Project Points:	
Wing Analysis Function:	700 points
Write-Up:	200 points
Total:	900 points

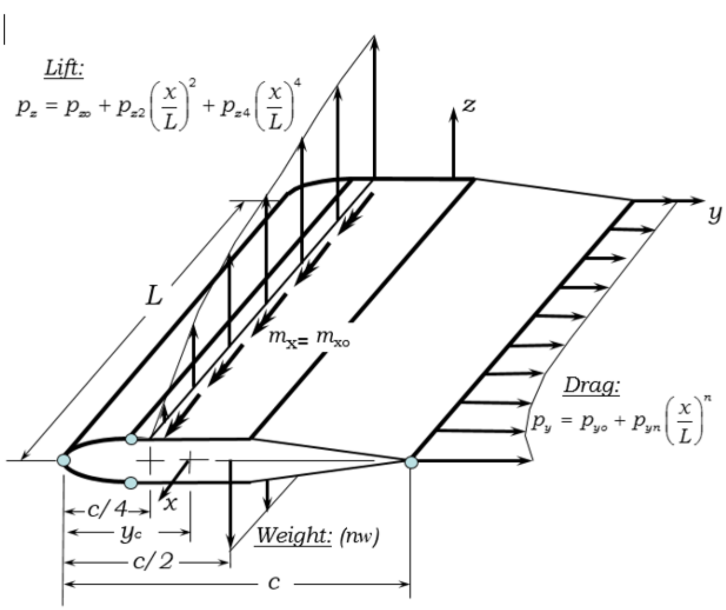
MATLAB Project: Single Cell Wing Bending, Torsion, and Shear Analysis
Due Date: Upload zip folder to Canvas by 11:58 PM, Thursday March 14, 2024

Files in CANVAS ZIP folder. Extract and put into your MATLAB folder:

Wing_Analysis_Main.p	Kosmatka Wing Analysis Main Code (encrypted p-version)
Wing_Analysis_Function.p	Kosmatka Wing Analysis Function (encrypted p-version)
Wing_Analysis_Function (Student Skeleton).m	Recommended Wing Function Starter Code
Wing_Analysis_WriteUp.pdf	Project Write Up (Version 1)
Wing_Analysis_Input.xlsx	Wing Analysis Excel Input File (Sample)
Wing_Analysis_Input (Blank).xlsx	Wing Analysis Excel Input File (Blank)
Wing_Analysis_Output.xlsx	Wing Analysis Excel Output File (Sample)
Wing_Analysis_Output (Blank).xlsx	Wing Analysis Excel Output File (Blank)

On or before March 14th, 2024, you will load the following six files into a zip folder and then upload the zip folder to the SE-160A Canvas Gradescope Account.

SE160A_2_LastName_FirstName.zip	Zip Folder
Wing_Analysis_Function.m	Your Wing Analysis Function With Your Name and PID Inside
Wing_Analysis_LastName_FirstName.pdf	Your solutions to answered questions and design studies.
Wing_Analysis_Input_AL.xlsx	Analysis Excel Input File (Design Study Aluminum)
Wing_Analysis_Output_AL.xlsx	Analysis Excel Output File (Design Study Aluminum)
Wing_Analysis_Input_CE.xlsx	Analysis Excel Input File (Design Study Carbon/Epoxy)
Wing_Analysis_Output_CE.xlsx	Analysis Excel Output File (Design Study Carbon/Epoxy)

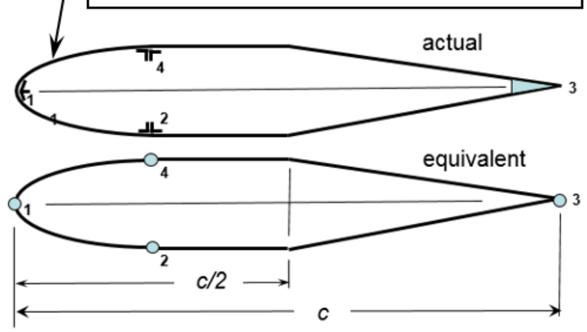


Nose is an ellipse between stringers (1, 2, 4)

