INDEX

1. Introduction 1
2. Metallic Design Trade Study Process 5
   2.1. Metallic Design Steps
   2.2. Final Metallic Design and Estimated Weight
   2.3. Metallic Design Trade Study
   2.4. Sketch of Final Metallic Design
3. Fuselage Design using composite materials 15
   3.1. Special Assumptions for Composite Materials
   3.2. Composite Design Process
   3.3. Final Composite Design and Estimated Weight
   3.4. Composite Design Trade Study
   3.5. Sketch of Final Composite Design
4. Results Summary 25
5. Conclusions 26
6. Design Code
   1.1 Metal Code 27
   1.2 Metal Stress Calculation Function
   1.3 Metal Trade Study Plot Generator
   2.1 Composite Code 33
   2.2 Composite Stress Calculation Function
   2.3 Composite Trade Study Plot Generator

1. INTRODUCTION:

While designing an aircraft, the absolute focus must be given to the overall weight. Durability is an important factor here and so is the weight. Every aircraft component has to be strong and stiff enough to withstand the various loads acting on it. Also, the design has to be fail-safe. That is to say, the critical components of an aircraft have to be designed in such a way that even if a single component fails, it should not result in a catastrophic failure of the whole aircraft while it is in operation and thus does not endanger the lives of its passengers. The mains sections of any aircraft are the Fuselage, wings, tail and engines. Every single one of these sections has to be designed to withstand the different types of loads acting on it and the design has to be most optimized for minimum possible weight. Many factors play a role in while designing a completely new aircraft such as,

- Type of Aircraft (Purpose - Military or Civilian)
- Overall Payload to be carried
- Materials used for engines, wing tips, airframe
- Controls used for the aircraft
- Range of the aircraft (long-range/mid-range/short range)
- Financial factors, economic feasibility of the aircraft (fuel consumption/passenger)

All these factors form the basis of the conceptual design phase. In this phase, many fundamental aspects of the aircraft design such as shape of the fuselage, engine size, wing geometry configuration and probable flight performance are evaluated.

The next phase is that of preliminary design in which slightly advanced design calculations are carried out such as computational fluid dynamics calculations of the aircraft shape, wind-tunnel testing of the aircraft body, preliminary structural load calculations are carried out. In this phase, any probable major flaws in the design are corrected.

The final phase of the aircraft design is detail designing. In this phase, every subsystem of the aircraft is designed in detail. Every component and control system of the aircraft is designed to the absolute minute details. Manufacturing aspects of the components is also a major factor that goes into consideration in this phase.

We will now focus our attention to the design of aircraft fuselage.

The Fuselage

The fuselage of an aircraft is the main body of the aircraft. It carries the payload of an aircraft. The load bearing member of this structure is often called the Air-frame. Simply put, if everything is taken away and stripped from the aircraft, airframe is what remains.

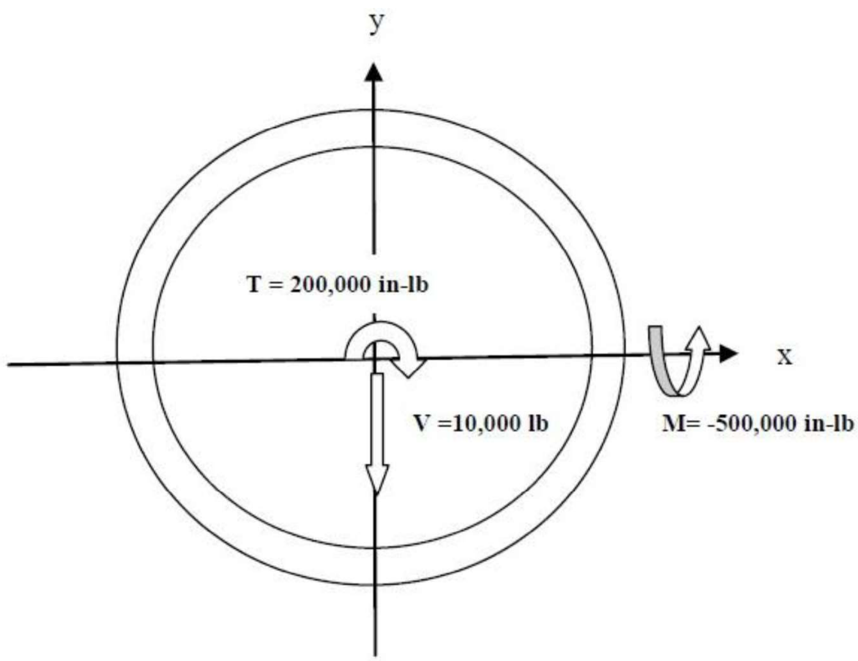
Fuselage consists mainly of three parts – skin, stiffeners and frames. Whenever stiffeners are combined with a section of the skin, it is called stringers. The difference between frames and stringers is stiffeners run along the length of the fuselage whereas the frame runs transverse to the fuselage shape. The stiffeners are usually attached to the skin. The fuselage has to be designed to withstand loads like pressure differential loads (at cruising altitudes because of cabin pressurization), bending moments (arising because of wing and tail lift forces), torsional loads (because of rudder and rolling movements), and shear loads because of weight (acting in the vertical downward direction).

Aim of the Project

The aim of this project is to develop a preliminary design of the fuselage section for minimum weight for the given loading conditions. We have to arrive at two design configurations, one by using metallic materials and another one by using composite materials.

Loading conditions and design constraints

The loads acting on the section are shown below in the fig. There is a shear load of 10,000 lb, a torque of 200,000 lb-inch and a bending moment of 500,000 lb-inch. The spacing between the frames is 20 inches. The diameter of the fuselage section is 40 inches. Minimum skin thickness should not be less than 0.032 inches. The design requirements also require us to design the section using only Z-type stiffeners.



The design calculations include selection of material, finding the maximum bending stress acting on the stiffeners for given number of stiffeners, calculating the critical buckling stress for stiffeners, calculating the critical shear buckling stress for skin, number of stiffeners and stiffener spacing for a safe design. The fuselage section is to be designed for minimum weight while deciding design parameters such as,

- Stiffener Cross-section Area
- Stiffener Thickness
- Number of stiffeners
- Skin thickness

Trade studies are done varying all these parameters with respect to one another. Parameters such as critical stresses, stiffener dimensions, critical stresses, safety factors are calculated. If the design passes the safety criteria, weight is calculated. Various trade studies are carried out keeping one parameter constant so as to observe the variations in other parameters. In the end, the minimum possible weight of the fuselage section for both metallic design and the composite design is determined.

General Assumptions:

The following assumptions were made while doing the design calculations:

For Stiffener calculations-

1. We assume same material for both stiffeners and skin in our calculations.
2. The stiffener spacing is assumed to be constant throughout the section. (There is same distance between neighboring stiffeners at any point.)
3. For Z-type stiffeners, Needham's method is used for calculating the value of critical compression buckling stress.
4. For stiffeners, the top and bottom flange lengths are assumed to be same. Also, it is assumed that the web length is twice the flange length.
5. The stiffeners are assumed to have a uniform thickness throughout the section, i.e. on both flange as well as the web sections.
6. The factor of safety assumed in stiffener buckling calculations is 1.0.

For Skin calculations-

1. The skin is assumed to be capable of withstanding only shear loads. Hence only shear buckling calculations are done for the skin and compression buckling of skin is ignored.
2. It is assumed that stiffener number will be more than 20 so that stiffener spacing will be comparatively less. This will be helpful as we will be neglecting the compression buckling effects of the skin.
3. The factor of safety assumed in skin shear buckling calculations is 1.0.

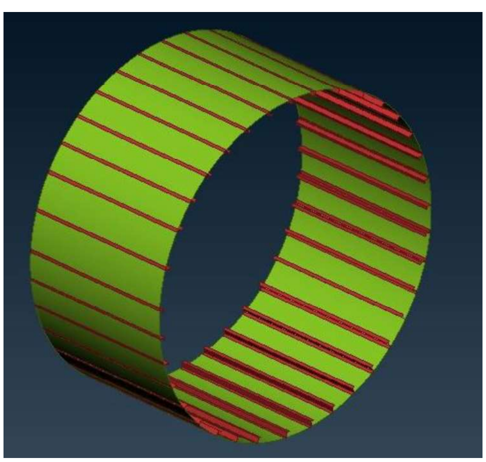
The loads acting on the fuselage are –

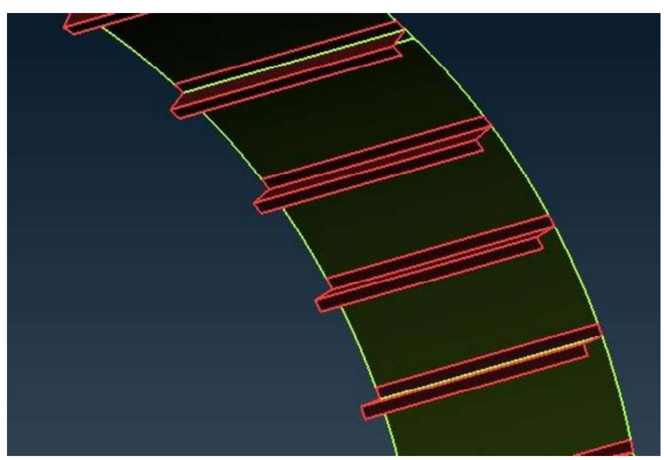
V (shear load) = 10000 lb

M (bending moment) = 500,000 lb-inch

T (torsional moment) = 200,000 lb-inch

The design calculations are carried out in MATLAB and various graphs are plotted against the weight of fuselage so that trade studies can be carried out easily. The following images show the general design of our fuselage section. The purple color is used to highlight stiffeners in the drawing.





2. METALLIC DESIGN TRADE STUDY PROCESS:

The design calculations were carried out in a Matlab code that accepted a series of inputs such as stiffener cross-section area, stiffener thickness, skin thickness and number of stiffeners and given design constraints were submitted in the design code.

