

Project (#4): Properties of Thin-Wall General and Airfoil Cross-Sections

Due Date: Upload zip folder to TED by 11:58 PM, Friday, March 13, 2020

Files that you need in your MATLAB Folder:

Download from TED: SE160A_4_Section_Input.xlsx
 Download from TED: SE160A_4_Section_Output.xlsx
 Download from TED: SE160A_4_Section.p
 Download from TED: createFigure.m
 Download from TED: deleteFigure.m
 Your created (m) file: For Undergraduate Students: SE160A_4_LastName_FirstName.m
 For Graduate Students: SE260A_4_LastName_FirstName.m

Problem Answers are saved in a (pdf):

For Undergraduate Students: SE160A_4_LastName_FirstName.pdf
 For Graduate Students: SE260A_4_LastName_FirstName.pdf

Upload your (m) file and (pdf) file into a (zip) folder of the same name:

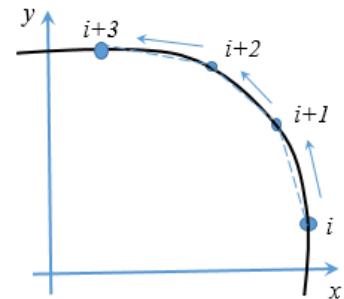
For Undergraduate Students: SE160A_4_LastName_FirstName.zip
 For Graduate Students: SE260A_4_LastName_FirstName.zip

Introduction

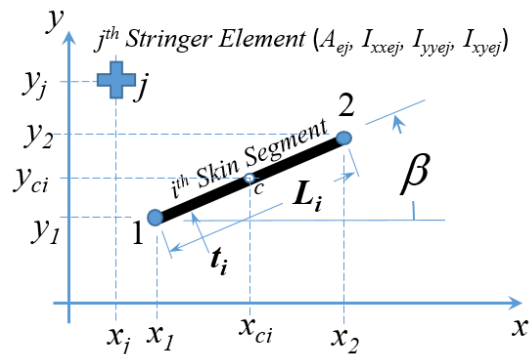
Aerospace structures are built-up from a wide variety of structural components (stringers, longerons, skins, etc.). The analysis of these structures requires that the section properties are known. In this MATLAB assignment, you will write a computer program that calculates the section properties of a general (arbitrary) cross-section that is composed of thin-wall straight “skin” segments and/or discrete “stringer” elements. In addition, you will calculate the section properties of a thin wall airfoil (NACA four series) with internal spars.

General Section

The curved skin is divided into straight segments that are defined using the (x,y) coordinate points at the segment ends, along with the skin thickness (t), density (ρ), and Young’s modulus (E). The discrete stringer elements are defined using their section properties (A_e , I_{xxe} , I_{yye} , I_{xye}) in their own local element frame along with the (x,y) coordinate location to the stringer element centroid and material properties (ρ , E).



The calculated section properties in this initial coordinate frame (x,y) include the structural area (A), centroidal location (x_c , y_c), and the inertia (I_{xx} , I_{yy} , I_{xy}) properties. In addition, the mass-weighted and modulus-weighted section properties are calculated in this initial frame. Next, all of the above section properties are calculated in the centroidal axis frame (origin moved to area centroid), then in the modulus-weighted axis frame (origin moved to modulus-weighted area centroid), and finally in a user defined location (x_o , y_o). All of these cross-section properties are calculated by making use of the parallel axis theorem. You will solve this problem by discretizing the arbitrary open or closed cell thin-wall cross-section into a series of straight skin segments along with the addition of discrete stringer elements, where the segments are defined in a counter clockwise order around the section. Internal spars can be treated by additional skin elements.



The curved skin is divided into straight segments that are defined using the (x,y) coordinate points at the segment ends, along with the skin thickness (t) , density (ρ) , and Young's modulus (E) . The discrete stringer elements are defined using their section properties $(A_e, I_{xxe}, I_{yye}, I_{xye})$ in their own local element frame along with the (x,y) coordinate location to the stringer element centroid and material properties (ρ, E) .

