

**EXAMPLES OF INCLUSION OF SIMULATION IN
MECHANICS,
DESIGN AND
CORE MECHANICAL ENGINEERING COURSES**

MECHANICS

Aerostructures Using COMSOL

DESIGN

Optimization

CORE MECHANICAL ENGINEERING COURSES

Examples with MATLAB Programming

Aerostructures (Aircraft Structures)

An elective course in the BSME curriculum

An important course in the Aerospace Option

Content is typical of advanced mechanics of materials

Exposure to multidimensional elasticity and systems of higher order partial differential equations

Content is strongly mathematical with the analysis being rigorous and time consuming

Depending on the University and the circumstances, there is never sufficient time to cover all of the topics, leave alone doing it thoroughly

A student starting professional practice in this area is most likely to use software for design and analysis

Exposure to Computation in ME @ RIT

“Problem Solving with Computers” in the first year –
Excel, VB, and maybe some MATLAB

“Measurements, Instrumentation, and Controls” - LABVIEW

“Numerical Methods” - MATLAB

“Advanced Computational Techniques” - ANSYS

“System Dynamics” – MATLAB and Simulink

Based on the diverse exposure, the students develop limited programming skills. Skills in CAE are also limited unless they use during their co-op experience

Course Constraints

Course lasts 10 weeks, with 4 contact hours per week, in two meetings of 2 hours

Students have only this course for information in aerospace structures, unlike in the aerospace engineering program

Must be exposed to theory and applications of aerospace structural mechanics

Course includes theory, analysis, and applications of elasticity (new to students)

Students have limited skills in MATLAB and very limited exposure to Ansys

COMSOL Multiphysics was new software for the students. The author strongly believes all engineering students must be able to use MATLAB effectively. Symbolic programming can be useful in elasticity problems

Course Strategy

Course conducted in computation laboratory where it was easy to transition between lectures and computation

7 out of 20 sessions were used for COMSOL and MATLAB.

COMSOL was introduced in stages and new features in each exercise. Students were challenged to discover features

Instructions for exercises were available in a consistent step-by-step procedure at the course web site. This allowed students to pay attention, avoid frustration, and learn at their pace

Modeling steps were reinforced in every exercise

The COMSOL Structural Mechanics Module made it very easy to develop exercises for the class

Konrad Juethner of COMSOL Inc. was a great resource, an excellent adviser, and provided significant encouragement during this development

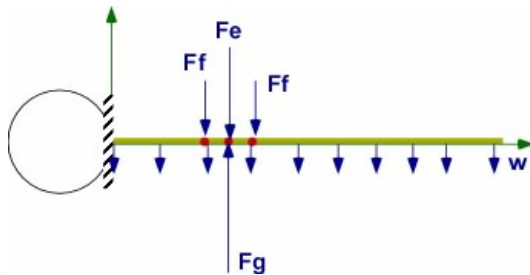
Exercises

Exercise	Topic	Analytical	MATLAB	COMSOL
1	Truss (2D/3D)	yes	yes	yes
2	Euler Bending	yes	yes	yes
3	Plane Stress	yes	optional	yes
4	Torsion	yes		yes
5	Thin Shell	yes		yes
6	Combine different application areas to prepare for Project – the Pratt bridge – from COMSOL documentation			yes
Project	Design of a 1 meter piece of a wing (3D) from an existing transport aircraft		yes (only for a part)	yes

Featured Example

This problem is a review of the techniques the students used in their first mechanics course, namely *singularity functions*. COMSOL has an application model for In-plane-Euler beam

It is a beam bending problem with fixed and distributed weights on the wing of a stationary aircraft

