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

<u>Files that you need in your MATLAB Folder:</u>

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**

<u>Problem Answers are saved in a (pdf):</u>

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

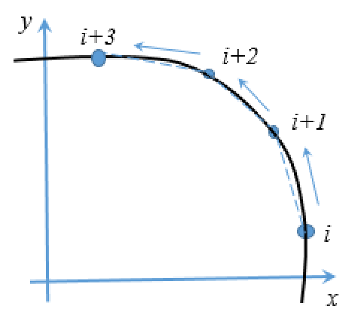
<u>Upload your (m) file and (pdf) file into a (zip) folder of the same name:</u>

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

Introduction

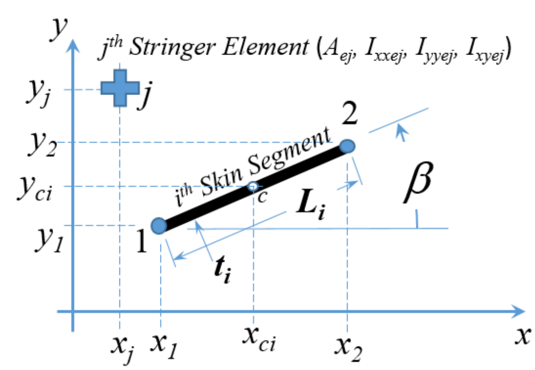
Aerospace structures are built-up from a wide variety of structural components (stringers, longerons, skins, etc.). The analysis of these structures requires that the section properties are known. In this MATLAB assignment, you will write a computer program that calculates the section properties of a 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.

<u>General Section</u>



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 ***<u>calculated section properties</u>*** in this initial coordinate frame (x,y) include the structural area (A), centroid 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:

$$L_i = \sqrt{\left(x_2 - x_1\right)^2 + \left(y_2 - y_1\right)^2}$$

$$x_{c_i} = \frac{1}{2}\left(x_1 + x_2\right)$$

$$y_{c_i} = \frac{1}{2}\left(y_1 + y_2\right)$$

$$I_{xx_i} = \frac{t_i L_i^{\,3}}{12}\sin^2\beta + A_i {y_{c_i}}^2 = \frac{A_i}{6}\left(y_1\left(2y_1 + y_2\right) + y_2\left(y_1 + 2y_2\right)\right)$$

$$I_{yy_i} = \frac{t_i L_i^{\,3}}{12}\cos^2\beta + A_i {x_{c_i}}^2 = \frac{A_i}{6}\left(x_1\left(2x_1 + x_2\right) + x_2\left(x_1 + 2x_2\right)\right)$$

$$I_{xy_i} = \frac{t_i L_i^{\,3}}{12}\cos\beta\sin\beta + A_i x_{c_i} y_{c_i} = \frac{A_i}{6}\left(x_1\left(2y_1 + y_2\right) + x_2\left(y_1 + 2y_2\right)\right)$$

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.

$$A = \sum_{i=1}^{n_s} A_{s_i} + \sum_{j=1}^{n_e} A_{e_j}$$

$$x_c = \frac{1}{A}\left(\sum_{i=1}^{n_s} A_{s_i} x_{c_i} + \sum_{j=1}^{n_e} A_{e_j} x_{e_j}\right)$$

$$y_c = \frac{1}{A}\left(\sum_{i=1}^{n_s} A_{s_i} y_{c_i} + \sum_{j=1}^{n_e} A_{e_j} y_{e_j}\right)$$

$$I_{xx} = \sum_{i=1}^{n_s} I_{xxi} + \sum_{j=1}^{n_e}\left(I_{xxej} + A_{e_j}\left(y_{e_j}\right)^2\right)$$

$$I_{yy} = \sum_{i=1}^{n_s} I_{yyi} + \sum_{j=1}^{n_e}\left(I_{yyej} + A_{e_j}\left(x_{e_j}\right)^2\right)$$

$$I_{xy} = \sum_{i=1}^{n_s} I_{xyi} + \sum_{j=1}^{n_e}\left(I_{xyej} + A_{e_j}\left(x_{e_j} y_{e_j}\right)\right)$$