NACA 4-Digit Airfoil Section

A 4-digit system of identifying standard airfoils was developed by NACA (National Advisory Committee for Aeronautics; the predecessor of NASA) in the 1930's, and both the system and the airfoils they represent are still used today in aircraft wings, tail sections, helicopter blades, and propellers. The first two digits (M and P) define the camber line, and the second two digits (TT) define the maximum thickness of the airfoil. It is a relatively simple system to program and use, and this family of airfoils provides an excellent medium for studying the effects of an airfoil's thickness and camber on its structural behavior. The equations for the four-digit definition are used to generate the linear skin segments. Internal vertical spars are defined at specific chord locations that connect the lower and upper skin. All of the skin segments are then used to determine the airfoil's cross-sectional properties in the original frame, centroidal frame, modulus-weighted frame, and the user-defined coordinate frame. The equations for the cambered airfoil are given in the appendix.

Cross-Section Properties

The section properties for the (i^{th}) straight skin segment about the initial coordinate frame (x, y) are given by:

$$\begin{aligned} L_i &= \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \\ x_{c_i} &= \frac{1}{2}(x_1 + x_2) \\ y_{c_i} &= \frac{1}{2}(y_1 + y_2) \\ I_{xx_i} &= \frac{t_i L_i^3}{12} \sin^2 \beta + A_i y_{c_i}^2 = \frac{A_i}{6} (y_1 (2y_1 + y_2) + y_2 (y_1 + 2y_2)) \\ I_{yy_i} &= \frac{t_i L_i^3}{12} \cos^2 \beta + A_i x_{c_i}^2 = \frac{A_i}{6} (x_1 (2x_1 + x_2) + x_2 (x_1 + 2x_2)) \\ I_{xy_i} &= \frac{t_i L_i^3}{12} \cos \beta \sin \beta + A_i x_{c_i} y_{c_i} = \frac{A_i}{6} (x_1 (2y_1 + y_2) + x_2 (y_1 + 2y_2)) \end{aligned}$$

The properties of the total cross-section are determined by simply summing the properties for all the (i^{th}) straight skin segments and all the (j^{th}) stringer elements.

$$\begin{aligned} A &= \sum_{i=1}^{n_s} A_{s_i} + \sum_{j=1}^{n_e} A_{e_j} \\ x_c &= \frac{1}{A} \left(\sum_{i=1}^{n_s} A_{s_i} x_{c_i} + \sum_{j=1}^{n_e} A_{e_j} x_{e_j} \right) \\ y_c &= \frac{1}{A} \left(\sum_{i=1}^{n_s} A_{s_i} y_{c_i} + \sum_{j=1}^{n_e} A_{e_j} y_{e_j} \right) \\ I_{xx} &= \sum_{i=1}^{n_s} I_{xx_i} + \sum_{j=1}^{n_e} \left(I_{xx_{ej}} + A_{e_j} (y_{e_j})^2 \right) \\ I_{yy} &= \sum_{i=1}^{n_s} I_{yy_i} + \sum_{j=1}^{n_e} \left(I_{yy_{ej}} + A_{e_j} (x_{e_j})^2 \right) \\ I_{xy} &= \sum_{i=1}^{n_s} I_{xy_i} + \sum_{j=1}^{n_e} \left(I_{xy_{ej}} + A_{e_j} (x_{e_j} y_{e_j}) \right) \end{aligned}$$

The mass-weighted properties of the total cross-section are determined by summing the product of the densities multiplied by the straight skin segments and the product of the densities multiplied by the stringer elements.