The design code carried out a number simulations varying each one these parameters within a given range and calculated various parameters required for a design such as stiffener critical buckling stress, skin shear buckling stress, stiffener dimensions and spacing between stiffeners.

The design code calculated the various critical stresses for stiffeners and skins and compared those values with the stresses in the fuselage design and calculated safety factors for the respective design. It then compared all these values with one another and calculated the most optimum design parameters (assuming safety factors as 1) and finally calculated the weight for those design parameters.

2.1 Metallic Design Steps:

The following design steps are followed while carrying out metallic design iterations in Matlab:

I. The very basic assumption or decision making comes in the first step itself when we have to choose the material for the fuselage and for the stiffeners.

   Mentioning correct values of mechanical properties such as Young's Modulus E, compressive yield strength and density are crucial before proceeding to design calculations.

II. To proceed with the calculations, certain basic dimensions such as the stiffener thickness, stiffener cross-sectional area, skin thickness and number of stringers are specified.

III. We do all of our shear flow and bending stress calculations only on half section of the fuselage because of structural symmetry about both axis. We take advantage of the symmetry about Y axis while doing calculations for shear flow, shear stresses and bending stresses.

   Hence, the number of stiffeners under consideration is,

$$N = \frac{n}{2} + 1$$

IV. After specifying the stiffener thickness and area, it will be easy to calculate stiffener dimensions such as the web height and the flange length. These dimensions are required later for stiffener design specifications.

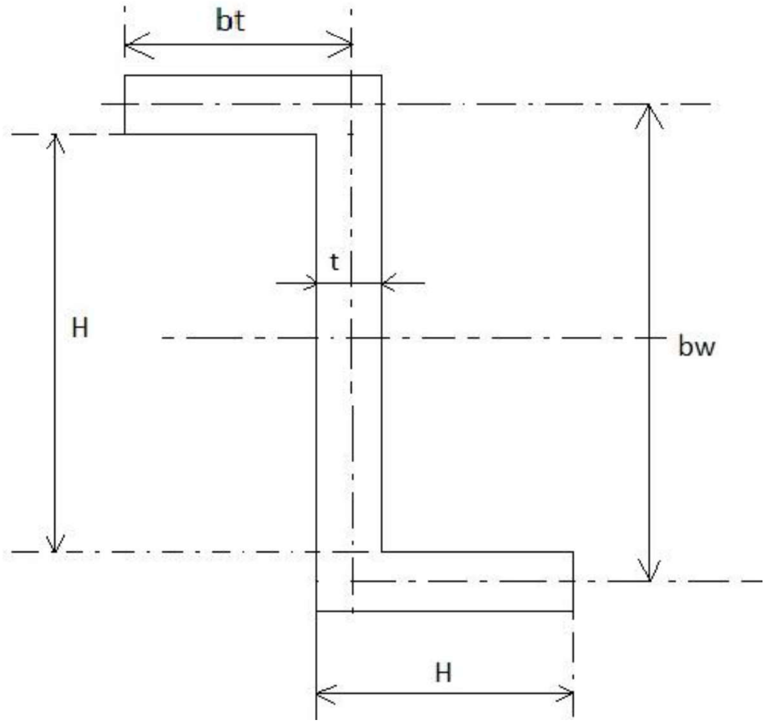
$$b_w = 2 \times b_f$$

   The length and height of the stiffener is given as,

$$L = b_f + \left(\frac{t}{2}\right)$$

$$H = b_w - t$$

   Where,
   $b_f = flange\ length$
   $b_w = web\ length$
   L = total length of flange
   H = height of web



V. The spacing between the stiffeners is calculated in this step by dividing the circumference of fuselage with the number of stiffeners.

The spacing b between the stiffeners is given by,

$$b = \frac{\pi D}{n}$$

Where,

D = Diameter of the fuselage section

n = Total No. of Stiffeners

VI. The stiffener crippling calculations are carried out in order to determine the minimum crippling stress under which the stiffener will cripple in bending. The assumptions made in this are that one edge of the Z section in free and hence the ke value is taken to be equal to 0.342. Needham's formula is used for calculating critical crippling stress.

$$\sigma_c = \frac{k_e (E_c\, \sigma_{cy})^{0.5}}{(b'/t)^{0.75}}$$

Where,

$$\sigma_c = crippling\ stress$$

$k_e = coefficient\ (equal\ to\ 0.342\ in\ our\ case\ because\ of\ one\ free\ edge)$

$E_c = compressive\ elastic\ modulus$

$\frac{b'}{t} = \frac{a+b}{2t} = \frac{b_f + b_w}{2t}$

$\sigma_{cy} = material\ compressive\ yield\ stress$

VII. For determining critical buckling stress, we first calculate the critical slenderness ratio of the stiffener. It is given by,

$$\left(\frac{L'}{\rho}\right)_{critical} = \sqrt{2}\pi\sqrt{\frac{E}{\sigma_c}}$$

VIII. Depending on the value of the critical slenderness ratio and the slenderness ratio of our stiffener, we calculate the critical buckling stress for the stiffener.

$$\sigma_b = \sigma_c\left[1 - \frac{\sigma_c\left(L'/\rho\right)^2}{4\pi^2 E}\right] \qquad when \left(\frac{L'}{\rho}\right) < \left(\frac{L'}{\rho}\right)_{critical}$$

$$\sigma_b = \left(\frac{\pi^2 E}{\left(L'/\rho\right)^2}\right) when \left(\frac{L'}{\rho}\right) > \left(\frac{L'}{\rho}\right)_{critical}$$

IX. After this, the critical skin shear buckling stress is calculated.

$$\tau_{cr} = KE\left(\frac{t}{b}\right)^2$$

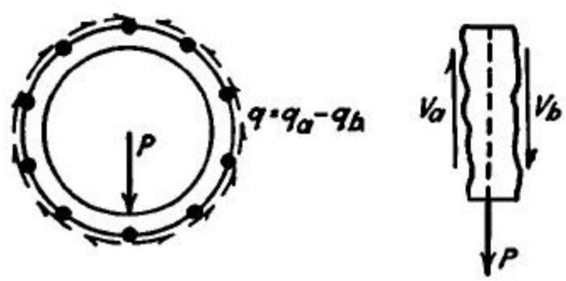
Where

K = calculated from graph depending on the ratio assuming simply supported edges of skin (a/b)

a = spacing between frames/stiffener length

X. Stiffeners in a fuselage carry most of the axial loads and bending loads whereas skins transfer shear loads. Then we proceed to calculating the actual bending stresses in the stiffeners and the actual shear stresses in the skin using principles of shear flows for primary structures design.

The stresses are calculated on half section of the fuselage.



The y co-ordinate is calculated using the formula $y = \frac{D}{2}\cos\theta$.

Shear flow in the skin between two stiffeners is given by,

$$q_b = \frac{V}{I}\sum yA_f \ldots\ldots\ldots\ldots\ldots (shear\ flow\ due\ to\ bending)$$

$$q_T = \frac{T}{2A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (shear\ flow\ due\ to\ torsion)$$

$$q = q_a + q_b$$

$$q = \frac{V_a - V_b}{I}\int y\, dA$$

The moment of area of the section is calculated by adding the area moments of all the stiffeners. The following table gives the configuration for our optimized design.

Metal Design Data Table for shear flow calculations:-

This table shows the shear and bending stress calculations for the finalized design.

Stiffener No.	Stiffener Area (A_f)	y	yA_f	y^2A_f	$\sum yA_f$	Shear flow due to bending (q_b)	Shear flow due to torsion (q_t)	Total Shear Flow q = (q_b+ q_t)	Shear Stress - (psi)	Bending Stress – (psi)
1	0.04	20.00	0.80	16.0	-	-				1562
2	0.08	19.75	1.58	31.21	0.80	25.00	79.58	104.57	2490	1543
3	0.08	19.02	1.52	28.94	2.38	74.38	79.58	153.96	3666	1486
4	0.08	17.82	1.42	25.04	3.90	121.93	79.58	201.51	4798	1392
5	0.08	16.18	1.29	10.94	5.32	166.49	79.58	246.06	5859	1264
6	0.08	14.14	1.13	16.00	6.62	206.94	79.58	286.52	6822	1105
7	0.08	11.76	0.94	11.05	7.75	242.29	79.58	321.87	7664	918
8	0.08	9.08	0.73	6.59	8.69	271.68	79.58	351.26	8363	709
9	0.08	6.18	0.49	3.05	9.42	294.38	79.58	373.96	8904	482
10	0.08	3.12	0.25	0.78	9.91	309.83	79.58	389.41	9272	244
11	0.08	0	0.00	0.00	10.16	317.65	79.58	397.23	9458	0.00
12	0.08	-3.12	-0.25	0.78	10.16	317.65	79.58	397.23	9458	-244
13	0.08	-6.18	-0.49	3.05	9.91	309.83	79.58	389.41	9272	-482
14	0.08	-9.08	-0.73	6.59	9.42	294.38	79.58	373.96	8904	-709
15	0.08	-11.76	-0.94	11.05	8.69	271.68	79.58	351.26	8363	-918
16	0.08	-14.14	-1.13	16.00	7.75	242.29	79.58	351.26	7664	-1105
17	0.08	-16.18	-1.29	20.94	6.62	206.94	79.58	286.52	6822	-1264
18	0.08	-17.82	-1.42	25.4	5.32	166.49	79.58	246.06	5859	-1392
19	0.08	-19.02	-1.52	28.94	3.90	121.94	79.58	201.51	4798	-1486
20	0.08	-19.75	-1.58	31.21	2.38	74.38	79.58	153.96	3666	-1543
21	0.04	-20.00	-0.80	16.00	0.80	25.00	79.58	104.57	2490	-1562
			$\sum I_y$	320						

A = 1256.637 inch² (Cross sectional area of the fuselage section)

XI. The maximum bending stress in the stiffeners is divided by the critical buckling stress for the stiffeners to get the safety factor for the stiffener. This is also called as the compression buckling safety factor.

