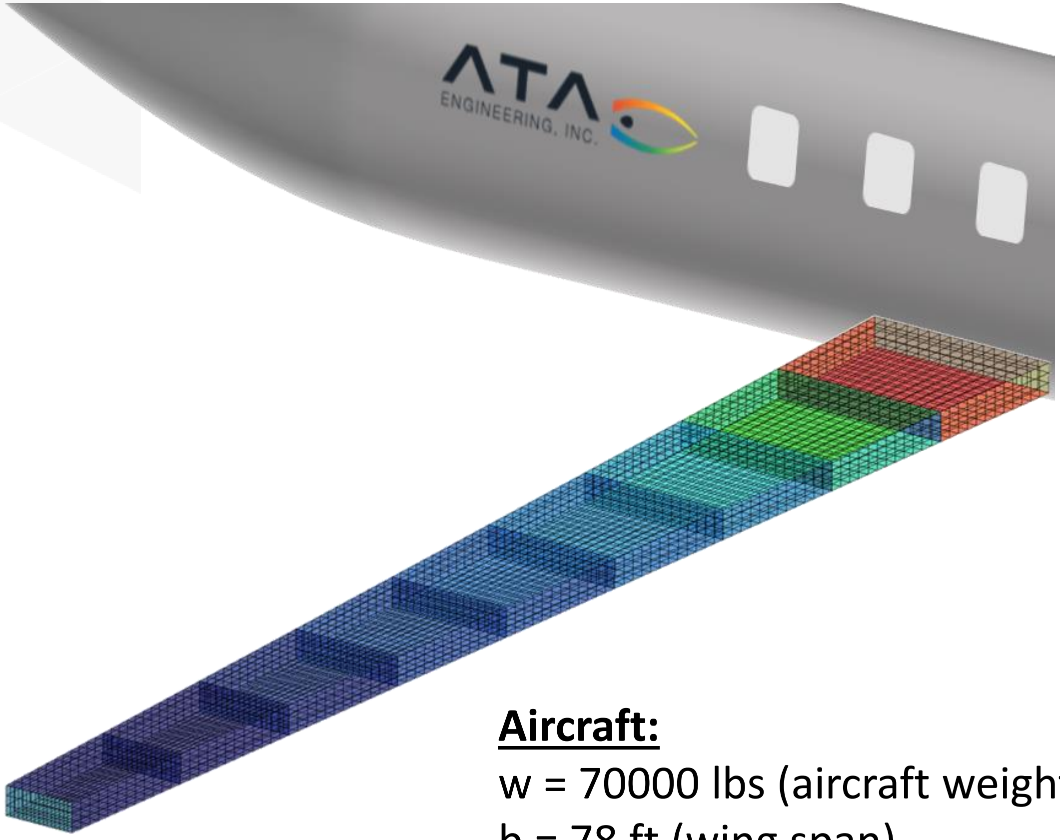


Final TEL Design



http://www.ata-e.com/wp-content/uploads/2019/12/TEL-Case-Study_2020.pdf#new_tab

Sizing an Aircraft Wing Structure Using Femap With Simcenter Nastran



Aircraft:
w = 70000 lbs (aircraft weight)
b = 78 ft (wing span)
Λ = 30 deg. (leading edge sweep)
C_r = b/6 (rood chord)
C_t = b/16 (tip chord)

Problem Statement

Objective: Minimize weight

Design variables: wing skin, spar, and rib thicknesses (26 total)