$$\begin{aligned}\rho A &= \sum_{i=1}^{n_s} \rho_i A_{s_i} + \sum_{j=1}^{n_e} \rho_j A_{e_j} \\ \rho I_{xx} &= \sum_{i=1}^{n_s} \rho_i I_{xxi} + \sum_{j=1}^{n_e} \rho_j \left(I_{xxej} + A_{e_j} (y_{e_j})^2 \right) \\ x_{cg} &= \frac{1}{\rho A} \left(\sum_{i=1}^{n_s} \rho_i A_{s_i} x_{c_i} + \sum_{j=1}^{n_e} \rho_j A_{e_j} x_{e_j} \right) \\ \rho I_{yy} &= \sum_{i=1}^{n_s} \rho_i I_{yyi} + \sum_{j=1}^{n_e} \rho_j \left(I_{yyej} + A_{e_j} (x_{e_j})^2 \right) \\ y_{cg} &= \frac{1}{\rho A} \left(\sum_{i=1}^{n_s} \rho_i A_{s_i} y_{c_i} + \sum_{j=1}^{n_e} \rho_j A_{e_j} y_{e_j} \right) \\ \rho I_{xy} &= \sum_{i=1}^{n_s} \rho_i I_{xyi} + \sum_{j=1}^{n_e} \rho_j \left(I_{xyej} + A_{e_j} (x_{e_j} y_{e_j}) \right)\end{aligned}$$

The modulus-weighted properties of the total cross-section are determined by summing the product of the Young's moduli multiplied by the straight skin segments and the product of the Young's moduli multiplied by the stringer elements.

$$\begin{aligned}EA &= \sum_{i=1}^{n_s} E_i A_{s_i} + \sum_{j=1}^{n_e} E_j A_{e_j} \\ EI_{xx} &= \sum_{i=1}^{n_s} E_i I_{xxi} + \sum_{j=1}^{n_e} E_j \left(I_{xxej} + A_{e_j} (y_{e_j})^2 \right) \\ x_{EA} &= \frac{1}{EA} \left(\sum_{i=1}^{n_s} E_i A_{s_i} x_{c_i} + \sum_{j=1}^{n_e} E_j A_{e_j} x_{e_j} \right) \\ EI_{yy} &= \sum_{i=1}^{n_s} E_i I_{yyi} + \sum_{j=1}^{n_e} E_j \left(I_{yyej} + A_{e_j} (x_{e_j})^2 \right) \\ y_{EA} &= \frac{1}{EA} \left(\sum_{i=1}^{n_s} E_i A_{s_i} y_{c_i} + \sum_{j=1}^{n_e} E_j A_{e_j} y_{e_j} \right) \\ EI_{xy} &= \sum_{i=1}^{n_s} E_i I_{xyi} + \sum_{j=1}^{n_e} E_j \left(I_{xyej} + A_{e_j} (x_{e_j} y_{e_j}) \right)\end{aligned}$$

Once the properties are known about the origin, then the parallel axis theorem can be used to determine the section properties about the centroid, or the modulus-weighted centroid, or the user-defined location (x_o, y_o) . For example, the area inertia properties about the centroid are:

$$I_{xxc} = I_{xx} - A y_c^2 \quad I_{yy c} = I_{yy} - A x_c^2 \quad I_{xyc} = I_{xy} - A x_c y_c$$

and about a user defined location (x_o, y_o) ;

$$I_{xxo} = I_{xxc} + A (y_o - y_c)^2 \quad I_{yyo} = I_{yy c} + A (x_o - x_c)^2 \quad I_{xyo} = I_{xyc} + A (x_o - x_c)(y_o - y_c)$$

This approach can be used to transform the mass- and modulus-weighted properties to different locations within the cross-section.

Appendix: NACA 4-Digit Airfoils

The outer profile of these airfoils is defined as the linear of sum of the functions defining (1) a symmetric (uncambered) airfoil representing minimum drag, and (2) a camber line representing maximum lift. The NACA 4-Digit airfoil is defined as:

$$\text{NACA} - \underline{M} \underline{P} \underline{T} \underline{T}$$

where, (M) and (P) define the camber line using two quadratic equations and (TT) defines the maximum thickness of the symmetric (uncambered) airfoil shape in percent of the chord. Here (M) defines the maximum camber (vertical displacement from the chord) in percent of the chord, and (P) defines the (x) location of the maximum camber in tenths of the chord. Stating;

$$\text{max vertical camber} = c \left(\frac{M}{100} \right) \quad \text{x-location of max camber} = c \left(\frac{P}{10} \right) \quad \text{max airfoil thickness} = c \left(\frac{TT}{100} \right)$$

where (c) is the airfoil chord length.