Reference Properties:
Ellipse area: πab
Circumference:

$$C \approx \pi\left[3(a+b) - \sqrt{(3a+b)(a+3b)}\right]$$

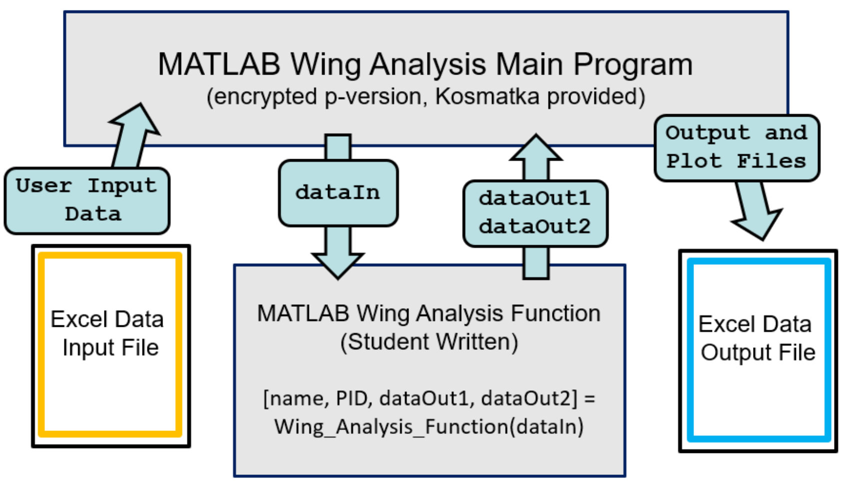
a = semi-major axis
b = semi-minor axis



INTRODUCTION

Maneuvering aircraft (and other aerospace vehicles) produce loads on their lifting and control surfaces. These loads vary greatly for different maneuvering conditions. In this MATLAB project, you will analyze a simplified uniform wing subjected to one-dimensional aerodynamic loads (lift, drag, and moment) and in-flight maneuvering loads. The wing is limited to a one cell symmetric cross-section with a maximum of 4 stringers, where the stringers are located at the leading edge (#1) and trailing edge (#4), and one stringer is located above the chord-line (#4) and one stringer below the chord-line (#2). The upper and lower stringers are located anywhere between the quarter-chord (C/4) and the mid-chord (C/2). The materials and cross-section shape for each stringer is unique (metallic or composite). The ***skin*** is defined using a single material and thickness. The skin shape is a ½ ellipse from the leading edge to the quarter chord, then horizontal flat panels from the quarter-chord (C/4) to the mid-chord (C/2), and finally sloped flat panels from the mid-chord (C/2) to the trailing edge. The ***aerodynamic loads***, all acting at the quarter chord, are approximated as a 4^{th} order polynomial for lift, r^{th} order polynomial for drag, and a constant twisting moment. In addition, a ***distributed wing weight*** is defined that acts along the mid-chord. (See figure below). The aerodynamic and weight polynomial coefficients are input parameters.

The project is developed using a Wing Analysis Main Program and a student programmed Wing Analysis Function. See below. The Main Program opens an Excel input file, an Excel output file, and the Wing Analysis Function. The main program, which is written in a MATLAB encrypted p-version, takes care of all of the data input and transferring the input data to the Wing Analysis Function. Next the Wing Analysis Function performs all the data analysis and organizes the data for output and plotting. The Main Program writes the calculated data to the Excel output file, as well as generating all of the needed plots and writing them to specific locations in the Excel output file. Thus, the student only needs to focus on performing the calculations and not worry about the cumbersome book-keeping effort of reading the input data from Excel and writing/plotting the calculated data to an Excel output file.



The six goals of this project include the calculation of:

- the cross-section section properties (stringers only), torsion constant (skin only), and shear center location
- the internal load distribution of the wing due to aerodynamic and maneuvering wing weight loads.
- the stringer stress distribution (σ_{xx}) and margins of safety (*MS*)
- the skin shear stress distribution (τ_{xs}) and margins of safety (*MS*)
- the wing lift- and drag-bending displacement distribution.
- the wing twist distribution about the modulus-weighted centroidal axis and the shear center.