Constraints:
$\sigma_{vm} \leq 30$ ksi (4.4g maneuver load)
$f_1 \geq 8$ Hz

Live Femap Demonstration

Optimization with 26 design variables two analysis types

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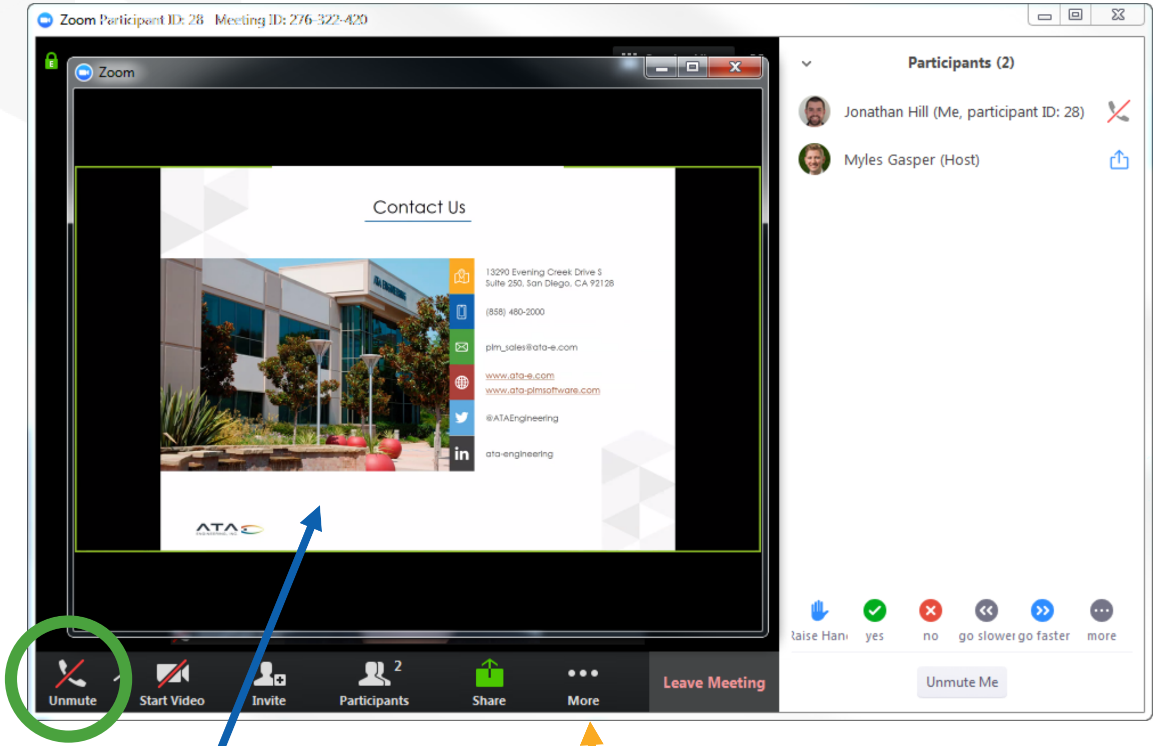
Questions?

Submit questions in the chat or unmute yourself now

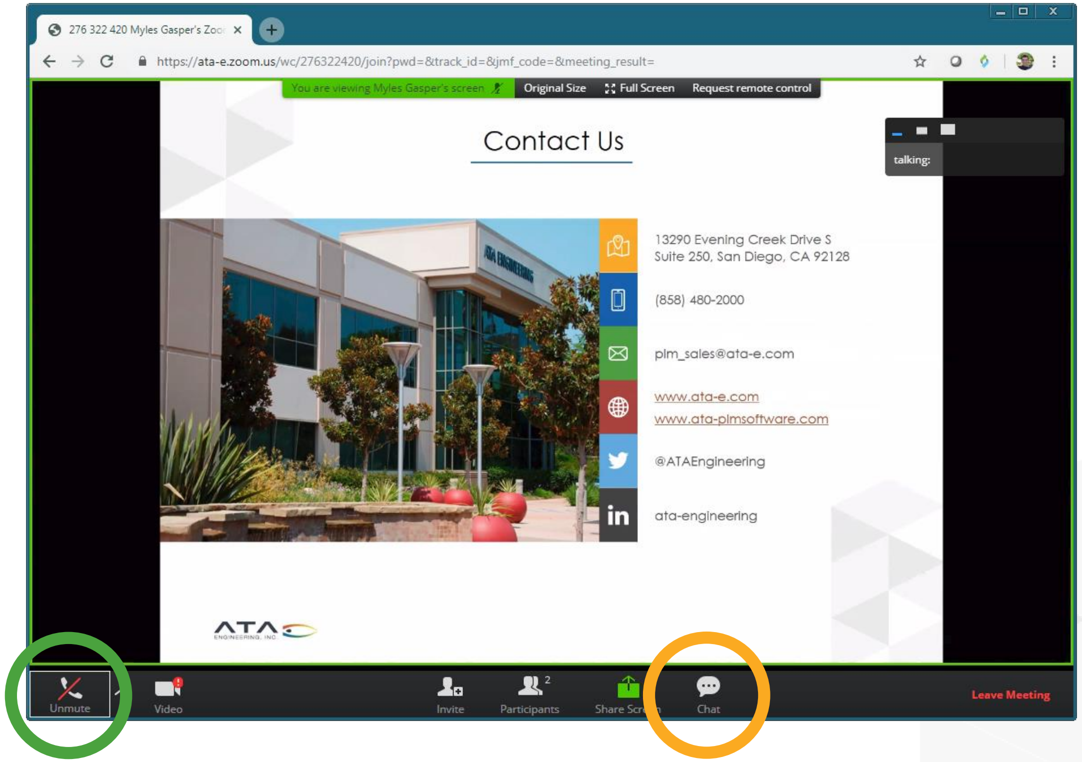
Zoom Application



Screenshare in separate window

Chat is available under More

Web Interface



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