The COMPLETE AIRFOIL SHAPE is given as the summation (for the upper surface) and the difference (for the lower surface) of the CAMBER LINE and SYMMETRIC AIRFOIL LINE:

$$y_a = y_c \pm y_s$$

where; the SYMMETRIC AIRFOIL is defined by the following function:

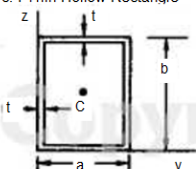
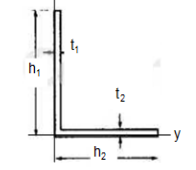
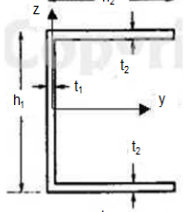
$$y_s = 5c \left(\frac{TT}{100} \right) \left\{ .2969 \sqrt{\frac{x}{c}} - .126 \left(\frac{x}{c} \right) - .3516 \left(\frac{x}{c} \right)^2 + .2843 \left(\frac{x}{c} \right)^3 - .1015 \left(\frac{x}{c} \right)^4 \right\}$$

and c is the chord length and the maximum airfoil thickness is $t_{max} = c(TT / 100)$.

The CAMBER LINE is defined by two quadratic equations: one defining the camber line from the leading edge to the point of maximum camber, and another defining the camber line from the point of maximum camber to the trailing edge. The coefficients A , B , and C of these two quadratic polynomials can be found by applying the boundary conditions of continuity and zero slope where the functions intersect and setting the function value to zero at the leading and trailing edges. In other words, the CAMBER LINE is determined to be

$$\begin{aligned} y_c &= c \left\{ -\frac{M}{P^2} \left(\frac{x}{c} \right)^2 + \frac{M}{5P} \left(\frac{x}{c} \right) \right\} & (0 \leq x < x_{\text{max camber}}) \\ &= \frac{cM}{100 - 20P + P^2} \left\{ -\left(\frac{x}{c} \right)^2 + \frac{P}{5} \left(\frac{x}{c} \right) + \left(1 - \frac{P}{5} \right) \right\} & (x_{\text{max camber}} \leq x < c) \end{aligned}$$

Thin-Wall Section Check Cases

Cross section	Area	Centroid	Inertia
<p>8.4 Thin Hollow Rectangle</p> 	$A = 2t(a + b)$	$y_c = \frac{a}{2}$ $z_c = \frac{b}{2}$	$I_{y_c} = \frac{tb^2}{2} \left(a + \frac{b}{3} \right)$ $I_{z_c} = \frac{ta^2}{2} \left(b + \frac{a}{3} \right)$
<p>8.7 Thin L-Section</p> 	$A = h_1 t_1 + h_2 t_2$	$y_c = \frac{1}{2} \frac{(h_1^2 t_1^2 + h_2^2 t_2^2)}{(h_1 t_1 + h_2 t_2)}$ $z_c = \frac{1}{2} \frac{(h_1^2 t_1 + h_2 t_2^2)}{(h_1 t_1 + h_2 t_2)}$	--
<p>8.8 Thin U-Channel</p> 	$A = h_1 t_1 + 2h_2 t_2$	$y_c = \frac{(h_1^2 t_1^2 + 2h_2^2 t_2^2)}{2(h_1 t_1 + h_2 t_2)}$ $z_c = 0$	--

Design Studies

Using your MATLAB program and the four provided EXCEL files calculate the section properties (A , X_c , Y_c , I_{xx} , I_{yy} , I_{xy}) for the four different beam sections: I-, L-, C-, and Box. Fill in the following table, where the centroid is measured from the bottom-left corner of the beam, and the inertia properties are calculated about the centroid. Calculate ($EI_{xx}/\rho A$) for each section and comment which of the four beams provides the greatest bending stiffness per pound of weight (maximum $EI_{xx}/\rho A$). Explain.