FUNCTION INPUT

```
Input Data Array: dataIn (65)

        dataIn(01):     Number of Output Plot Data Points
        dataIn(02):     Wing Length (inch)
        dataIn(03):     Wing Chord (inch)
        dataIn(04):     Maximum Wing Thickness (inch)
        dataIn(05):     Secondary Structure Added Wing Weight (%)

        dataIn(06):     Wing Skin Thickness (inch)
        dataIn(07):     Wing Skin Weight Density (lb/in^3)
        dataIn(08):     Skin Material Shear Modulus (Msi)
        dataIn(09):     Skin Material Yield Strength - Shear (Ksi)
        dataIn(10):     Skin Material Ultimate Strength - Shear (Ksi)

        dataIn(11):     Stringer (#1) y-location (inch)
        dataIn(12):     Stringer (#1) Cross-Section Area (inch^2)
        dataIn(13):     Stringer (#1) Iyy Inertia about y-axis (inch^4)
        dataIn(14):     Stringer (#1) Izz Inertia about z-axis (inch^4)
        dataIn(15):     Stringer (#1) Iyz Product of Inertia (inch^4)
        dataIn(16):     Stringer (#1) Weight Density (lb/in^3)
        dataIn(17):     Stringer (#1) Material Young’s Modulus (Msi)
        dataIn(18):     Stringer (#1) Yield Strength - Tension (Ksi)
        dataIn(19):     Stringer (#1) Ultimate Strength - Tension (Ksi)
        dataIn(20):     Stringer (#1) Yield Strength - Compression (Ksi)
        dataIn(21):     Stringer (#1) Ultimate Strength - Compression (Ksi)

        dataIn(22):     Stringer (#2) y-location (inch)
        dataIn(23):     Stringer (#2) Cross-Section Area (inch^2)
        dataIn(24):     Stringer (#2) Iyy Inertia about y-axis (inch^4)
        dataIn(25):     Stringer (#2) Izz Inertia about z-axis (inch^4)
        dataIn(26):     Stringer (#2) Iyz Product of Inertia (inch^4)
        dataIn(27):     Stringer (#2) Weight Density (lb/in^3)
        dataIn(28):     Stringer (#2) Material Young’s Modulus (Msi)
        dataIn(29):     Stringer (#2) Yield Strength - Tension (Ksi)
        dataIn(30):     Stringer (#2) Ultimate Strength - Tension (Ksi)
        dataIn(31):     Stringer (#2) Yield Strength - Compression (Ksi)
        dataIn(32):     Stringer (#2) Ultimate Strength - Compression (Ksi)

        dataIn(33):     Stringer (#3) y-location (inch)
        dataIn(34):     Stringer (#3) Cross-Section Area (inch^2)
        dataIn(35):     Stringer (#3) Iyy Inertia about y-axis (inch^4)
        dataIn(36):     Stringer (#3) Izz Inertia about z-axis (inch^4)
        dataIn(37):     Stringer (#3) Iyz Product of Inertia (inch^4)
        dataIn(38):     Stringer (#3) Weight Density (lb/in^3)
        dataIn(39):     Stringer (#3) Material Young’s Modulus (Msi)
        dataIn(40):     Stringer (#3) Yield Strength - Tension (Ksi)
        dataIn(41):     Stringer (#3) Ultimate Strength - Tension (Ksi)
        dataIn(42):     Stringer (#3) Yield Strength - Compression (Ksi)
        dataIn(43):     Stringer (#3) Ultimate Strength - Compression (Ksi)

        dataIn(44):     Stringer (#4) y-location (inch)
        dataIn(45):     Stringer (#4) Cross-Section Area (inch^2)
        dataIn(46):     Stringer (#4) Iyy Inertia about y-axis (inch^4)
```

```
  dataIn(47):     Stringer (#4) Izz Inertia about z-axis (inch^4)
  dataIn(48):     Stringer (#4) Iyz Product of Inertia (inch^4)
  dataIn(49):     Stringer (#4) Weight Density (lb/in^3)
  dataIn(50):     Stringer (#4) Material Young’s Modulus (Msi)
  dataIn(51):     Stringer (#4) Yield Strength - Tension (Ksi)
  dataIn(52):     Stringer (#4) Ultimate Strength - Tension (Ksi)
  dataIn(53):     Stringer (#4) Yield Strength - Compression (Ksi)
  dataIn(54):     Stringer (#4) Ultimate Strength - Compression (Ksi)

  dataIn(55):     Safety Factor - Yield
  dataIn(56):     Safety Factor - Ultimate

  dataIn(57):     Aircraft Load Factor
  dataIn(58):     Drag Distribution - Constant (lb/in)
  dataIn(59):     Drag Distribution - rth order (lb/in)
  dataIn(60):     Drag Distribution - polynomial order
  dataIn(61):     Lift Distribution - Constant (lb/in)
  dataIn(62):     Lift Distribution - 2nd Order (lb/in)
  dataIn(63):     Lift Distribution - 4th Order (lb/in)
  dataIn(64):     Twist Moment Distribution - Constant (lb-in/in)
  dataIn(65):     Twist Moment Distribution - 1st Order (lb-in/in)
```