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.

$$\rho A = \sum_{i=1}^{n_s} \rho_i A_{s_i} + \sum_{j=1}^{n_e} \rho_j A_{e_j} \qquad \rho I_{xx} = \sum_{i=1}^{n_s} \rho_i I_{xxi} + \sum_{j=1}^{n_e} \rho_j \left(I_{xxej} + A_{e_j} \left(y_{e_j} \right)^2 \right)$$

$$x_{cg} = \frac{1}{\rho A} \left(\sum_{i=1}^{n_s} \rho_i A_{s_i} x_{c_i} + \sum_{j=1}^{n_e} \rho_j A_{e_j} x_{e_j} \right) \qquad \rho I_{yy} = \sum_{i=1}^{n_s} \rho_i I_{yyi} + \sum_{j=1}^{n_e} \rho_j \left(I_{yyej} + A_{e_j} \left(x_{e_j} \right)^2 \right)$$

$$y_{cg} = \frac{1}{\rho A} \left(\sum_{i=1}^{n_s} \rho_i A_{s_i} y_{c_i} + \sum_{j=1}^{n_e} \rho_j A_{e_j} y_{e_j} \right) \qquad \rho I_{xy} = \sum_{i=1}^{n_s} \rho_i I_{xyi} + \sum_{j=1}^{n_e} \rho_j \left(I_{xyej} + A_{e_j} \left(x_{e_j} y_{e_j} \right) \right)$$

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.

$$EA = \sum_{i=1}^{n_s} E_i A_{s_i} + \sum_{j=1}^{n_e} E_j A_{e_j} \qquad EI_{xx} = \sum_{i=1}^{n_s} E_i I_{xxi} + \sum_{j=1}^{n_e} E_j \left(I_{xxej} + A_{e_j} \left(y_{e_j} \right)^2 \right)$$

$$x_{EA} = \frac{1}{EA} \left(\sum_{i=1}^{n_s} E_i A_{s_i} x_{c_i} + \sum_{j=1}^{n_e} E_j A_{e_j} x_{e_j} \right) \qquad EI_{yy} = \sum_{i=1}^{n_s} E_i I_{yyi} + \sum_{j=1}^{n_e} E_j \left(I_{yyej} + A_{e_j} \left(x_{e_j} \right)^2 \right)$$

$$y_{EA} = \frac{1}{EA} \left(\sum_{i=1}^{n_s} E_i A_{s_i} y_{c_i} + \sum_{j=1}^{n_e} E_j A_{e_j} y_{e_j} \right) \qquad EI_{xy} = \sum_{i=1}^{n_s} E_i I_{xyi} + \sum_{j=1}^{n_e} E_j \left(I_{xyej} + A_{e_j} \left(x_{e_j} y_{e_j} \right) \right)$$

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:

$$I_{xxc} = I_{xx} - A y_c^{\,2} \qquad I_{yyc} = I_{yy} - A x_c^{\,2} \qquad I_{xyc} = I_{xy} - A x_c y_c$$

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

$$I_{xxo} = I_{xxc} + A\left(y_o - y_c \right)^2 \qquad I_{yyo} = I_{yyc} + A\left(x_o - x_c \right)^2 \qquad I_{xyo} = I_{xyc} + A\left(x_o - x_c \right)\left(y_o - y_c \right)$$

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;

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

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:

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

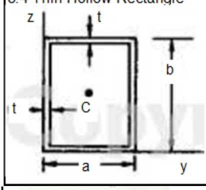
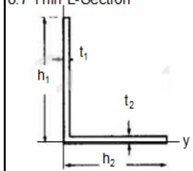
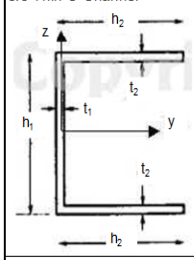
and c is the chord length and the maximum airfoil thickness is $t_{max} = c\left(TT/100\right)$.