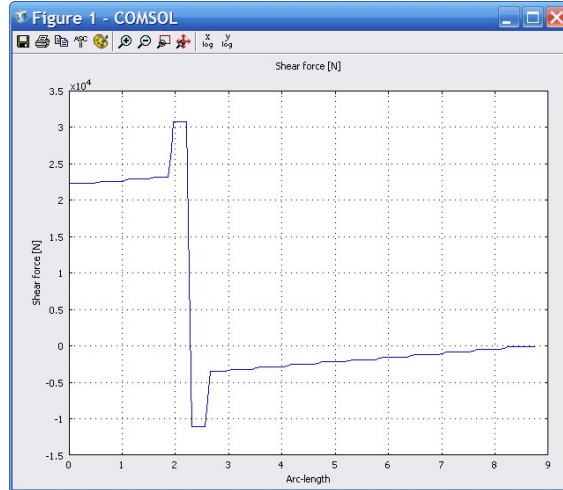


Exercise Features:

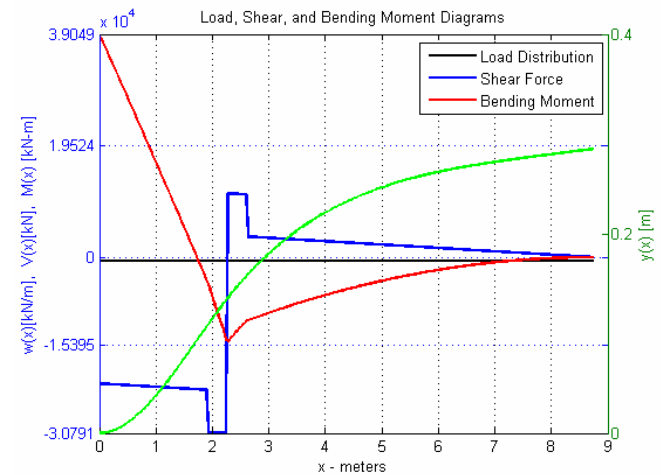
- Introduction to COMSOL Euler bending
- COMSOL solution is visualized in several ways
- COMSOL solution is compared to analytical solution obtained using singularity function implemented in MATLAB

Comparison of Solutions

COMSOL solution for shear



MATLAB Solution



Project

Computational resource and time limitation did impact the project definition. The explicit project requirements were:

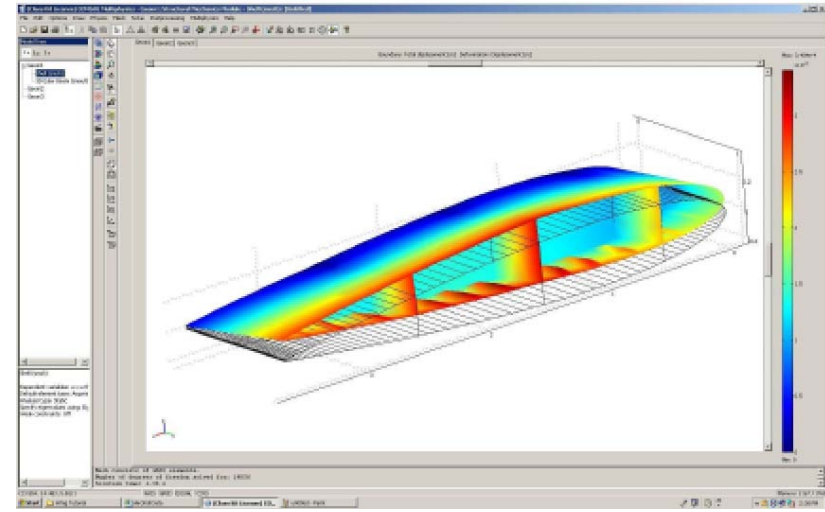
For a passenger aircraft in level flight

Obtain information of geometry, performance and dimension from references

Examine a 1 m length of the wing

Obtain load, shear, and moment over that length using Euler bending

Analyze the design using the COMSOL software



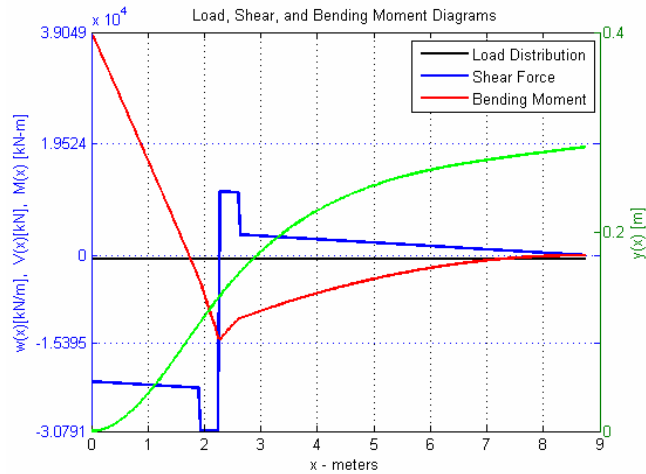
Author's Course Page :