FUNCTION OUTPUT

```
Name:             Name of student author

PID:              UCSD Student ID number

dataOut1:         Packed calculated output variable data
  dataOut1(01):   Modulus Weighted Centroid y-direction (inch)
  dataOut1(02):   Modulus Weighted Centroid z-direction (inch)
  dataOut1(03):   Cross-Section Weight rhoA (lb/in)
  dataOut1(04):   Axial   Stiffness EA   (lb)
  dataOut1(05):   Bending Stiffness EIyy (lb-in^2)
  dataOut1(06):   Bending Stiffness EIzz (lb-in^2)
  dataOut1(07):   Bending Stiffness EIyz (lb-in^2)
  dataOut1(08):   Torsion Stiffness GJ   (lb-in^2)
  dataOut1(09):   Shear Center, y-direction (inch)
  dataOut1(10):   Shear Center, z-direction (inch)
  dataOut1(11):   Total Half-Span Wing Weight including added weight factor (lb)

  dataOut1(12):   Root Internal Force - X Direction (lb)
  dataOut1(13):   Root Internal Force - Y Direction (lb)
  dataOut1(14):   Root Internal Force - Z Direction (lb)
  dataOut1(15):   Root Internal Moment - about X Direction (lb-in)
  dataOut1(16):   Root Internal Moment - about Y Direction (lb-in)
  dataOut1(17):   Root Internal Moment - about Z Direction (lb-in)

  dataOut1(18):   Stringer (#1) Calculated Axial Stress (lb/in^2)
  dataOut1(19):   Stringer (#1) Allowable Stress - Tension (lb/in^2)
  dataOut1(20):   Stringer (#1) Allowable Stress - Compression (lb/in^2)
  dataOut1(21):   Stringer (#1) Margin of Safety

  dataOut1(22):   Stringer (#2) Calculated Axial Stress (lb/in^2)
  dataOut1(23):   Stringer (#2) Allowable Stress - Tension (lb/in^2)
```

```
    dataOut1(24):   Stringer (#2) Allowable Stress - Compression (lb/in^2)
    dataOut1(25):   Stringer (#2) Margin of Safety

    dataOut1(26):   Stringer (#3) Calculated Axial Stress (lb/in^2)
    dataOut1(27):   Stringer (#3) Allowable Stress - Tension (lb/in^2)
    dataOut1(28):   Stringer (#3) Allowable Stress - Compression (lb/in^2)
    dataOut1(29):   Stringer (#3) Margin of Safety

    dataOut1(30):   Stringer (#4) Calculated Axial Stress (lb/in^2)
    dataOut1(31):   Stringer (#4) Allowable Stress - Tension (lb/in^2)
    dataOut1(32):   Stringer (#4) Allowable Stress - Compression (lb/in^2)
    dataOut1(33):   Stringer (#4) Margin of Safety

    dataOut1(34):   Skin Panel (1.2) Calculated Shear Stress (lb/in^2)
    dataOut1(35):   Skin Panel (1.2) Allowable Stress - Shear (lb/in^2)
    dataOut1(36):   Skin Panel (1.2) Margin of Safety

    dataOut1(37):   Skin Panel (2.3) Calculated Shear Stress (lb/in^2)
    dataOut1(38):   Skin Panel (2.3) Allowable Stress - Shear (lb/in^2)
    dataOut1(39):   Skin Panel (2.3) Margin of Safety

    dataOut1(40):   Skin Panel (3.4) Calculated Shear Stress (lb/in^2)
    dataOut1(41):   Skin Panel (3.4) Allowable Stress - Shear (lb/in^2)
    dataOut1(42):   Skin Panel (3.4) Margin of Safety

    dataOut1(43):   Skin Panel (4.1) Calculated Shear Stress (lb/in^2)
    dataOut1(44):   Skin Panel (4.1) Allowable Stress - Shear (lb/in^2)
    dataOut1(45):   Skin Panel (4.1) Margin of Safety

    dataOut1(46):   Tip Displacement  - Y Direction (inch)
    dataOut1(47):   Tip Displacement  - Z Direction (inch)
    dataOut1(48):   Tip Twist (degree)
    dataOut1(49):   Tip Bending Slope (dv/dx) (inch/inch)
    dataOut1(50):   Tip Bending Slope (dw/dx) (inch/inch)

 dataOut2:          Packed calculated output plot data
    column( 1):     X direction coordinate (inch)
    column( 2):     Applied distributed drag force (lb/in)
    column( 3):     Applied distributed lift force (lb/in)
    column( 4):     Applied distributed torque (lb-in/in)
    column( 5):     Internal shear force  - Vy (lb)
    column( 6):     Internal shear force  - Vz (lb)
    column( 7):     Internal axial torque - Mx (lb-in)
    column( 8):     Internal bending moment - My (lb-in)
    column( 9):     Internal bending moment - Mz (lb-in)
    column(10):     Stringer (#1) Axial Stress (lb/in^2)
    column(11):     Stringer (#2) Axial Stress (lb/in^2)
    column(12):     Stringer (#3) Axial Stress (lb/in^2)
    column(13):     Stringer (#4) Axial Stress (lb/in^2)
    column(14):     Skin Panel (1.2) Shear Stress (lb/in^2)
    column(15):     Skin Panel (2.3) Shear Stress (lb/in^2)
    column(16):     Skin Panel (3.4) Shear Stress (lb/in^2)
    column(17):     Skin Panel (4.1) Shear Stress (lb/in^2)
    column(18):     Displacement - Y Direction (inch)
    column(19):     Displacement - z Direction (inch)
```

```
column(20):     Twist (degree)
column(21):     Bending Slope (dv/dx) (inch/inch)
column(22):     Bending Slope (dw/dx) (inch/inch)
```