XII. The maximum shear stress in the section is divided by the skin critical buckling shear stress to get the safety factor for skin. This is also called as the shear buckling safety factor.

XIII. If the safety factors for both of them are greater than 1, then only we calculate the weight of the fuselage. The weight of the section is given by,

$$W_{fuselage} = W_{stiffeners} + W_{skin}$$

$$W_{stiffeners} = n \times A_f \times t_{stiffener}$$

$$W_{skin} = \pi a \times t_{skin}$$

XIV. A number of iterations are performed so as to try different combinations of stiffener cross-section areas, stiffener thicknesses, skins thicknesses and number of stiffeners using the MATLAB code.

XV. As the last step, we use the MATLAB code to determine the minimum weight out of these combinations.

2.2 Final Metallic Design and Estimated Weight:

- The material used for the metallic design is 8090 T8151 Aluminium alloy which is used very commonly in the industry. The properties of this alloy are as follows, also note that the values were found online through ASM Aerospace Specification Metals, inc.:

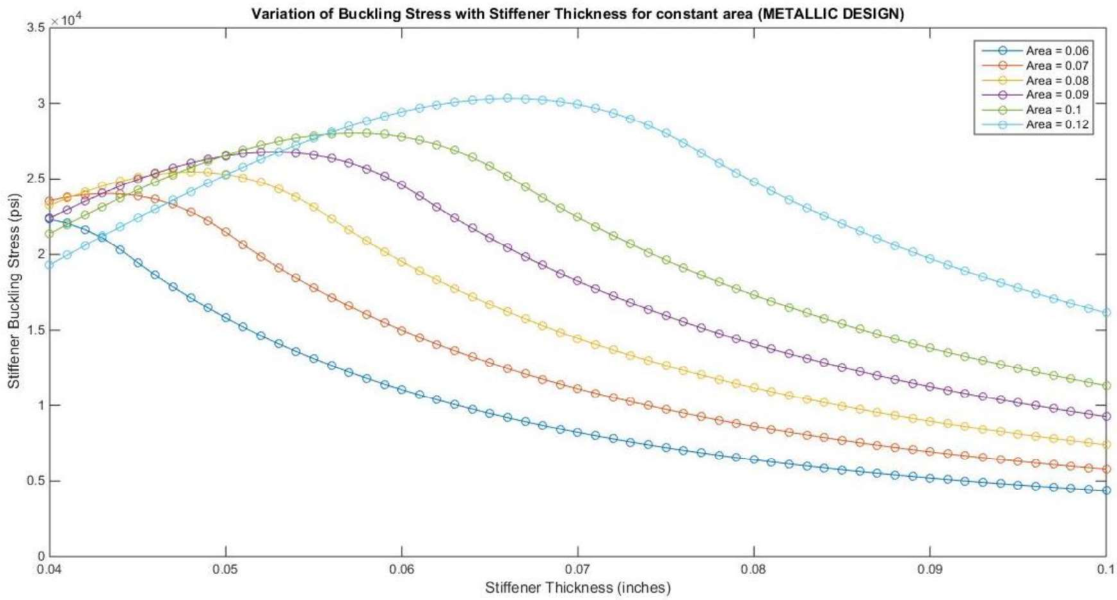
Modulus of Elasticity E = 11200 ksi

Compressive Yield Strength $C_y = 53700$ psi

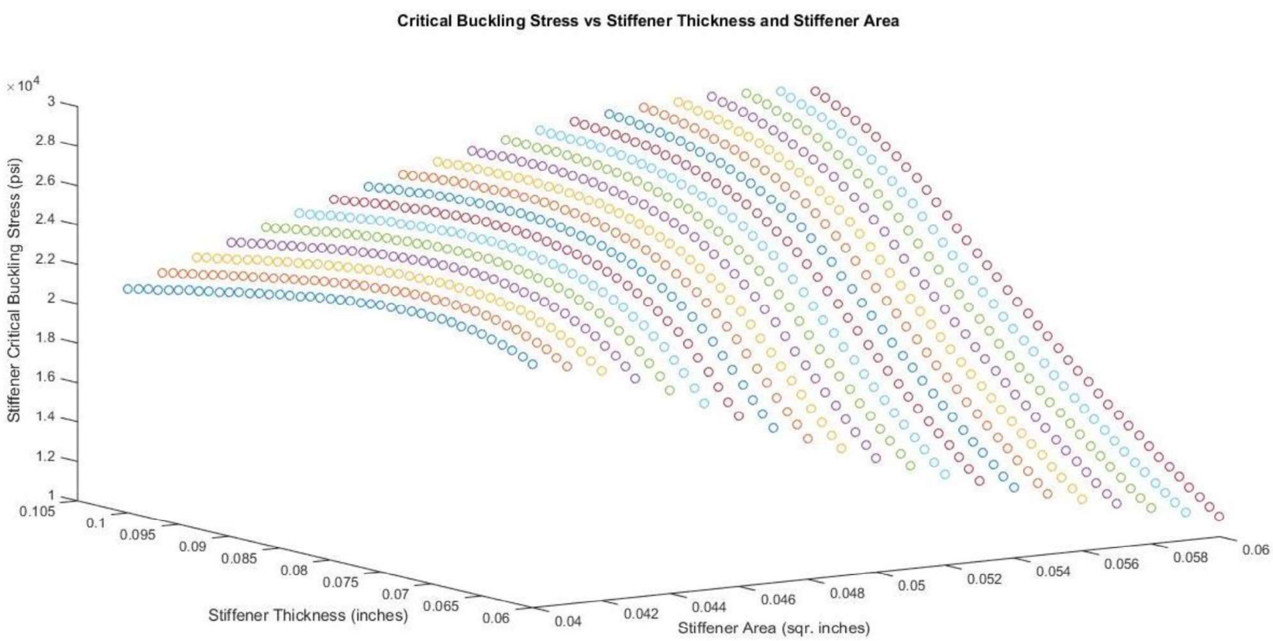
Density = 0.0918 lbs/inch^3

- The final design achieved weighed only **14.58 lbs**. It has **40** stiffeners, stiffener thickness of **0.043 inches**, skin thickness **0.042 inches** and stiffener dimensions as **0.4651 inches** of flange length and **0.9302 inches** of web length.

2.3 Metallic Design Trade Study:



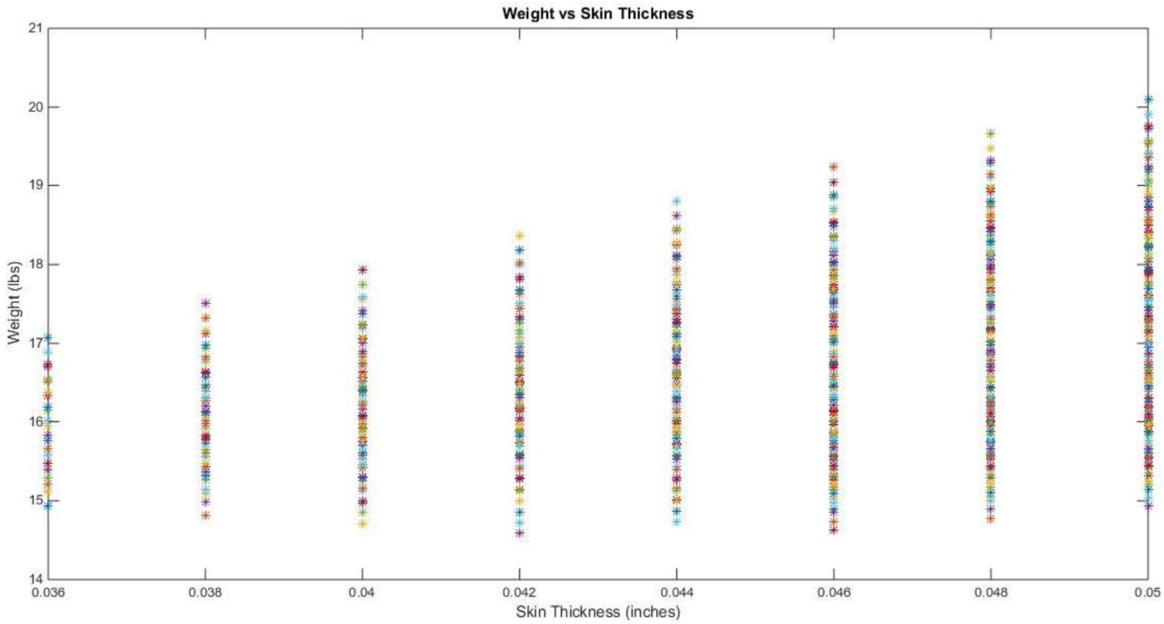
1. Above graph shows the variation of critical buckling stress for stiffeners when thickness is increased keeping the area constant. There is a maximum value attained for the stiffener buckling stress for a given area and thickness. If there are constraints on external dimensions of the stiffener and hence the overall cross-section area of the stiffener, the optimum thickness value for maximum buckling stress can be obtained from this graph.



