Assignment 2: Simple and Detailed Stress Analyses

24-370 Engineering Design I
Due @ 12:30, Wednesday February 2^{nd} 2011

Name:

The Giant's Flute

A set of large stainless steel tubes, with an axial hole pattern, are to be statically loaded in various ways following installation. Use your new-found skills at analytical and SolidWorks modeling to estimate the peak component stresses, determine the underlying relationships, and make recommendations.

* For your calculations below, please keep equations in symbolic form, i.e., do not make numerical substitutions, until the last possible moment. Please give all numerical answers in English units, e.g., psi.

Part 1: The Giant's Flute, in Bending

1.a: Simple Model of a Flute in Bending

The first tube will be cantilevered. One end will be perfectly fixed and the other end will receive a static load of $\boldsymbol{F}$ = 5,000 lbf. Tube geometry is defined in the engineering drawing on the final page (dimensions in inches). The tube will be oriented such that the small holes are on the top and bottom during loading. In other words, the force will be applied in the same direction as the axes of the small holes. The tube will be fabricated from AISI 304 stainless steel, which has a yield stress $\boldsymbol{\sigma_y}$ = 30,000 psi and an elongation at failure of $\boldsymbol{\epsilon_f}$ = 0.70.

1.a.i - Loading analysis. Please draw a Free Body Diagram of a simplified version of the tube, using load = $\boldsymbol{F}$ and tube length = $\boldsymbol{L}$. Please include the reaction force(s) and moment(s) and their values.

1.a.ii - Simplest stress analysis. Using the simplest model of interest, derive an equation for the peak stress in the tube, using tube outer diameter = $\boldsymbol{D_o}$, and tube outer diameter = $\boldsymbol{D_i}$.

1.a.iii - Simplest stress value prediction. After you have derived the peak stress symbolically, substitute in prescribed parameter values to estimate the peak tube stress, $\boldsymbol{\sigma_m}$, and factor of safety, ***FOS***. Please report stress to three significant digits, e.g., 123000, and factor of safety to two, e.g. 1.2.

1.a.iv - Simple stress concentrators. Using figure 3-29 from Shigley, determine an appropriate stress concentration factor, $\boldsymbol{K_t}$, for the model. For simplicity, use the outer diameter as *w*, and round to two significant digits, e.g., 1.2. Apply the stress concentration factor to obtain a new peak tube stress, $\boldsymbol{\sigma_m}'$, and factor of safety, $\boldsymbol{FOS}'$. Please report stress to three significant digits, e.g., 123000, and factor of safety to two, e.g. 1.2.

1.a.v - Shear. Using the correct beam shape formula, e.g. from table 3-2 in Shigley, determine the peak shear stress, $\boldsymbol{\tau_m}$, in the tube, to three significant digits. Compare this to the peak bending stress from 1.a.iii. What is the ratio of $\boldsymbol{\tau_m}$ to $\boldsymbol{\sigma_m}$, to one significant digit? Is shear important to this design?

1.a.vi - The inverse problem. Given an outer diameter of the tube D_o^*, what is the minimum inner diameter D_i^* that will produce a factor of safety ***F.O.S.****? Please form your answer symbolically first. If D_o^* = 10 and ***F.O.S.**** = 1.5, what is D_i^* to three significant digits?

1.a.vii - ***Bonus problem:*** Parametric analysis. First, derive the mass **m** of the tube symbolically, using density = ρ. Next, substitute the relationship for D_i determined in 1.a.v, so as to derive the mass m as a function of D_o. Using Matlab, plot the mass over the range of D_o = [7.5:0.1:30]; using ρ = 0.3 pounds per cubic inch and ***F.O.S.*** = 1.5. Provide a copy of your figure. For what value of D_o is the mass minimized? How might our simple model become physically unrealistic as we decrease mass? (In addition to proof of your awesomeness, up to 5 extra points will be added to your cumulative homework score.)

1.b Detailed Model of a Flute in Bending

Now perform a more detailed analysis of the tube in bending using SolidWorks. The part geometry and loading will remain the same as in part 1.a.

1.b.i - SolidWorks part modeling. Create the part in SolidWorks using the described geometry and material. Please include a screen shot (Save As --> Save as type: JPEG) of your model. What is the part ***mass***, in kilograms, to the nearest integer? Use the Evaluate tab --> Mass Properties. You may change units by selecting Options --> Use custom settings, in the mass properties window.