APPENDIX A:
Running the MATLAB P-code with YOUR Function

1) In your MATLAB directory include the following files:

```
Wing_Analysis_Input.xlsx                         Excel Input File
Wing_Analysis_Output.xlsx                        Excel Output File
Wing_Analysis_Main.p                       Project Main Code p-code
Wing_Analysis_Function.m              (function that you will write)
```

2) Open MATLAB in that directory
3) Make sure both the Excel input and output files are closed
4) Run the p-code. Do not try and open a (*.p) code

```
>> run Wing_Analysis_Main.p
```

The main code will open the Excel input file, your Wing_Analysis_Function, and the Excel output file. Then the input data is passed to the function for calculation, followed by the calculated data being returned to the main program. Finally, the main program writes the data and plots to the Excel output file.

5) Open the Excel output file and review results.

Note: It is recommended that you start with the Wing_Analysis_Function (student skeleton).m. This example function has lots of useful code.

Note: If you want to check your results, replace your Wing_Analysis_Function.m with the provided Wing_Analysis_Function.p, which was provided in your zip folder. Using the above command, run the main program, which will now call the p-version function. The correct answers are written to the output file. Save the output file for comparing with your function results.

Appendix 2:
Summary of Acceptable Wing Cross-Sections:

Layout:

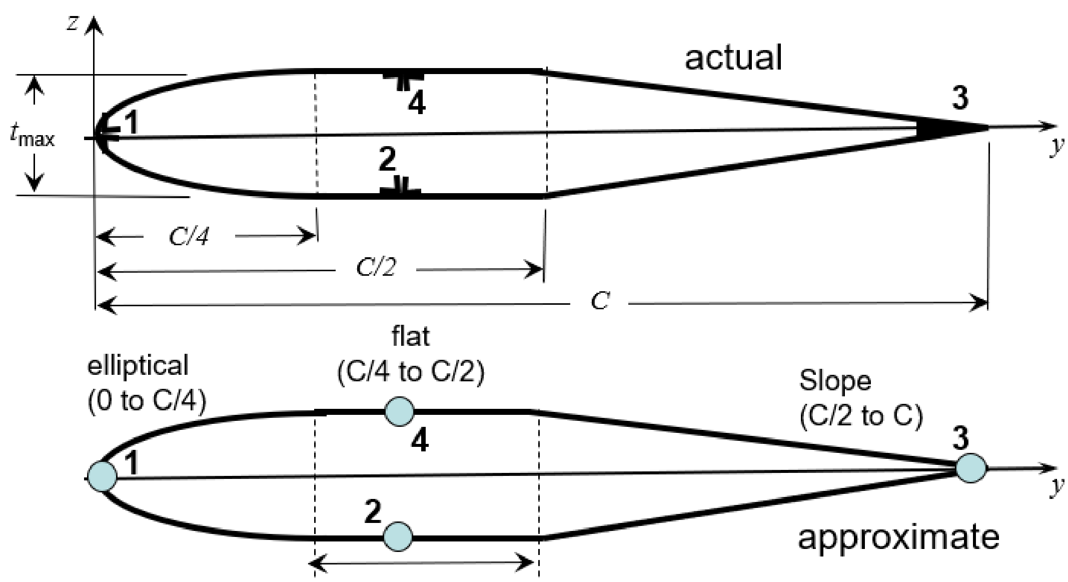
- The wing cross-section is defined using four stringers and four skin segments