	I-Section (A)	L-Section (B)	C-Section (C)	Box (D)
A (inch ²)				
ρA (lb/in)				
X_c (inch)				
Y_c (inch)				
I_{xx} (inch ⁴)				
I_{yy} (inch ⁴)				
I_{xy} (inch ⁴)				
$EI_{xx}/\rho A$				

Design Studies: NACA 4-Digit Airfoil

Using your MATLAB program and the four provided airfoil EXCEL files answer the following:

- 1.) Calculate the section properties for three different airfoil thicknesses; thin (NACA-0008), nominal (NACA-0014), and thick (NACA-0018). Also calculate the section properties for a highly cambered airfoil (NACA-4414). Calculate ($EI_{xx}/\rho A$) for each wing about the modulus-weighted centroid. Which airfoil provides the greatest wing bending stiffness per pound of wing weight?

	NACA-0008	NACA-0014	NACA-0018	NACA-4414
$EI_{xx}/\rho A$				

- 2.) Calculate the NACA-0014 section properties for regular skin and internal spar thickness, and compare to an airfoil with double skin and internal spar thickness. Fill in the following table with the wing bending stiffness (EI_{xx}) and wing bending stiffness per wing weight ($EI_{xx}/\rho A$) for each. Comment on the effectiveness of increasing the wing skin thickness in order to increase the wing bending stiffness (EI_{xx}). Is the added weight (ρA) worth it?

	NACA-0014 (Regular wall thickness)	NACA-0014 (Double wall thickness)
I_{xx}		
$EI_{xx}/\rho A$		

1	A	B	C	D	E	F	G	H	I	J	K	L	M	N				
2	MATLAB Project (#4) - Properties of Thin-Wall Structural Cross-Sections																	
3	SE-160A Aerospace Structural Analysis, University of California, San Diego (Copyright J.B. Kosmatka, 2020)																	
4																		
5	Version:		Winter, 2020 (v1)															
6																		
7	Project Title:		Test Case															
8																		
9	Variable		Description		Value		Units		Units Reference									
10	iInput		Input Units		1		1 = US, 2 = SI											
11	iOutput		Output Units		1		1 = US, 2 = SI		X		inch		cm					
12									Y		inch		cm					
13	Variable		Description		Value				t		inch		cm					
14	isection		Cross-Section Type		1		1 = General, 2 = NACA Airfoil		A		in ²		cm ²					
15	Xo		User defined origin		0				I _{xx} I _{yy} I _{xy}		in ⁴		cm ⁴					
16	Yo		User defined origin		0				ρ		lb/in ³		g/cm ³					
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18																		
19	X	Option 1: General Thin Wall Cross-Section																
20																		
21	Variable		Description		Value		Units											
22	#nodes		Number of nodes		2		max of 20											
23	#segment		Number of Segments		2		max of 20											
24																		
25	Node Definition with Stringers (Concentated Sections)																	
26	#		X _i		Y _i		A		I _{xx}		I _{yy}		I _{xy}		ρ		E	
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69		20											
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72	X	Option 2: NACA 4-Digit Airfoil											
73													
74				M	P	TT							
75		4-Digit Definition Code:											
76													
77		Airfoil Outer Skin Geometry and Material Definition											
78			Description	Value	Units								
79		#segments	segments along chord										
80		c	chord length										
81		t	wall thickness										
82		ρ	density										
83		E	Young's modulus										
84													
85		Vertical Spar Geometry and Material Definition (maximum of 5)											
86		x/c	t	ρ	E								
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93		Stringer property and Material Definition (maximum of 20)											
94		(#)	X_i	Y_i	A	I_{xx}	I_{yy}	I_{xy}	ρ	E			
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99		5											
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1	A	B	C	D	E	F	G	H	I	J	K	L	M	N				
2	MATLAB Project (#1) - Properties of Thin-Wall General Cross-Sections																	
3	SE-160A Aerospace Structural Analysis, University of California, San Diego (Copyright J.B. Kosmatka, 2020)																	
4																		
5	Version:		Winter, 2020 (v1)															
6																		
7	Student Name:																	
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14	Variable		Description		Value		Units		Units Reference									
15	iInput		Input Units		1		1 = US, 2 = SI		US									
16	iOutput		Output Units		1		1 = US, 2 = SI		inch									
17									cm									
18	Variable		Description		Value				inch									
19	isection		Cross-Section Type		1		1 = General, 2 = NACA Airfoil		cm									
20	Xo		User defined origin		0				in ²									
21	Yo		User defined origin		0				cm ²									
22									in ⁴									
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26									10 ⁶ lb/in ²									
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30	X Option 1: General Thin Wall Cross-Section																	
31																		
32	Variable		Description		Value		Units											
33	#nodes		Number of nodes				max of 20											
34	#segment		Number of Segments				max of 20											
35																		
36	Node Definition with Stringers (Concentated Sections)																	
37	#		Xi		Yi		A		Ixx		Iyy		Ixy		ρ		E	
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40	3																	
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74		20											
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76													
77	OUTPUT:												
78													
79	1.) Section Properties about Original Axes												
80													
81	Area Properties				Mass Properties (Mass-Weighted)								
82	Variable	Description	Value	Units	Variable	Description	Value	Units					
83	A	Area		inch ²	ρA	Weight		lb/inch					
84	X _c	Centroid		inch	X _{cg}	CG		inch					
85	Y _c	Centroid		inch	Y _{cg}	CG		inch					
86	I _{xx}	Inertia about x		inch ⁴	ρI _{xx}	Mass Inertia about x		lb-inch					
87	I _{yy}	Inertia about y		inch ⁴	ρI _{yy}	Mass Inertia about y		lb-inch					
88	I _{xy}	Product of Inertia		inch ⁴	ρI _{xy}	Mass Product of Inertia		lb-inch					
89													
90	Stiffness Properties (Modulus-Weighted)												
91	Variable	Description	Value	Units									
92	EA	Axial Stiffness		inch ²									
93	X _{EA}	Mod weighted centroid		inch									
94	Y _{EA}	Mod weighted centroid		inch									
95	EI _{xx}	Inertia about x		inch ⁴									
96	EI _{yy}	Inertia about y		inch ⁴									
97	EI _{xy}	Product of Inertia		inch ⁴									
98													
99													
100	Plot of Cross-Section in Initial Coordinate System												
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130													
131	2.) Section Properties about Centroidal Axes (origin is placed at area centroid)												