<http://people.rit.edu/pnveme/EMEM671/>

COMSOL Educator Resource Center:

<http://www.comsol.com/academic/resources/courses/venkataraman/>

Problem Definition



Design Constraints:

$F_{app} = F(0)$; Applied shear load

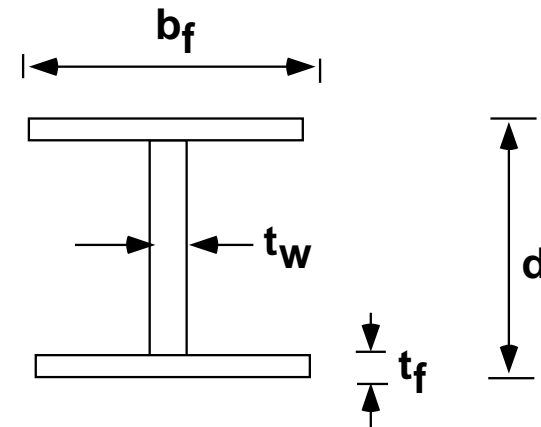
$M_{app} = M(0)$; Applied bending moment

y ; Deflection

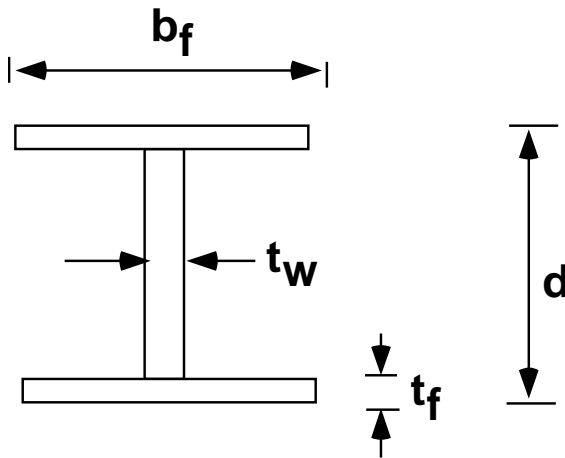
We assume the wing spar will bear most of the shear and bending load

We further assume that the cross section of the beam has an “I” shape

Cross-section definition



Design Functions

Choose d , b_f , t_w , t_f 

$$g_1 : \frac{M_{app} d / 2}{I} \leq \frac{\sigma_{max}}{FOS};$$

$$g_2 : \frac{F_{app} Q_c}{I t_w} \leq \frac{\tau_{max}}{FOS};$$

$$g_3 : \frac{y(L)}{EI} \leq \delta_{max}$$

$$g_4 : \gamma LA$$

A , I , Q_c are calculated from d , b_f , t_w , t_f

σ_{max} , τ_{max} , E , γ are known once material is chosen

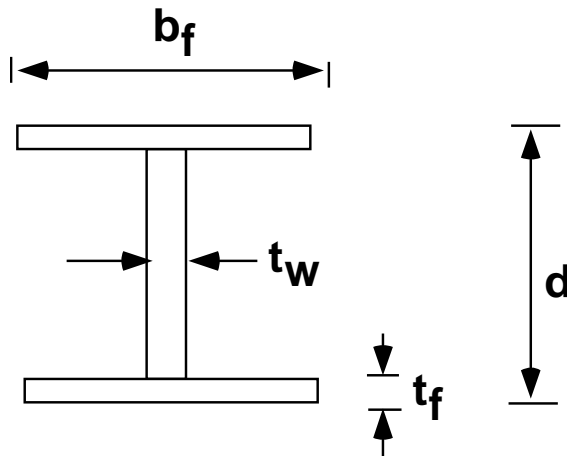
FOS , δ_{max} are designers choice

Design Optimization – Standard Format

Design Variables: d (x_1), b_f (x_2), t_w (x_3), t_f (x_4)