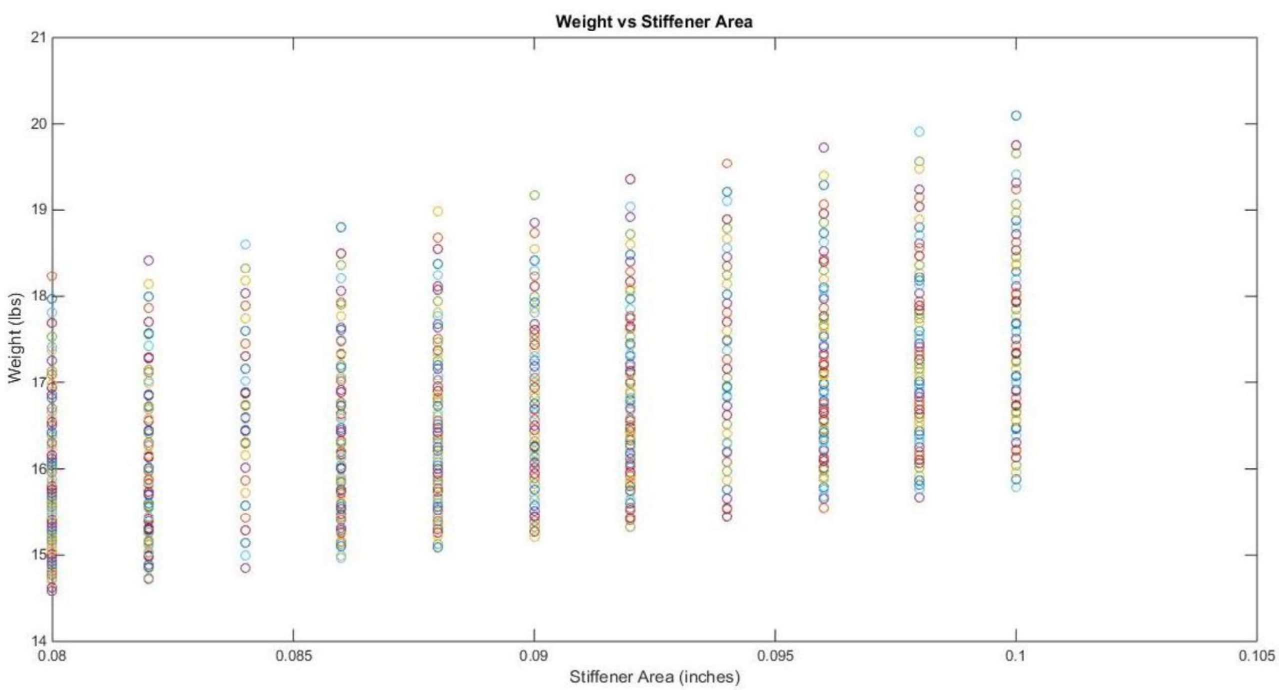
2. The graph above shows the variation of stiffener thickness and stiffener area with stiffener buckling stress. It is clear from the graph that not only the stiffener thickness, but stiffener cross-sectional area also plays an important role in the stiffener buckling stress calculations. The critical buckling stress increases as the cross-sectional area of the stiffener increases.

The following graphs show the variation of weight with respect to a single parameter, while the effects of the variation of all other factors are also plotted.

1. Weight variation with increase for different skin thicknesses while all other parameters are changed. From the plot below it can be seen that there are combinations of all other factors that lead to the lightest weight being achieved where the skin thickness is notably larger than the smallest possible value.

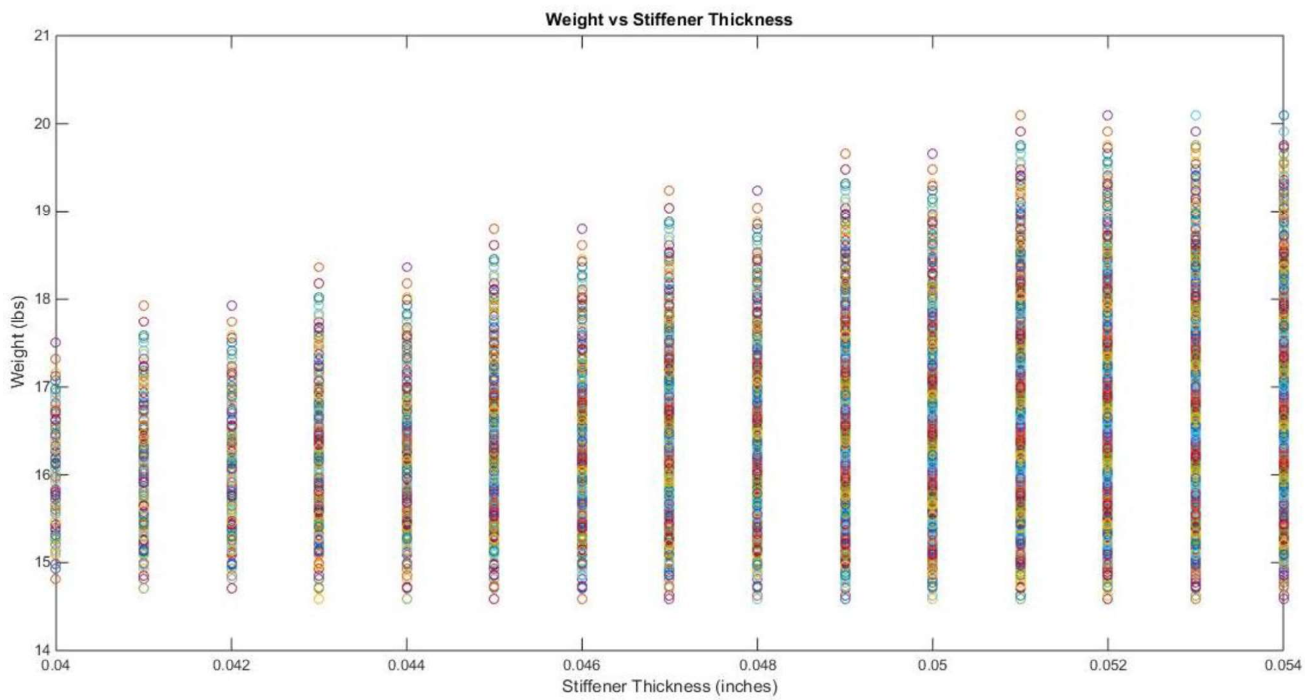


2. Weight variation with increase in stiffener area while all other parameters are simultaneously changed. Note that the minimum weight achievable for various combinations minimizes out at a mid-range thickness of 0.042”, after which a smaller skin actually leads to a larger weight.

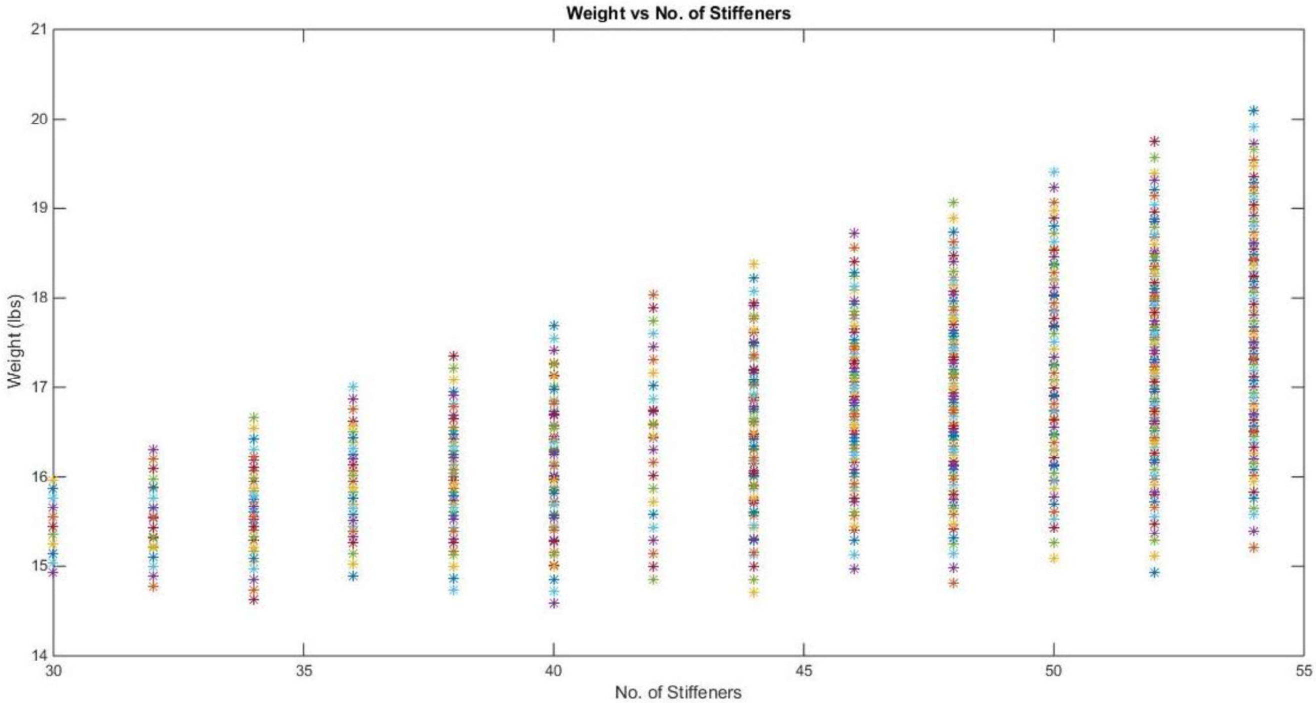


The above graph shows how the weight and the stiffener cross-sectional area are inter-related to one another for different combinations of design parameters. Weight of the section goes on increasing as the stiffener area increases.

3. Weight variation with increase in stiffener area while all other parameters are simultaneously changed. The trends from the below trade leads to the conclusion that the thickness of the stiffener does not play a direct role in reducing weight, but if the stiffener is too small it will lead to an increase of weight as the other components will compensate for the lack of strength in the stiffener.