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

$$y_c = c\left\{-\frac{M}{P^2}\left(\frac{x}{c}\right)^2 + \frac{M}{5P}\left(\frac{x}{c}\right)\right\} \qquad (0 \le x < x_{\text{max camber}})$$

$$= \frac{cM}{100 - 20P + P^2}\left\{-\left(\frac{x}{c}\right)^2 + \frac{P}{5}\left(\frac{x}{c}\right) + \left(1 - \frac{P}{5}\right)\right\} \qquad (x_{\text{max camber}} \le x < c)$$

Thin-Wall Section Check Cases

Cross section	Area	Centroid	Inertia
8.4 Thin Hollow Rectangle 	$A = 2t(a+b)$	$y_C = \frac{a}{2}$ $z_C = \frac{b}{2}$	$I_{yy_c} = \frac{tb^2}{2}\left(a + \frac{b}{3}\right)$ $I_{zz_c} = \frac{ta^2}{2}\left(b + \frac{a}{3}\right)$
8.7 Thin L-Section 	$A = h_1t_1 + h_2t_2$	$y_C = \frac{1}{2}\frac{\left(h_1t_1^2 + h_2^2t_2\right)}{\left(h_1t_1 + h_2t_2\right)}$ $z_C = \frac{1}{2}\frac{\left(h_1^2t_1 + h_2t_2^2\right)}{\left(h_1t_1 + h_2t_2\right)}$	--
8.8 Thin U-Channel 	$A = h_1t_1 + 2h_2t_2$	$y_C = \frac{\left(h_1t_1^2 + 2h_2^2t_2\right)}{2\left(h_1t_1 + h_2t_2\right)}$ $z_C = 0$	--

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}/ρA). 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}		
$EI_{xx}/\rho A$		

MATLAB Project (#4) - Properties of Thin-Wall Structural Cross-Sections

SE-160A Aerospace Structural Analysis, University of California, San Diego (Copyright J.B. Kosmatka, 2020)

Version: **Winter, 2020 (v1)**

Project Title: **Test Case**

Variable	Description	Value	Units
iInput	Input Units	1	1 = US, 2 = SI
iOutput	Output Units	1	1 = US, 2 = SI

Variable	Description	Value	
isection	Cross-Section Type	1	1 = General, 2 = NACA Airfoil
Xo	User defined origin	0	
Yo	User defined origin	0	

	Units Reference	
	US	*SI*
X	*inch*	*cm*
Y	*inch*	*cm*
t	*inch*	*cm*
A	in^2	cm^2
I_{xx}, I_{yy}, I_{xy}	in^4	cm^4
ρ	lb/in^3	g/cm^3
E	$10^6\ lb/in^2$	GPa

X **Option 1: General Thin Wall Cross-Section**

Variable	Description	Value	Units
#nodes	Number of nodes	2	max of 20
#segment	Number of Segments	2	max of 20

Node Definition with Stringers (Concentated Sections)

(#)	X_i	Y_i	A	I_{xx}	I_{yy}	I_{xy}	ρ	E
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								

Segment Connectivity

(#)	*node (i)*	*node (j)*	t	ρ	E
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					

19					
20					

X **Option 2: NACA 4-Digit Airfoil**

	M	P	T T
4-Digit Definition Code:			

Airfoil Outer Skin Geometry and Material Definition

	Description	Value	Units
#segments	segments along chord		
c	chord length		
t	wall thickness		
ρ	density		
E	Young's modulus		

Vertical Spar Geometry and Material Definition (maximum of 5)

x/c	*t*	*ρ*	*E*

Stringer property and Material Definition (maximum of 20)

(#)	X_i	Y_i	A	I_{xx}	I_{yy}	I_{xy}	ρ	E
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								

0 **END OF FILE**

MATLAB Project (#1) - Properties of Thin-Wall General Cross-Sections

SE-160A Aerospace Structural Analysis, University of California, San Diego (Copyright J.B. Kosmatka, 2020)