Stringer Definition:

- The wing cross-section can have four unique stringers that have unique section properties (area, inertia properties), material Young's stiffnesses, and strengths.
- Stringer (#1) is located at the leading edge defined at the origin (0,0)
- Stringer (#3) is located at the trailing edge defined on the y-axis at the chord length (c,0)
- Stringers (#2) and (#4) are located on the airfoil skin, anywhere between (y = C/4) and (y = C/2).
- If stringers (#2) and (#4) are at different locations and/or have different shapes or materials, then the section is not symmetric and (EI_{yz}) is not equal to zero. For the design study only, The section is defined so that ($EI_{yz} = 0$).

Skin Definition:

- There are four unique wing skin segments between the four stringers. Each skin segment has the same material properties and thickness.
- Both the upper and lower skin segments between stringer (#1) and the (C/4) is defined as a quarter-ellipse.
- Both the upper and lower skin segments between (C/4) and (C/2) are horizontal skin segments. Stringers (#2) and (#4) are located in this region.
- Both the upper and lower skin segments between, (C/2) and the trailing edge are linear sloped segments.



Note: Stringers (#2) and (#4) can be located anywhere between (C/4) and (C/2)

DESIGN STUDY

Now let's use your MATLAB code to perform a preliminary structural analysis on a single-cell wing of length (L = 240 inch) and chord (c = 48 inch), where we will look at the approximate cruise condition and the four corners of the *V-n* diagram (see Table 1) for both an aluminum and a composite wing design. You will use your code to determine the minimum stringer cross-section area and skin thickness for each wing design, so that the effective weight savings can be determined. We will limit our design studies to ensure cross-sections remain symmetric ($EI_{yz} = z_c = 0$). Thus, the cross-section shape, material properties, and y-locations of stringer (#2) and (#4) must be identical. Obviously, further weight savings can be obtained if the individual stringers or skins were unique, but this would lead to an unsymmetric cross-section.

Table 1: Load case definition for cruise and the four corners of V-n diagram

		Load Cases					
Variable	**Description**	***Cruise***	***PHAA***	***PLAA***	***NHAA***	***NLAA***	
n	Load factor	1	3.8	3.8	-1.5	-1.5	
p_{yo}	Drag distribution (constant)	1.8	2.4	60	2.4	60	lb/inch
p_{yr}	Drag distribution (rth order)	0.4	0.4	6	0.4	6	lb/inch
r	Drag distribution (polynomial order)	10	10	10	10	10	
p_{zo}	Lift distribution (constant)	15	57	57	-22.5	-22.5	lb/inch
p_{z2}	Lift distribution (2nd order)	-4	-15.2	-15.2	6	6	lb/inch
p_{z4}	Lift distribution (4th order)	-1	-3.8	-3.8	1.5	1.5	lb/inch
m_{xo}	Twist moment distribution	50	15	200	15	200	lb-inch/inch
m_{x1}	Twist moment distribution (linear)	0	0	0	0	0	lb-inch/inch

Table 2: Aluminum and Graphite/Epoxy Properties

Property	Al 7075-T6	Carbon/epoxy	Units
ρ	0.10	0.056	lb./in^3
E	10	23.5	Msi
G	3.75	6	Msi
σ_{Ty}	37	263	Ksi
σ_{Tu}	43	263	Ksi
σ_{Cy}	-37	-263	Ksi
σ_{Cu}	-43	-263	Ksi
τ_y	24	88	Ksi
τ_u	28	88	Ksi