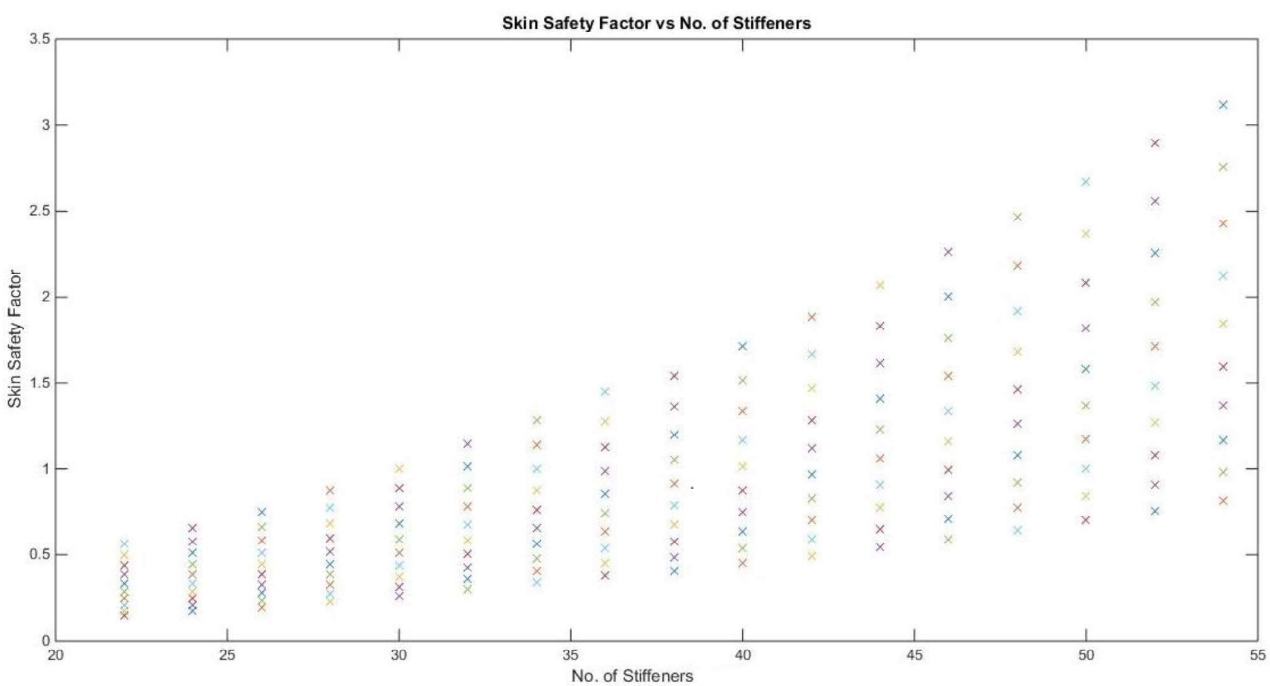


4. Weight variation with for different no of stiffeners while all other parameters are also changed. From this trade it can be seen that the number of stiffeners does not necessarily lead to a decrease in weight, more that there is a spread of “sweet spot” numbers of stiffeners across the range examined.



Each of the four graphs shown above plots the weight values for every valid design and the value corresponding to the minimum weight from each of the graphs is selected. In every graph, one value is altered while simultaneously altering other values.

Other graph such as Skin safety factor vs number of stiffeners is also plotted so as to study the effect of variation of indirect parameters such as no of stiffeners can be done. The following graph shows the effect of changing the number of stiffeners on skin safety factor or shear buckling factor.



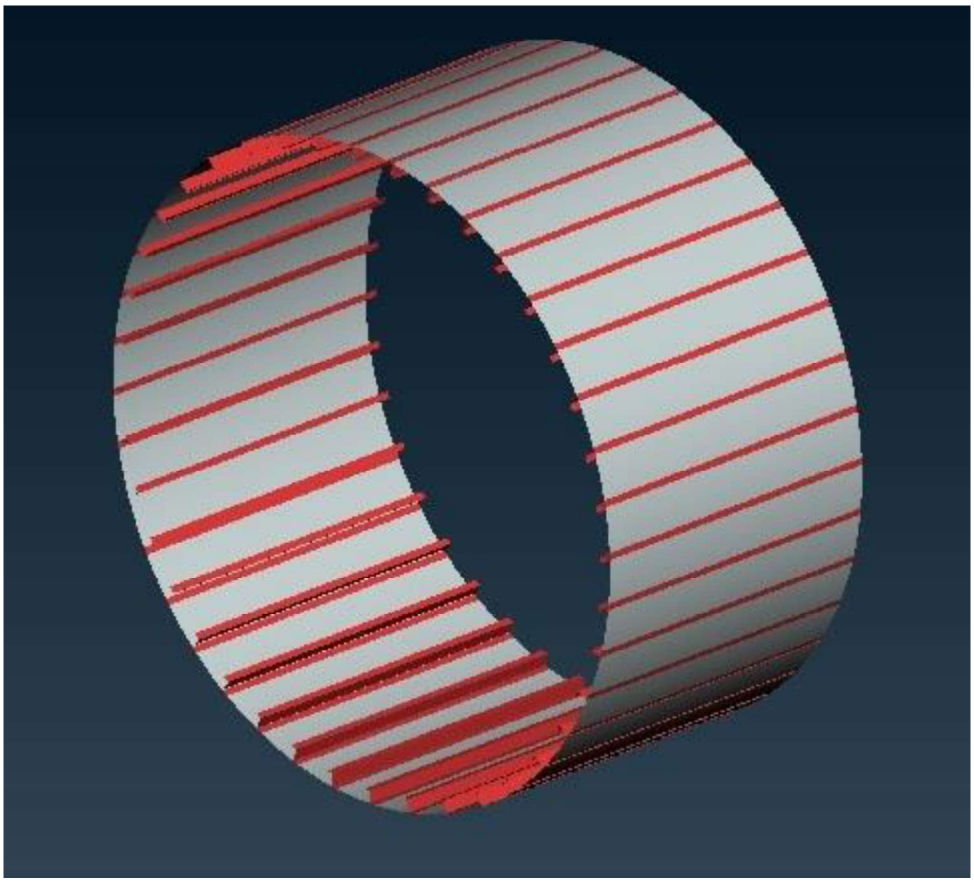
We will explain the dependence of the parameters on one another.

1. The shear flows and hence shear stresses in the skin are inversely proportional to the number of stiffeners. The shear stress reduces as the number of stiffeners increases. This is because the spacing between the stiffeners also reduces. Hence, increasing the number of stiffeners results in reduction of skin thickness, but there is trade-off as increasing the number of stiffeners makes the design more complex and the weight of the stiffeners also needs to be accounted for.

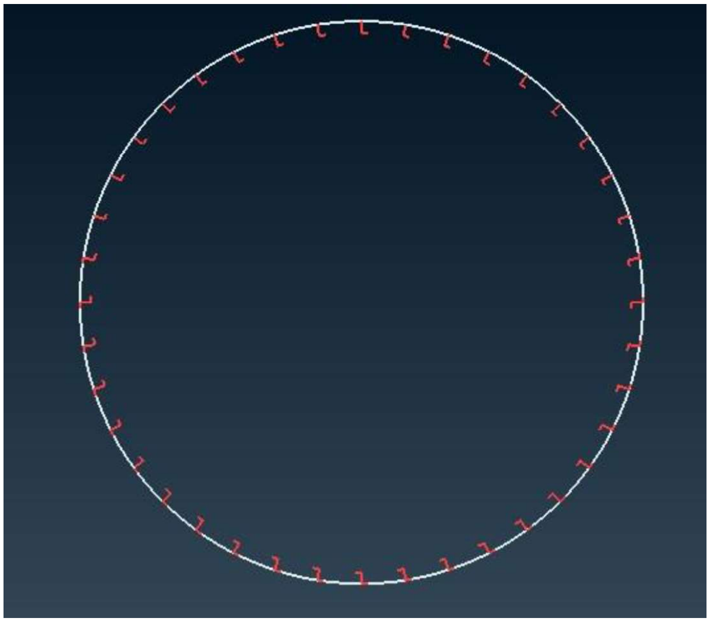
2. The stiffener thickness and cross-sectional area can be reduced even further as the safety factor in compression buckling is 2.05. But, stiffener thickness is always more than the skin thickness and hence this forces us to increase the stiffener thickness along with the skin thickness if the skin is failing in design. (This explains why the stiffeners have been designed to higher safety margins than the skin.)

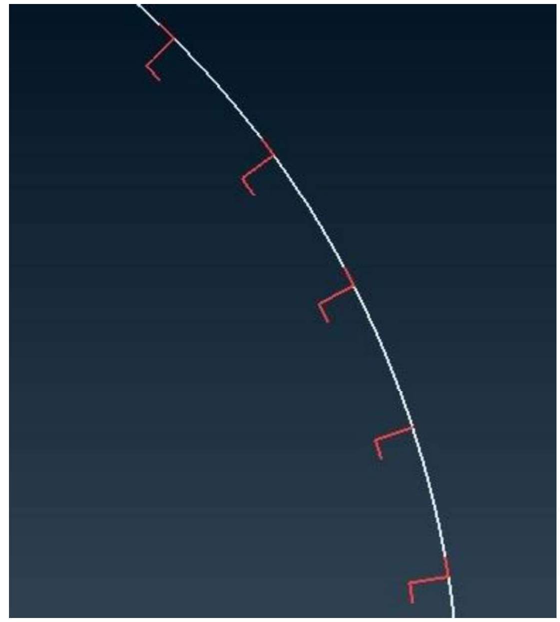
2.4 Sketch of Final Metallic Design:

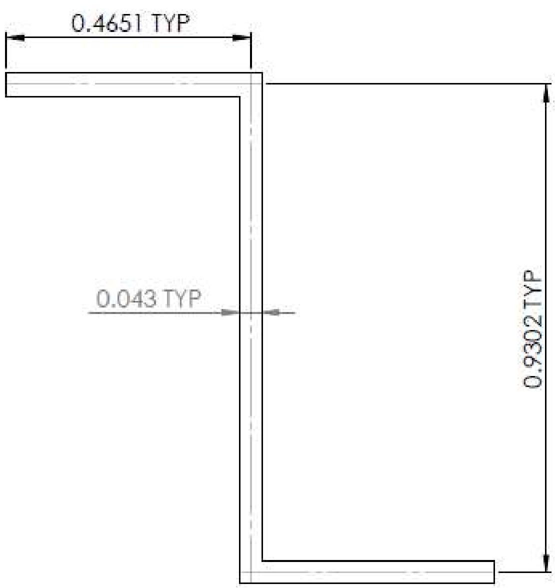
1. Complete Structure:

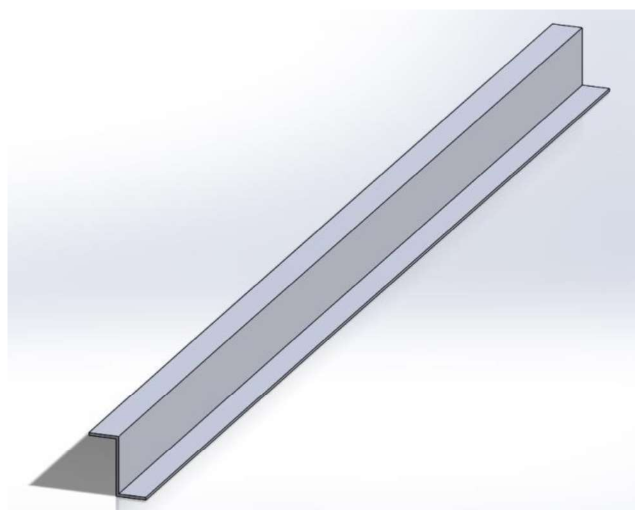


2. Details of Complete Structure:









3. DESIGN USING COMPOSITE MATERIALS:

3.1 Special Assumptions for Composite Materials:

i. The material assumed for our design calculations is Graphite with 100% $\pm 45°$ fiber orientations. Different fiber orientations can be used for different sections of the fuselage depending on the local loading conditions.

ii. The composite materials exhibit different mechanical properties in different directions. The overall properties depend on a variety of factors such as number of plies, ply thickness, fiber volume ratio and individual properties of fibers and binding resin. These properties are calculated following a series of complex calculations involving extension-extension matrix (A matrix), bending-extension matrix (B matrix) and bending stiffness matrix (D matrix). These values are computed and following this, the various failure criteria required for composites such as Tsai-Hill criteria, Tsai-Wu criteria are calculated to check the validity of design.

However, we will be not be doing any of the above matrices calculations and we will assume constant material properties in all directions for our design calculations.

3.2 Composite Design Process:

The following design steps are followed while carrying out composite design iterations in Matlab. Most of the design steps follow the same approach as that of the metallic design.

I. The very basic assumptions and first major decision comes into play in the first step, when we have to choose the material for the fuselage and for the stiffeners. In this case, we will be using composite materials for our design. Composite materials are fundamentally made up of fine strands of fibers and a binding resin that holds the fibers together and gives them a shape for design.

   Composite materials exhibit different mechanical properties in different directions but we will be assuming a single E value for easier calculations. The material assumed for our design calculations is Graphite with 100% $\pm 45°$ fiber orientations. The value of

   Mentioning correct values of mechanical properties such as Young's Modulus E, compressive yield strength and density are crucial before proceeding to design calculations.

II. To proceed with the calculations, certain basic dimensions such as the stiffener thickness, stiffener cross-sectional area, skin thickness and number of stringers are specified.

III. We do all of our shear flow and bending stress calculations only on half section of the fuselage because of structural symmetry about both axis. We take advantage of the symmetry about Y axis while doing calculations for shear flow, shear stresses and bending stresses.

   Hence, the number of stiffeners under consideration is,

$$N = \frac{n}{2} + 1$$

IV. After specifying the stiffener thickness and area, it will be easy to calculate stiffener dimensions such as the web height and the flange length. These dimensions are required later for stiffener design specifications.

$$b_w = 2 \times b_f$$

   The length and height of the stiffener is given as,

$$L = b_f + \left(\frac{t}{2}\right)$$

$$H = b_w - t$$

   Where,
   $b_f = flange\ length$
   $b_w = web\ length$
   L = total length of flange
   H = height of web … … … … … (Dimesnsions are similar to those in Metallic design)

V. The spacing between the stiffeners is calculated in this step by dividing the circumference of fuselage with the number of stiffeners.

The spacing b between the stiffeners is given by,

$$b = \frac{\pi D}{n}$$

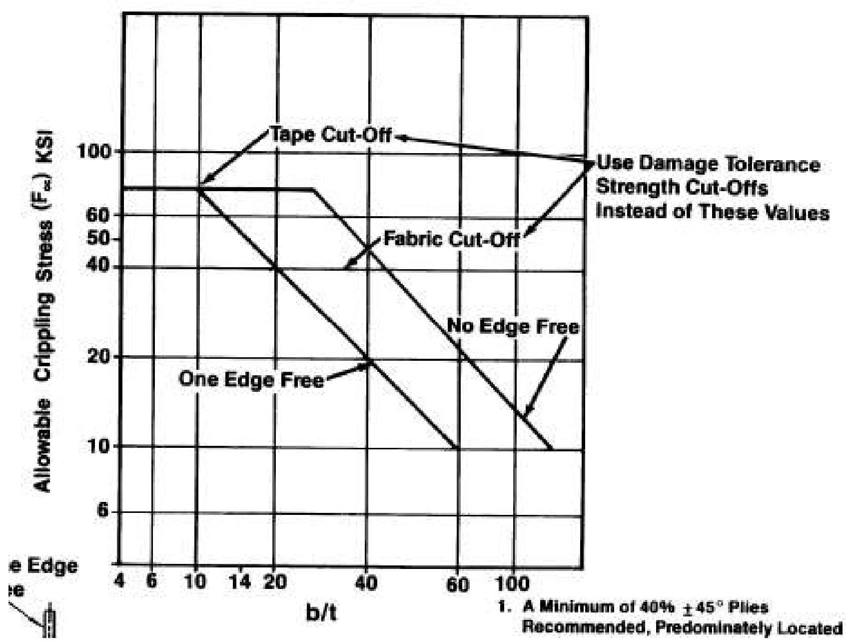
Where,

D = Diameter of the fuselage section

n = Total No. of Stiffeners

VI. Calculations of stiffener crippling stress:

Stiffeners are assumed to have one edge free and one edge for flange and web respectively. The values of (b/t) ratio are calculated for the flange and the web separately. These two ratios give us two different values of the critical crippling stress. One is for the flange section of the stiffener and the other is for the web section of the stiffener.



VII. Depending on the value of the critical slenderness ratio and the slenderness ratio of our stiffener, we calculate the critical buckling stress for the stiffener.

$$\sigma_b = \sigma_c\left[1 - \frac{\sigma_c\left(L'/\rho\right)^2}{4\pi^2 E}\right] \qquad when\ \left(\frac{L'}{\rho}\right) < \left(\frac{L'}{\rho}\right)_{critical}$$

$$\sigma_b = \left(\frac{\pi^2 E}{\left(L'/\rho\right)^2}\right) when\ \left(\frac{L'}{\rho}\right) > \left(\frac{L'}{\rho}\right)_{critical}$$

VIII. After this, the critical skin shear buckling stress is calculated.

$$\tau_{cr} = KE\left(\frac{t}{b}\right)^2$$

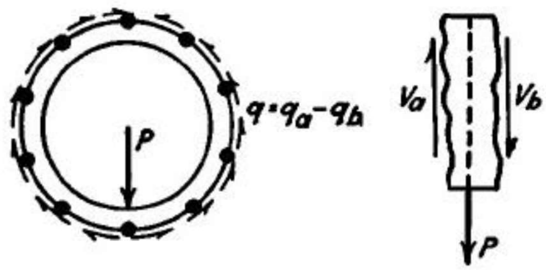
Where

K = calculated from graph depending on the ratio assuming simply supported edges of skin (a/b)

a = spacing between frames/stiffener length

IX. Stiffeners in a fuselage carry most of the axial loads and bending loads whereas skins transfer shear loads. Then we proceed to calculating the actual bending stresses in the stiffeners and the actual shear stresses in the skin using principles of shear flows for primary structures design.

The stresses are calculated on half section of the fuselage.



The y co-ordinate is calculated using the formula $y = \frac{D}{2}\cos\theta$.

Shear flow in the skin between two stiffeners is given by,

$$q_b = \frac{V}{I}\sum yA_f \ldots\ldots\ldots\ldots\ldots (shear\ flow\ due\ to\ bending)$$

$$q_T = \frac{T}{2A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (shear\ flow\ due\ to\ torsion)$$

$$q = q_a + q_b$$

$$q = \frac{V_a - V_b}{I}\int y\, dA$$

The moment of area of the section is calculated by adding the area moments of all the stiffeners. The table on the next page gives the shear flow calculations for our optimize design of **42** stiffeners, stiffener area **0.076** stiffener thickness **0.045** and skin thickness **0.044.**

<u>Composite Design Stress Calculation Table:</u>

This table shows the shear and bending stress calculations for the finalized design.

Stiffener No.	Stiffener Area (A_f)	y	yA_f	y^2A_f	$\sum yA_f$	Shear flow due to bending (q_b)	Shear flow due to torsion (q_t)	Total Shear Flow q = (q_b+ q_t)	Shear Stress	Bending Stress
1	0.038	20.00	0.76	15.20						1566
2	0.076	19.77	1.50	29.72	0.76	23.81	79.57	103.39	2349	1549
3	0.076	19.11	1.45	27.76	2.26	70.89	79.57	150.47	3150	1497
4	0.076	18.02	1.37	24.68	3.71	116.40	79.57	195.97	4454	1411

5	0.076	16.52	1.26	20.75	5.08	159.30	79.57	238.89	5429	1294
6	0.076	14.66	1.11	16.34	6.34	198.64	79.57	278.23	6323	1148
7	0.076	12.47	0.94	11.82	7.45	233.55	79.57	313.13	7117	976.6
8	0.076	10.00	0.76	7.60	8.40	263.25	79.57	342.83	7791	783.2
9	0.076	7.31	0.55	4.05	9.16	287.06	79.57	366.63	8333	572.3
10	0.076	4.45	0.34	1.50	9.72	304.45	79.57	384.03	8728	348.6
11	0.076	1.49	0.11	1.50	10.05	315.04	79.57	394.63	8969	117.1
12	0.076	-1.49	-0.11	0.17	10.17	318.61	79.57	398.18	9049	-117.1
13	0.076	-4.45	-0.33	0.17	10.05	315.04	79.57	394.63	8969	-348.6
14	0.076	-7.31	-0.55	1.50	9.72	304.45	79.57	384.03	8728	-572.3
15	0.076	-10.00	-0.76	4.06	9.16	287.05	79.57	366.63	8333	-783.2
16	0.076	-12.47	-0.95	7.60	8.40	263.24	79.57	342.83	7791	-976.6
17	0.076	-14.66	-1.11	11.82	7.45	233.55	79.57	313.13	7117	-1148
18	0.076	-16.52	-1.26	16.34	6.34	198.64	79.57	278.22	6323	-1294
19	0.076	-18.02	-1.37	20.75	5.08	159.30	79.57	238.89	5429	-1411
20	0.076	-19.11	-1.45	24.68	3.71	116.40	79.57	195.98	4454	-1497
21	0.076	-19.78	-1.50	27.76	2.26	70.89	79.57	150.47	3150	-1549
22	0.038	-20	-0.76	15.20	0.76	23.81	79.57	103.38	2349	-1556
				$\sum I_y$						

A = 1256.637 inch² (Cross sectional area of the fuselage section)

X. The maximum bending stress in the stiffeners is divided by the critical buckling stress for the stiffeners to get the safety factor for stiffener (compression buckling safety factor).