1.b.ii - SolidWorks part Simulation. Create a Simulation Study of the part under the static loading conditions described, in the manner discussed in class. What is the maximum stress in the part, σ_m, in psi, to three significant digits? Compare this with your value from 1.a.iv. What is the error, e_{simple}, expressed as a percentage of the FEA predicted stress, to the nearest integer?

1.b.iii - Validation using simplest model. Determine the peak stress in the tube without the stress concentrators. You may find the Suppress function useful in this part, which can be accessed by right-clicking and selecting the Suppress icon, which is a yellow box over a gray box, found in the middle of the top row. What is the maximum stress, σ_m, in psi, to three significant digits? Compare this to your answer from part 1.a.iii. What is the apparent error, e_{FEA}, expressed as a percentage of the simple model predicted stress, to the nearest integer? Given your result from 1.b.ii, what was the weakest aspect of our simple modeling in part 1.a, in 5 words or less?

1.b.iv - Interpretation. Will any portion of this beam yield? Please write “yield: “ and either “yes” or “no”. Given the material properties, and our discussion of ductility in class, will the beam fail? Please write “fail: “ and either “yes” or “no”. If the beam were constructed from Gray Cast Iron, e.g. ASTM 20, with ultimate stress σ_u = 22,000 psi and an elongation at failure of ϵ_f = 0.01, would the beam fail? Please write: “cast iron fail: “ with “yes” or “no”.

Part 2: The Giant's Flute, in Torsion

2.a: Simple Model of a Tube in Torsion

The *second* tube will be placed in pure torsion. One end will be fixed and the other will receive a static torque $\boldsymbol{T}$ = 500,000 lbf in. with direction of rotation along the axis of the tube. The geometry and material will be the same as in part 1.

2.a.i - Loading analysis. Please draw a Free Body Diagram of a simplified version of the tube, using load = $\boldsymbol{T}$. Please include the reaction force(s) and moment(s) and their (symbolic) values.

2.a.ii - Simplest stress analysis. Using the simplest model of interest, derive a simple equation for the peak stress in the tube, using tube outer diameter = $\boldsymbol{D_o}$, and tube outer diameter = $\boldsymbol{D_i}$. If you have trouble recalling/finding the equations of interest, section 3-12 and table A-18 of Shigley could prove useful.

2.a.iii - Simplest stress value prediction. After you have derived the peak stress symbolically, substitute the prescribed values to estimate the peak tube stress, $\boldsymbol{\tau_m}$, and factor of safety, ***FOS***. Note that you have determined the maximum shear stress, but yield stress is typically reported in terms of tensile (normal) stresses. Use the shear yield strength predicted by the distortion-energy theory to obtain the yield stress in shear, $\boldsymbol{\tau_y} = 0.58 \cdot \boldsymbol{\sigma_y}$, before calculating ***FOS***. Finally, use the inverse of this equation to obtain the maximum stress in von Mises stresses, i.e. $\boldsymbol{\sigma_m} = \boldsymbol{\tau_m} \cdot 0.58^{-1}$. Please report stress and factor of safety to three significant digits each.

2.a.iv - Simple stress concentrators. Using the stress concentration factor, $\boldsymbol{K_t}$, determined above, determine the peak estimated tube stress, $\boldsymbol{\sigma_m}'$, and factor of safety, ***FOS***$'$. Use the inverse of the shear yield equation from 2.a.iii to first convert your values into normal stresses. Please report stress to three significant digits and factor of safety to two. Bonus: where might we find a more accurate value for $\boldsymbol{K_t}$, and what would it be? Up to 2 extra points will be added to your cumulative homework score.