A	B	C	D	E	F	G	H	I	J	K	L	M	N
132													
133		Area Properties					Mass Properties (Mass-Weighted)						
134		Variable	Description	Value	Units		Variable	Description	Value	Units			
135		A	Area		inch ²		ρA	Weight		lb/inch			
136		X_c	Centroid		inch		X_{cg}	CG		inch			
137		Y_c	Centroid		inch		Y_{cg}	CG		inch			
138		I_{xx}	Inertia about x		inch ⁴		ρI_{xx}	Mass Inertia about x		lb-inch			
139		I_{yy}	Inertia about y		inch ⁴		ρI_{yy}	Mass Inertia about y		lb-inch			
140		I_{xy}	Product of Inertia		inch ⁴		ρI_{xy}	Mass Product of Inertia		lb-inch			
141													
142		Stiffness Properties (Modulus-Weighted)											
143		Variable	Description	Value	Units								
144		EA	Axial Stiffness		inch ²								
145		X_{EA}	Mod weighted centroid		inch								
146		Y_{EA}	Mod weighted centroid		inch								
147		EI_{xx}	Inertia about x		inch ⁴								
148		EI_{yy}	Inertia about y		inch ⁴								
149		EI_{xy}	Product of Inertia		inch ⁴								
150													
151		3.) Section Properties about Modulus-Weighted Centroid (origin is placed at modulus weighted centroid)											
152													
153		Area Properties					Mass Properties (Mass-Weighted)						
154		Variable	Description	Value	Units		Variable	Description	Value	Units			
155		A	Area		inch ²		ρA	Weight		lb/inch			
156		X_c	Centroid		inch		X_{cg}	CG		inch			
157		Y_c	Centroid		inch		Y_{cg}	CG		inch			
158		I_{xx}	Inertia about x		inch ⁴		ρI_{xx}	Mass Inertia about x		lb-inch			
159		I_{yy}	Inertia about y		inch ⁴		ρI_{yy}	Mass Inertia about y		lb-inch			
160		I_{xy}	Product of Inertia		inch ⁴		ρI_{xy}	Mass Product of Inertia		lb-inch			
161													
162		Stiffness Properties (Modulus-Weighted)											
163		Variable	Description	Value	Units								
164		EA	Axial Stiffness		inch ²								
165		X_{EA}	Mod weighted centroid		inch								
166		Y_{EA}	Mod weighted centroid		inch								
167		EI_{xx}	Inertia about x		inch ⁴								
168		EI_{yy}	Inertia about y		inch ⁴								
169		EI_{xy}	Product of Inertia		inch ⁴								
170													
171		4.) Section Properties about User-Defined Origin											
172													
173		Area Properties					Mass Properties (Mass-Weighted)						
174		Variable	Description	Value	Units		Variable	Description	Value	Units			
175		A	Area		inch ²		ρA	Weight		lb/inch			
176		X_c	Centroid		inch		X_{cg}	CG		inch			
177		Y_c	Centroid		inch		Y_{cg}	CG		inch			
178		I_{xx}	Inertia about x		inch ⁴		ρI_{xx}	Mass Inertia about x		lb-inch			
179		I_{yy}	Inertia about y		inch ⁴		ρI_{yy}	Mass Inertia about y		lb-inch			
180		I_{xy}	Product of Inertia		inch ⁴		ρI_{xy}	Mass Product of Inertia		lb-inch			
181													
182		Stiffness Properties (Modulus-Weighted)											
183		Variable	Description	Value	Units								
184		EA	Axial Stiffness		inch ²								
185		X_{EA}	Mod weighted centroid		inch								
186		Y_{EA}	Mod weighted centroid		inch								
187		EI_{xx}	Inertia about x		inch ⁴								
188		EI_{yy}	Inertia about y		inch ⁴								
189		EI_{xy}	Product of Inertia		inch ⁴								
190													
191		End of Output											