XI. The maximum shear stress in the section is divided by the skin critical buckling shear stress to get the safety factor for skin (shear buckling safety factor).

XII. If the safety factors for both of them are greater than 1, then only we calculate the weight of the fuselage. The weight of the section is given by,

$$W_{fuselage} = W_{stiffeners} + W_{skin}$$

$$W_{stiffeners} = n \times A_f \times t_{stiffener}$$

$$W_{skin} = \pi a \times t_{skin}$$

XIII. A number of iterations are performed so as to try different combinations of stiffener cross-section areas, stiffener thicknesses, skins thicknesses and number of stiffeners using the MATLAB code.

XIV. As the last step, we use the MATLAB code to determine the minimum weight out of these combinations of parameters.

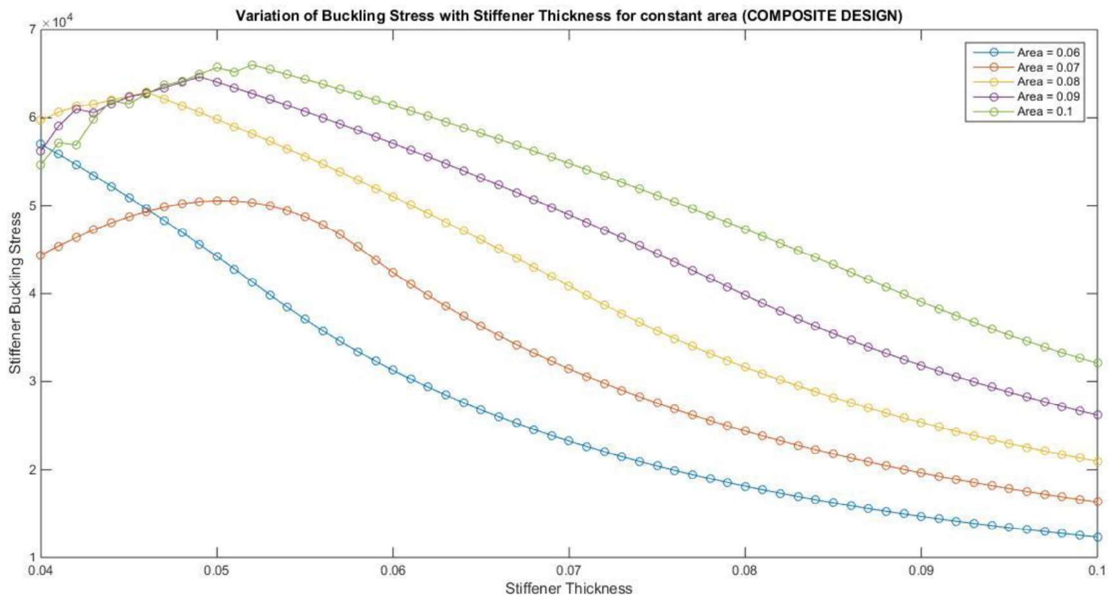
3.3 Final Composite Design and Estimated Weight:

- The material used for the metallic design is carbon fiber graphite with 100% $\pm$ 45° fibers which is an ultra-light composite material used commonly in the industry. The material properties are as follows and note that they are sourced from the information given in the Polymers and Composites class held at Arizona State University:

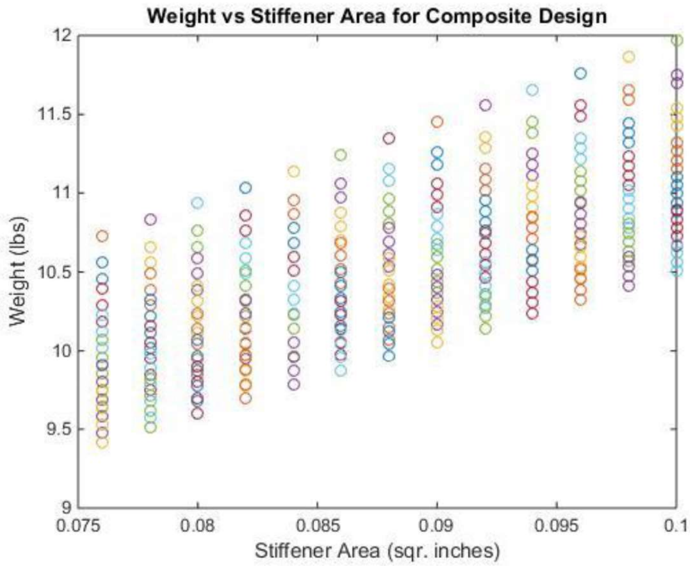
  Modulus of Elasticity E = 30,000 kpsi

  Density = 0.05704 lbs/inch^3
- The final design achieved weight only **9.418** lbs. It has **42** stiffeners, skin thickness of **0.044 inches** and stiffener dimensions as **0.0422 inches** of flange length and **0.0844** of web length.
- If we compare this with our metallic design weight, the composite design has resulted in saving weight of about 35%.

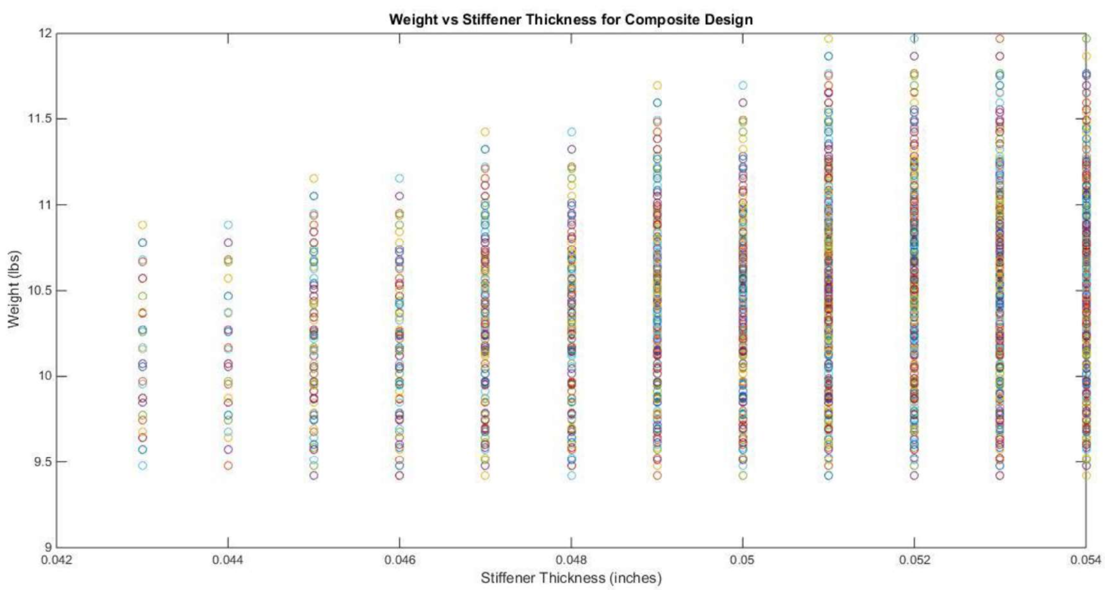
3.4 Composite Design Trade Study:



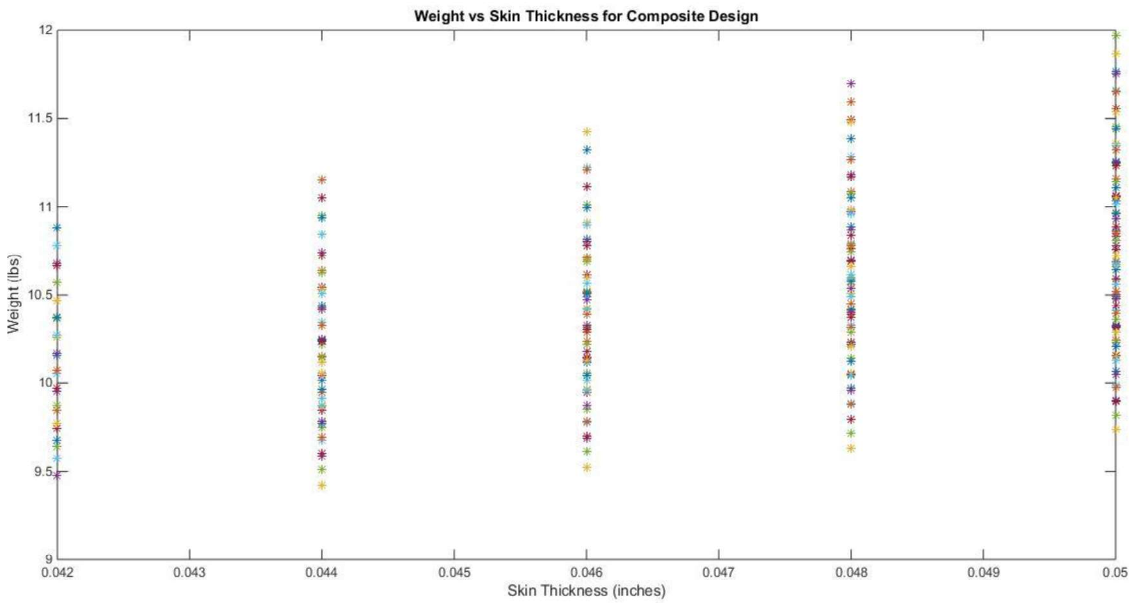
1. The above plot displays the variation of critical buckling stress for stiffeners as the thickness is increased while keeping the area constant. For each area there is maximum value obtained for the buckling stress. Note that for most of the stiffener areas at very thin thicknesses, they are all able to attain similar levels of buckling stress. However, after some thickness is gained they reorganize to being based on area, where a lower area leads to higher stiffener buckling stress.