Version: Winter, 2020 (v1)

Student Name:

Student ID:

Project Title:

INPUT ECHO:

Variable	Description	Value	Units
iInput	Input Units	1	1 = US, 2 = SI
iOutput	Output Units	1	1 = US, 2 = SI

Variable	Description	Value	
isection	Cross-Section Type	1	1 = General, 2 = NACA Airfoil
Xo	User defined origin	0	
Yo	User defined origin	0	

	Units Reference	
	US	*SI*
X	*inch*	*cm*
Y	*inch*	*cm*
t	*inch*	*cm*
A	in^2	cm^2
I_{xx}, I_{yy}, I_{xy}	in^4	cm^4
ρ	lb/in^3	g/cm^3
E	$10^6\ lb/in^2$	*GPa*

X **Option 1: General Thin Wall Cross-Section**

Variable	Description	Value	Units
#nodes	Number of nodes		max of 20
#segment	Number of Segments		max of 20

Node Definition with Stringers (Concentated Sections)

(#)	X_i	Y_i	A	I_{xx}	I_{yy}	I_{xy}	ρ	E
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								

Segment Connectivity

(#)	*node (i)*	*node (j)*	t	ρ	E
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					

13					
14					
15					
16					
17					
18					
19					
20					

OUTPUT:

1.) Section Properties about Original Axes

Area Properties

Variable	Description	Value	Units
A	Area		inch^2
X_c	Centroid		inch
Y_c	Centroid		inch
I_{xx}	Inertia about x		inch^4
I_{yy}	Inertia about y		inch^4
I_{xy}	Product of Inertia		inch^4

Mass Properties (Mass-Weighted)

Variable	Description	Value	Units
ρA	Weight		lb/inch
X_{cg}	CG		inch
Y_{cg}	CG		inch
ρI_{xx}	Mass Inertia about x		lb-inch
ρI_{yy}	Mass Inertia about y		lb-inch
ρI_{xy}	Mass Product of Inertia		lb-inch

Stiffness Properties (Modulus-Weighted)

Variable	Description	Value	Units
EA	Axial Stiffness		inch^2
X_{EA}	Mod weighted centroid		inch
Y_{EA}	Mod weighted centroid		inch
EI_{xx}	Inertia about x		inch^4
EI_{yy}	Inertia about y		inch^4
EI_{xy}	Product of Inertia		inch^4

Plot of Cross-Section in Initial Coordinate System

2.) Section Properties about Centroidal Axes (origin is placed at area centroid)

Area Properties

Variable	Description	Value	Units
A	Area		inch^2
X_c	Centroid		inch
Y_c	Centroid		inch
I_{xx}	Inertia about x		inch^4
I_{yy}	Inertia about y		inch^4
I_{xy}	Product of Inertia		inch^4

Mass Properties (Mass-Weighted)

Variable	Description	Value	Units
ρA	Weight		lb/inch
X_{cg}	CG		inch
Y_{cg}	CG		inch
ρI_{xx}	Mass Inertia about x		lb-inch
ρI_{yy}	Mass Inertia about y		lb-inch
ρI_{xy}	Mass Product of Inertia		lb-inch

Stiffness Properties (Modulus-Weighted)

Variable	Description	Value	Units
EA	Axial Stiffness		inch^2
X_{EA}	Mod weighted centroid		inch
Y_{EA}	Mod weighted centroid		inch
EI_{xx}	Inertia about x		inch^4
EI_{yy}	Inertia about y		inch^4
EI_{xy}	Product of Inertia		inch^4

3.) Section Properties about Modulus-Weighted Centroid (origin is placed at modulus weighted centroid)

Area Properties

Variable	Description	Value	Units
A	Area		inch^2
X_c	Centroid		inch
Y_c	Centroid		inch
I_{xx}	Inertia about x		inch^4
I_{yy}	Inertia about y		inch^4
I_{xy}	Product of Inertia		inch^4

Mass Properties (Mass-Weighted)