A	B	C	D	E	F	G	H	I	J	K	L	M
1												N
2	MATLAB Project (#4) - Properties of Thin-Wall NACA 4-Digit Airfoil Cross-Sections											
3	SE-160A Aerospace Structural Analysis, University of California, San Diego (Copyright J.B. Kosmatka, 2020)											
4												
5		Version:	Winter, 2020 (v1)									
6												
7		Student Name:										
8		Student ID:										
9												
10		Project Title:										
11												
12	INPUT ECHO:											
13												
14		Variable	Description	Value	Units					Units Reference		
15		iInput	Input Units	1	1 = US, 2 = SI					US	SI	
16		iOutput	Output Units	1	1 = US, 2 = SI				X	inch	cm	
17									Y	inch	cm	
18		Variable	Description	Value					t	inch	cm	
19		isection	Cross-Section Type	1	1 = General, 2 = NACA Airfoil				A	in ²	cm ²	
20		Xo	User defined origin	0					Ixx, Iyy, Ixy	in ⁴	cm ⁴	
21		Yo	User defined origin	0					ρ	lb/in ³	g/cm ³	
22									E	10 ⁶ lb/in ²	GPa	
23												
24	X	Option 2: NACA 4-Digit Airfoil										
25												
26				M	P	T	T					
27		4-Digit Definition Code:										
28												
29	Airfoil Outer Skin Geometry and Material Definition											
30			Description	Value	Units							
31		#segments	segments along chord									
32		c	chord length									
33		t	wall thickness									
34		ρ	density									
35		E	Young's modulus									
36												
37	Vertical Spar Geometry and Material Definition (maximum of 5)											
38		x/c	t	ρ	E							
39												
40												
41												
42												
43												
44												
45	Stringer property and Material Definition (maximum of 20)											
46		(#)	X _i	Y _i	A	I _{xx}	I _{yy}	I _{xy}	ρ	E		
47		1										
48		2										
49		3										
50		4										
51		5										
52		6										
53		7										
54		8										
55		9										
56		10										
57		11										
58		12										
59		13										
60		14										
61		15										
62		16										
63		17										
64		18										
65		19										
66		20										