2.b Detailed Model of a Flute in Bending

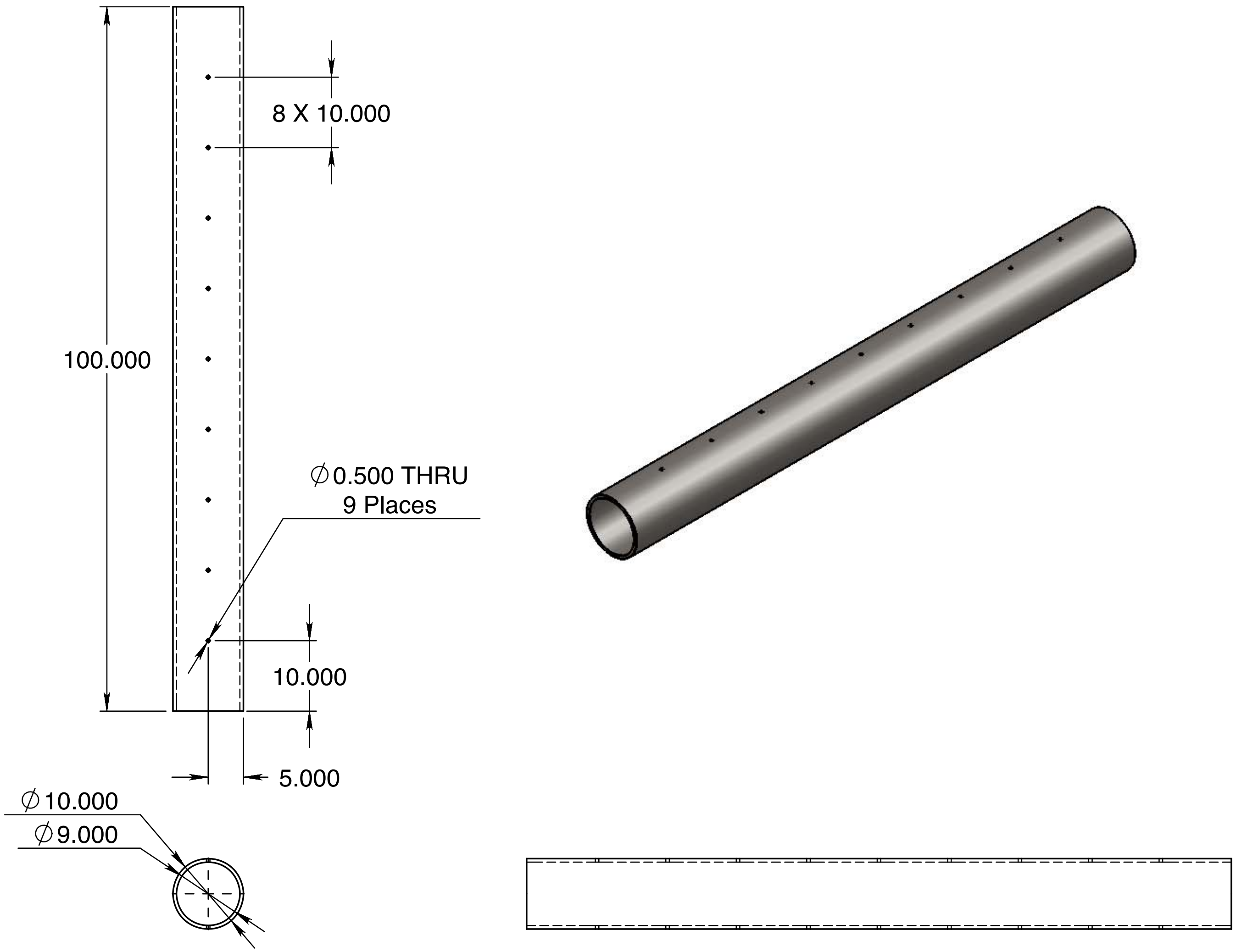
Now perform a more detailed analysis of the tube in bending using SolidWorks. The part geometry and loading will remain the same as in part 2.a.

2.b.i - You may use the same model as in part 1.b.i.

2.b.ii - SolidWorks part Simulation. Create a new Simulation Study of the part under the static loading conditions described. [To apply the torque load, right click on External Loads and select Torque. Select the face to which the load will be applied. Next click in the pink dialog box (in left panel, below blue box) to enable selection of the toque application direction. Select a cylindrical face of the tube, whose axis is collinear to the torsional axis. Purple arrows will appear tangent to the outer and inner circular edges of the face. You will need the full version of SolidWorks to apply a torque load.] What is the maximum stress in the part, $\boldsymbol{\sigma_m}$, in psi, to three significant digits? Note that the default setting displays von Mises stresses. Compare this with your value from 1.a.iv. What is the error, $\boldsymbol{e_{simple}}$, expressed as a percentage of the FEA predicted stress, to the nearest integer? What do you guess is the source of this error, in 5 words or less?

2.b.iii - Validation using simplest model. Determine the peak stress in the tube without the stress concentrators. You may find the Suppress function useful. What is the maximum stress, $\boldsymbol{\sigma_m}$, in psi, to three significant digits? Compare this to your answer from part 1.a.iii. What is the apparent error, $\boldsymbol{e_{FEA}}$, expressed as a percentage of the simple model predicted stress, to the nearest integer?

2.b.iv - Interpretation. Try different values for the inner and outer diameters of the tube in SolidWorks and observe the corresponding changes in mass and maximum stress. Consider how you might do this using the equations you derived above. What are the strengths and weaknesses of the two approaches, in 5 words or less for each strength and weakness?



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL	COMMENTS:		
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TITLE:

Flute_Under_Stress

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