Variable	Description	Value	Units
ρA	Weight		lb/inch
X_{cg}	CG		inch
Y_{cg}	CG		inch
ρI_{xx}	Mass Inertia about x		lb-inch
ρI_{yy}	Mass Inertia about y		lb-inch
ρI_{xy}	Mass Product of Inertia		lb-inch

Stiffness Properties (Modulus-Weighted)

Variable	Description	Value	Units
EA	Axial Stiffness		inch^2
X_{EA}	Mod weighted centroid		inch
Y_{EA}	Mod weighted centroid		inch
EI_{xx}	Inertia about x		inch^4
EI_{yy}	Inertia about y		inch^4
EI_{xy}	Product of Inertia		inch^4

4.) Section Properties about User-Defined Origin

Area Properties

Variable	Description	Value	Units
A	Area		inch^2
X_c	Centroid		inch
Y_c	Centroid		inch
I_{xx}	Inertia about x		inch^4
I_{yy}	Inertia about y		inch^4
I_{xy}	Product of Inertia		inch^4

Mass Properties (Mass-Weighted)

Variable	Description	Value	Units
ρA	Weight		lb/inch
X_{cg}	CG		inch
Y_{cg}	CG		inch
ρI_{xx}	Mass Inertia about x		lb-inch
ρI_{yy}	Mass Inertia about y		lb-inch
ρI_{xy}	Mass Product of Inertia		lb-inch

Stiffness Properties (Modulus-Weighted)

Variable	Description	Value	Units
EA	Axial Stiffness		inch^2
X_{EA}	Mod weighted centroid		inch
Y_{EA}	Mod weighted centroid		inch
EI_{xx}	Inertia about x		inch^4
EI_{yy}	Inertia about y		inch^4
EI_{xy}	Product of Inertia		inch^4

End of Output

MATLAB Project (#4) - Properties of Thin-Wall NACA 4-Digit Airfoil Cross-Sections

SE-160A Aerospace Structural Analysis, University of California, San Diego (Copyright J.B. Kosmatka, 2020)

Version: Winter, 2020 (v1)

Student Name:

Student ID:

Project Title:

INPUT ECHO:

Variable	Description	Value	Units
iInput	Input Units	1	1 = US, 2 = SI
iOutput	Output Units	1	1 = US, 2 = SI

Variable	Description	Value	
isection	Cross-Section Type	1	1 = General, 2 = NACA Airfoil
Xo	User defined origin	0	
Yo	User defined origin	0	

Units Reference

	US	SI
X	*inch*	*cm*
Y	*inch*	*cm*
t	*inch*	*cm*
A	in^2	cm^2
I_{xx}, I_{yy}, I_{xy}	in^4	cm^4
ρ	lb/in^3	g/cm^3
E	$10^6\ lb/in^2$	*GPa*

X **Option 2: NACA 4-Digit Airfoil**

	M	P	T T
4-Digit Definition Code:			

Airfoil Outer Skin Geometry and Material Definition

	Description	Value	Units
#segments	segments along chord		
c	chord length		
t	wall thickness		
ρ	density		
E	Young's modulus		

Vertical Spar Geometry and Material Definition (maximum of 5)

x/c	t	ρ	E

Stringer property and Material Definition (maximum of 20)

(#)	X_i	Y_i	A	I_{xx}	I_{yy}	I_{xy}	ρ	E
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								

OUTPUT:

1.) Section Properties about Leading Edge

Area Properties

Variable	Description	Value	Units
A	Area		$inch^2$
X_c	Centroid		inch
Y_c	Centroid		inch
I_{xx}	Inertia about x		$inch^4$
I_{yy}	Inertia about y		$inch^4$
I_{xy}	Product of Inertia		$inch^4$

Mass Properties (Mass-Weighted)

Variable	Description	Value	Units
ρA	Weight		lb/inch
X_{cg}	CG		inch
Y_{cg}	CG		inch
ρI_{xx}	Mass Inertia about x		lb-inch
ρI_{yy}	Mass Inertia about y		lb-inch
ρI_{xy}	Mass Product of Inertia		lb-inch