Objective Function

Minimize $f : \gamma LA$



Constraint functions

$$g_1 : \frac{M_{app} d / 2}{I} - \frac{\sigma_{max}}{FOS} \leq 0$$

$$g_2 : \frac{F_{app} Q_c}{I t_w} - \frac{\tau_{max}}{FOS} \leq 0$$

$$g_3 : \frac{y(L)}{EI} - \delta_{max} \leq 0$$

Side Constraints:

$$0.01 < d < 0.25; \quad 0.001 < t_w < 0.05$$

$$0.01 < b_f < 0.25; \quad 0.001 < t_f < 0.05$$

Design Variables: $d(x_1)$, $b_f(x_2)$, $t_w(x_3)$, $t_f(x_4)$

Use of MATLAB Optimization Toolbox

FMINCON finds a constrained minimum of a function of several variables.

min $F(X)$
 subject to: $C(X) \leq 0$ (nonlinear inequality)
 $Ceq(X) = 0$ (nonlinear equality)
 $A * X \leq B$ (linear inequality)
 $Aeq * X = Beq$ (linear equality)
 $LB \leq X \leq UB$ (side constraints)

$X = \mathbf{FMINCON}(FUN, X0, A, B, Aeq, Beq, LB, UB, \dots, \mathbf{NONLCON}, \mathbf{OPTIONS})$

Objective Function

Minimize $f : \gamma LA$

Constraint functions

$$g_1 : \frac{M_{app} d / 2}{I} - \frac{\sigma_{max}}{FOS} \leq 0$$

$$g_2 : \frac{F_{app} Q_c}{I t_w} - \frac{\tau_{max}}{FOS} \leq 0$$

$$g_3 : \frac{y(L)}{EI} - \delta_{max} \leq 0$$

Side Constraints:

$$0.01 < d < 0.25; \quad 0.001 < t_w < 0.05$$

$$0.01 < b_f < 0.25; \quad 0.001 < t_f < 0.05$$

Off-the-shelf design – ONE design variable

Discrete Optimization

Design Variables: d (x_1), b_f (x_2), t_w (x_3), t_f (x_4)

Objective Function

Minimize $f : \gamma LA$

Constraint functions

$$g_1 : \frac{M_{app} d / 2}{I} - \frac{\sigma_{max}}{FOS} \leq 0$$

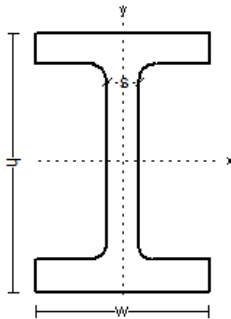
$$g_2 : \frac{F_{app} Q_c}{I t_w} - \frac{\tau_{max}}{FOS} \leq 0$$

$$g_3 : \frac{y(L)}{EI} - \delta_{max} \leq 0$$

Side Constraints:

$$0.01 < d < 0.25; \quad 0.001 < t_w < 0.05$$

$$0.01 < b_f < 0.25; \quad 0.001 < t_f < 0.05$$



Designation	Dimensions					Static Parameters			
	Imperial (in x in)	Depth h (in)	With w (in)	Web Thickness s (in)	Sectional Area (in ²)	Weight (lb/ft)	I _x (in ⁴)	I _y (in ⁴)	W _x (in ³)
3 x 2 1/2	3	2 1/2	0.13	1.39	1.64	2.24	0.52	1.49	0.42
3 x 2 1/2	3	2 1/2	0.15	1.73	2.03	2.71	0.68	1.81	0.54
4 x 3	4	3	0.15	1.97	2.31	5.62	1.04	2.81	0.69
4 x 3	4	3	0.17	2.38	2.79	6.71	1.31	3.36	0.87
5 x 3 1/2	5	3 1/2	0.19	3.15	3.70	13.9	2.29	5.58	1.31
6 x 4	6	4	0.19	3.43	4.03	22.0	3.10	7.33	1.55
6 x 4	6	4	0.21	3.99	4.69	25.5	3.74	8.50	1.87
7 x 4 1/2	7	4 1/2	0.23	4.93	5.80	42.9	5.78	12.3	2.57
8 x 5	8	5	0.23	5.26	6.18	59.7	7.30	14.9	2.92
8 x 5	8	5	0.25	5.97	7.02	67.8	8.55	16.9	3.42
9 x 5 1/2	9	5 1/2	0.27	7.11	8.36	102	12.2	22.7	4.44
10 x 6	10	6	0.25	7.35	8.65	132	14.8	26.42	4.93
10 x 6	10	6	0.29	8.75	10.29	156	18.0	31.2	6.01
12 x 7	12	7	0.29	9.93	11.67	256	26.9	42.6	7.69
12 x 7	12	7	0.31	12.2	14.29	317	35.5	52.9	10.1

www.EngineeringToolbox.com

Reference:

Applied Optimization with MATLAB Programming

The Web Resource

Provost Learning Innovation Grant RIT 2006	Sustained Analysis across Engineering							
	Curriculum using Same Software							
P. Venkataraman			Mechanical Engineering					
Resources ▶	Statics ▶	Strength of Materials ▶	Dynamics ▶	Thermodynamics ▶	Fluid Mechanics ▶	Heat Transfer ▶	Machine Design ▶	System Dynamics ▶
HOME	Vector Components ▶	Rigid Body Equilibrium ▶	Plane Truss	Equations	Problem Definition	Solution	MATLAB Solution	

Current use of software in education, in the core courses, in all institutions, is spotty and inconsistent. It is discontinued. The phenomenal power that these tools can bring to problem solving and concept visualization. It is instructor dependent. Particular teaching philosophy, prejudice, and depth of knowledge of the tool.

It is difficult to recommend universal adoption of the same software in all courses (where it is possible) unless it can be shown to be effective. To become a useful instrument in student's learning, it must be tried out in the complete sequence. To become part of the experience there must be a resource from where the faculty and the students can be shown how it can be incorporated. This web site delivers such a resource.

The faculty and the student should possess some knowledge of MATLAB (must have used it before) in order that this site be effective. This site is not recommended for learning MATLAB. There are links in the **resources** menu for accomplishing that. However, for the student, a formal exposure would be the most effective.

The Horizontal menu at the top invites you visit the following core courses in Mechanical Engineering: **Statics, Strength of Materials, Dynamics, Thermodynamics, Fluid Mechanics, Heat Transfer, Machine Design, System Dynamics, Statistics, and Matrix applications.** Most of the problems are chosen from examples in the current text books recommended for these courses. This makes the site immediately relevant.

The software is **MATLAB**

http://people.rit.edu/pnveme/Plig_2006/

Motivation

The presenter has been trying for several years to have all engineering students to be exposed to MATLAB in their freshman year –In ME this can be done in “Problem Solving with Computers”

Instructors/students can harness powerful visualization tools to understand concepts

Students become comfortable with programming by junior year if simulation is used in courses along the way

Students can become more confident in math application which will positively affect every other academic activity

The reason it is difficult is that RIT students co-op at many small companies where acquiring MATLAB is not an option and calculations are not challenging enough to replace Excel

Students complaint about engineering subjects being dry - can be changed with **animation** and **what if** exploration

Currently simulation is not an option due to lack of skills

Site Content

Courses

Statics

Strength of Materials

Dynamics

Thermodynamics

Fluid Mechanics

Heat Transfer

Machine Design

System Dynamics

Statistics

Matrices

For each course

There are three examples from early, middle, and end of the course

For each example

Problem Definition

Nominal Solution : How it is traditionally solved

MATLAB Solution : Solution through MATLAB with **code** and graphics

Thank You

Questions ?