Step 1: Preliminary structural analysis of an aluminum wing

Perform a structural analysis of a single-cell aluminum wing for cruise and the four corners of the *V-n* diagram. The input data file is given at the end of this project statement. During this preliminary study, ignore stringer section properties (I_{yy}, I_{zz}, I_{yz}) and assume all four stringers have the same properties. Using your results from the five analysis cases, fill out the following table and calculate the total wing weight. Use this total wing weight in your study.

	units	Cruise	PHAA	PLAA	NHAA	NLAA
MS - stringer (minimum)						
MS – skin (minimum)						
Tip vertical displacement	(inch)					
Tip twist	(degree)					
Wing weight	(lb)					

Note: (1) the minimum stringer margin of safety (MS) is defined as the minimum value observed for all four stringers at the root ($x = 0$), (2) the minimum skin MS is defined as the minimum value observed for all four skin sections at the root ($x = 0$), and (3) the calculated wing weight is determined using:

$$W = (S\rho_{skin}t_{skin} + \sum_{i=1}^{4}\rho_i A_i)L\left(1+K_w\right)$$

where;

- S = wing cross-section perimeter
- ρ_{skin} = wing skin material density
- t_{skin} = skin thickness
- ρ_i = wing stringer material density
- A_i = i^{th} stringer area
- L = wing length (= b/2)
- K_w = Additional wing weight from secondary or tertiary structures (typically 10-20%)

Note: It is recommended that you use the above equation to calculate the wing weight.

<u>Step 2: Preliminary structural analysis of a carbon/epoxy wing</u>

Perform a structural analysis of a single-cell carbon/epoxy wing for cruise and the four corners of the V-n diagram. The input data file is given at the end of this project statement. During this preliminary study, ignore stringer section properties (I_{yy}, I_{zz}, I_{yz}) and assume all four stringers have the same properties. Using your results from the five analysis cases, fill out the following table and calculate the wing weight assuming the density of carbon/epoxy is ($\rho = 0.056$ lb/in^3). If the displacements are unrealistically large (> 15 inch) , you may have to increase stringer areas.

	units	Cruise	PHAA	PLAA	NHAA	NLAA
MS - stringer (minimum)						
MS – skin (minimum)						
Tip vertical displacement	(inch)					
Tip twist	(degree)					
Wing weight	(lb)					

<u>Step 3: Design analysis of an aluminum wing</u>

Using the results from the table in Step 1, determine the minimum stringer areas (A_s) and minimum skin thickness (t_s) so that all the margins are safety for all five analysis cases are greater than or equal to zero. Rerun the five analysis cases from step (1) with the new section properties and fill out the table. (Hint: All MS > 0)

Stringer (#1) Area (minimum)	(inch^2)	
Stringer (#2) Area (minimum)	(inch^2)	
Stringer (#3) Area (minimum)	(inch^2)	
Stringer (#4) Area (minimum)	(inch^2)	
Skin Thickness (minimum)	(inch)	

	Units	Cruise	PHAA	PLAA	NHAA	NLAA
MS - stringer (minimum)						
MS – skin (minimum)						
Tip vertical displacement	(inch)					
Tip twist	(degree)					
Minimum Aluminum Wing Weight	(lb)					

Step 4: Design analysis of a carbon/epoxy wing

Using the results from the table in Step 2, determine the minimum composite stringer area (A_s) and minimum composite skin thickness (t_s) so that all the margins are safety for all five load cases are greater than or equal to zero. Rerun the five analysis cases from step 2 with the new section properties and fill out the table.

Stringer (#1) Area (minimum)	(inch^2)	
Stringer (#2) Area (minimum)	(inch^2)	
Stringer (#3) Area (minimum)	(inch^2)	
Stringer (#4) Area (minimum)	(inch^2)	
Skin Thickness (minimum)	(inch)	

	Units	Cruise	PHAA	PLAA	NHAA	NLAA
MS - stringer (minimum)						
MS – skin (minimum)						
Tip vertical displacement	(inch)					
Tip twist	(degree)					
Minimum Carbon/epoxy Wing Weight	(lb)					

Step 5: Comment on the weight savings between the aluminum wing and the composite wing.