Stiffness Properties (Modulus-Weighted)

Variable	Description	Value	Units
EA	Axial Stiffness		$inch^2$
X_{EA}	Mod weighted centroid		inch
Y_{EA}	Mod weighted centroid		inch
EI_{xx}	Inertia about x		$inch^4$
EI_{yy}	Inertia about y		$inch^4$
EI_{xy}	Product of Inertia		$inch^4$

Plot of the NACA 4-Digit Airfoil Cross-Section in Initial Coordinate System

2.) Section Properties about Centroidal Axes (origin is placed at area centroid)

Area Properties

Variable	Description	Value	Units
A	Area		$inch^2$
X_c	Centroid		inch
Y_c	Centroid		inch
I_{xx}	Inertia about x		$inch^4$
I_{yy}	Inertia about y		$inch^4$
I_{xy}	Product of Inertia		$inch^4$

Mass Properties (Mass-Weighted)

Variable	Description	Value	Units
ρA	Weight		lb/inch
X_{cg}	CG		inch
Y_{cg}	CG		inch
ρI_{xx}	Mass Inertia about x		lb-inch
ρI_{yy}	Mass Inertia about y		lb-inch
ρI_{xy}	Mass Product of Inertia		lb-inch

Stiffness Properties (Modulus-Weighted)

Variable	Description	Value	Units
EA	Axial Stiffness		$inch^2$
X_{EA}	Mod weighted centroid		inch
Y_{EA}	Mod weighted centroid		inch
EI_{xx}	Inertia about x		$inch^4$
EI_{yy}	Inertia about y		$inch^4$
EI_{xy}	Product of Inertia		$inch^4$

3.) Section Properties about Modulus-Weighted Centroid (origin is placed at modulus weighted centroid)

Area Properties

Variable	Description	Value	Units
A	Area		$inch^2$
X_c	Centroid		inch
Y_c	Centroid		inch
I_{xx}	Inertia about x		$inch^4$
I_{yy}	Inertia about y		$inch^4$
I_{xy}	Product of Inertia		$inch^4$

Mass Properties (Mass-Weighted)

Variable	Description	Value	Units
ρA	Weight		lb/inch
X_{cg}	CG		inch
Y_{cg}	CG		inch
ρI_{xx}	Mass Inertia about x		lb-inch
ρI_{yy}	Mass Inertia about y		lb-inch
ρI_{xy}	Mass Product of Inertia		lb-inch

Stiffness Properties (Modulus-Weighted)

Variable	Description	Value	Units

EA	Axial Stiffness		inch^2
X_{EA}	Mod weighted centroid		inch
Y_{EA}	Mod weighted centroid		inch
EI_{xx}	Inertia about x		inch^4
EI_{yy}	Inertia about y		inch^4
EI_{xy}	Product of Inertia		inch^4

4.) Section Properties about User-Defined Origin

Area Properties

Variable	Description	Value	Units
A	Area		inch^2
X_c	Centroid		inch
Y_c	Centroid		inch
I_{xx}	Inertia about x		inch^4
I_{yy}	Inertia about y		inch^4
I_{xy}	Product of Inertia		inch^4

Mass Properties (Mass-Weighted)

Variable	Description	Value	Units
ρA	Weight		lb/inch
X_{cg}	CG		inch
Y_{cg}	CG		inch
ρI_{xx}	Mass Inertia about x		lb-inch
ρI_{yy}	Mass Inertia about y		lb-inch
ρI_{xy}	Mass Product of Inertia		lb-inch

Stiffness Properties (Modulus-Weighted)

Variable	Description	Value	Units
EA	Axial Stiffness		inch^2
X_{EA}	Mod weighted centroid		inch
Y_{EA}	Mod weighted centroid		inch
EI_{xx}	Inertia about x		inch^4
EI_{yy}	Inertia about y		inch^4
EI_{xy}	Product of Inertia		inch^4

End of Output