A	B	C	D	E	F	G	H	I	J	K	L	M	N
73		Area Properties					Mass Properties (Mass-Weighted)						
74		Variable	Description	Value	Units		Variable	Description	Value	Units			
75		A	Area		inch ²		ρA	Weight		lb/inch			
76		X_c	Centroid		inch		X_{cg}	CG		inch			
77		Y_c	Centroid		inch		Y_{cg}	CG		inch			
78		I_{xx}	Inertia about x		inch ⁴		ρI_{xx}	Mass Inertia about x		lb-inch			
79		I_{yy}	Inertia about y		inch ⁴		ρI_{yy}	Mass Inertia about y		lb-inch			
80		I_{xy}	Product of Inertia		inch ⁴		ρI_{xy}	Mass Product of Inertia		lb-inch			
81													
82		Stiffness Properties (Modulus-Weighted)											
83		Variable	Description	Value	Units								
84		EA	Axial Stiffness		inch ²								
85		X_{EA}	Mod weighted centroid		inch								
86		Y_{EA}	Mod weighted centroid		inch								
87		EI_{xx}	Inertia about x		inch ⁴								
88		EI_{yy}	Inertia about y		inch ⁴								
89		EI_{xy}	Product of Inertia		inch ⁴								
90													
91		Plot of the NACA 4-Digit Airfoil Cross-Section in Initial Coordinate System											
92													
93													
94													
95													
96													
97													
98													
99													
100													
101													
102													
103													
104													
105													
106		2.) Section Properties about Centroidal Axes (origin is placed at area centroid)											
107													
108		Area Properties					Mass Properties (Mass-Weighted)						
109		Variable	Description	Value	Units		Variable	Description	Value	Units			
110		A	Area		inch ²		ρA	Weight		lb/inch			
111		X_c	Centroid		inch		X_{cg}	CG		inch			
112		Y_c	Centroid		inch		Y_{cg}	CG		inch			
113		I_{xx}	Inertia about x		inch ⁴		ρI_{xx}	Mass Inertia about x		lb-inch			
114		I_{yy}	Inertia about y		inch ⁴		ρI_{yy}	Mass Inertia about y		lb-inch			
115		I_{xy}	Product of Inertia		inch ⁴		ρI_{xy}	Mass Product of Inertia		lb-inch			
116													
117		Stiffness Properties (Modulus-Weighted)											
118		Variable	Description	Value	Units								
119		EA	Axial Stiffness		inch ²								
120		X_{EA}	Mod weighted centroid		inch								
121		Y_{EA}	Mod weighted centroid		inch								
122		EI_{xx}	Inertia about x		inch ⁴								
123		EI_{yy}	Inertia about y		inch ⁴								
124		EI_{xy}	Product of Inertia		inch ⁴								
125													
126		3.) Section Properties about Modulus-Weighted Centroid (origin is placed at modulus weighted centroid)											
127													
128		Area Properties					Mass Properties (Mass-Weighted)						
129		Variable	Description	Value	Units		Variable	Description	Value	Units			
130		A	Area		inch ²		ρA	Weight		lb/inch			
131		X_c	Centroid		inch		X_{cg}	CG		inch			
132		Y_c	Centroid		inch		Y_{cg}	CG		inch			
133		I_{xx}	Inertia about x		inch ⁴		ρI_{xx}	Mass Inertia about x		lb-inch			
134		I_{yy}	Inertia about y		inch ⁴		ρI_{yy}	Mass Inertia about y		lb-inch			
135		I_{xy}	Product of Inertia		inch ⁴		ρI_{xy}	Mass Product of Inertia		lb-inch			
136													
137		Stiffness Properties (Modulus-Weighted)											
138		Variable	Description	Value	Units								

[illegible]