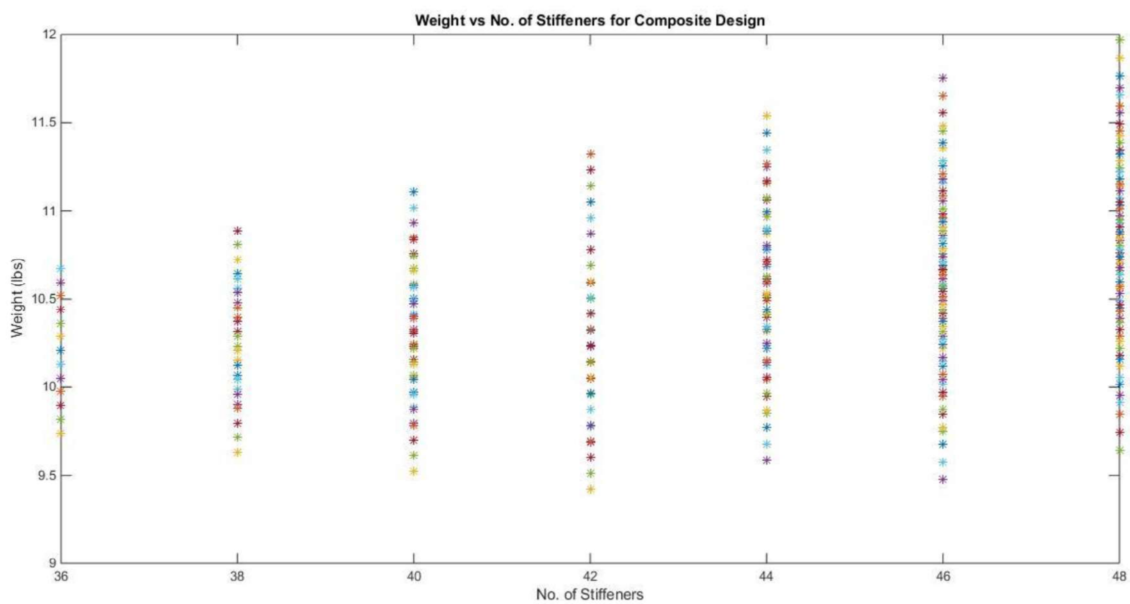
2. Above is a plot displaying the weight variation with an increase in stiffener area, with all other parameters are simultaneously changed. This plot displays similar behavior as was seen in the metal structure trades. Where there is a linear relationship between the weight of the structure and area of the stiffener, leading to the conclusion that a smaller stiffener area will create lower weights.



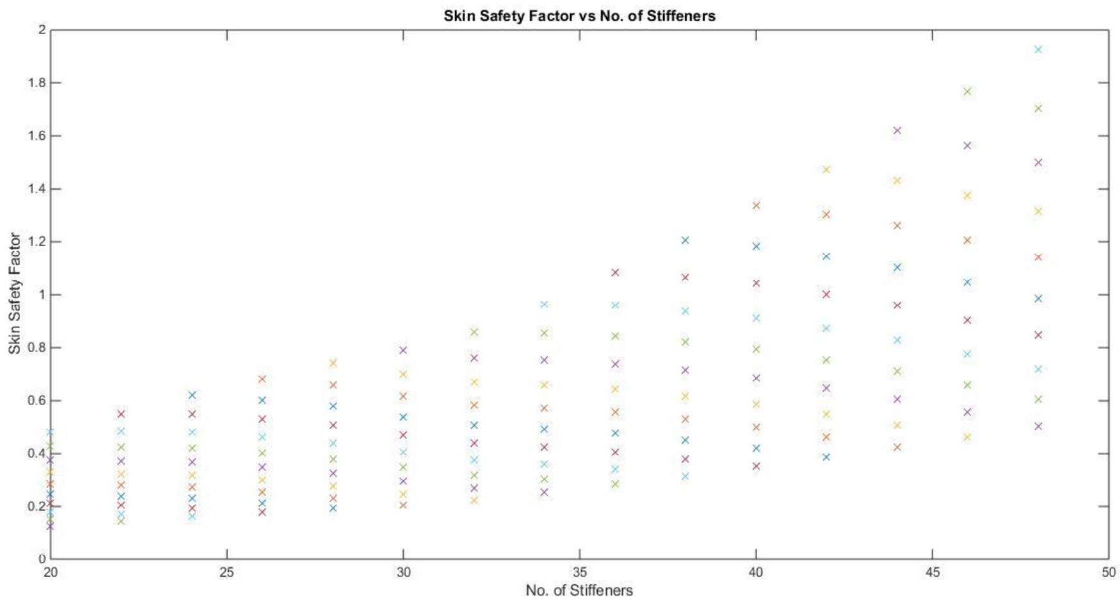
3. Weight variation with increase in stiffener thickness while all other parameters are changed. As was found with the metal case, the thickness of the stiffener does not hold direct control authority over driving the weight of the overall structure. However it is important to note that with smaller thicknesses the range of weights achieved is decreased.



4. The plot above displays the weight variation with for different skin thicknesses while all other parameters are changed. A similar behavior is achieved as was found with the metals; where the skin thickness' control over weight reaches a minimum at 0.044". After this point a decrease in skin thickness leads to increased weight.



5. The above plot displays the weight variation with for different number of stiffeners while all other parameters are also changed. This plot produced similar results as were found in the metals case. There are certain "sweet spots" for ideal number of stiffeners, but at the maximum and minimum number of stiffeners the weight takes a penalty.



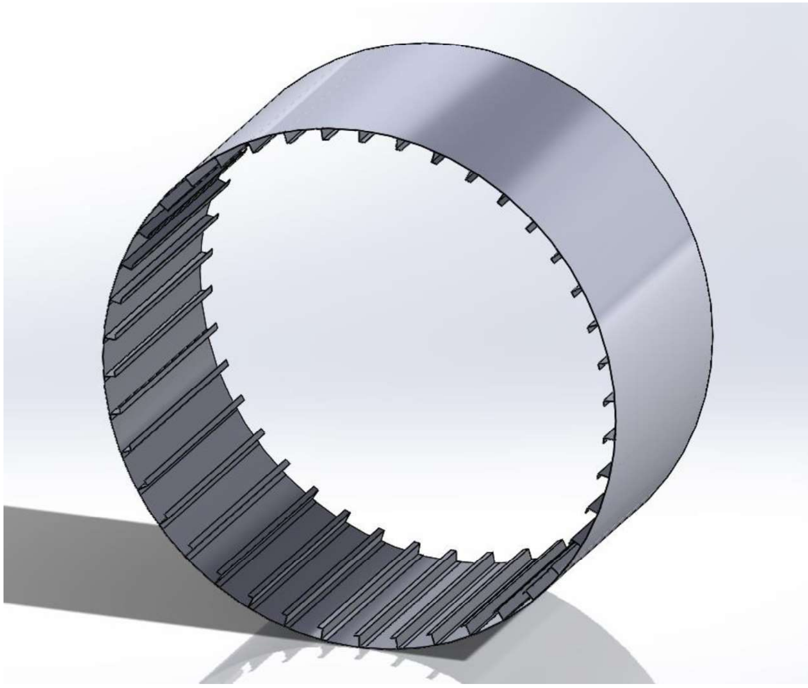
6. Above is a plot comparing the number of stiffeners with the skin safety factor, while other factors are simultaneously varied. From this plot it can be see that, as with the metals, the number of stiffeners on structure lead to an increased minimum skin safety factor and increased range of possible skin safety factors. Also it is important to note that with less than about 35 stiffeners it becomes impossible to achieve a passable skin safety factor.

Next we will discuss the dependence of parameters on one another. Note that the majority of results from the trade studies above yielded highly similar behavior as was found in the metal case.

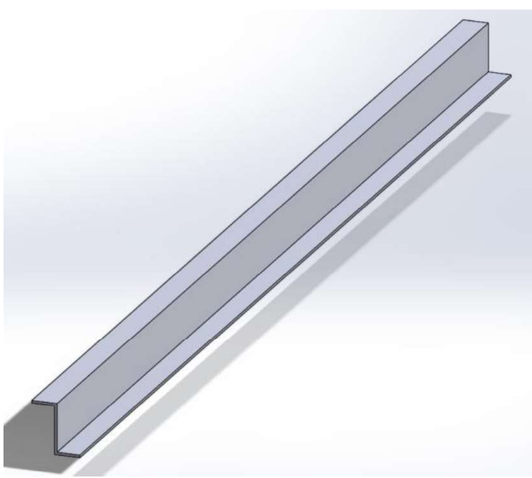
1. The shear flows and hence shear stresses in the skin are inversely proportional to the number of stiffeners. The shear stress reduces as the number of stiffeners increases. This is because the spacing between the stiffeners also reduces. Hence, increasing the number of stiffeners results in reduction of skin thickness, but there is trade-off as increasing the number of stiffeners makes the design more complex and the weight of the stiffeners also needs to be accounted for.
2. The stiffener thickness and cross-sectional area can be reduced even further due to the applied compression buckling safety factor. But, stiffener thickness is always more than the skin thickness and hence this forces us to increase the stiffener thickness along with the skin thickness if the skin is failing in design.

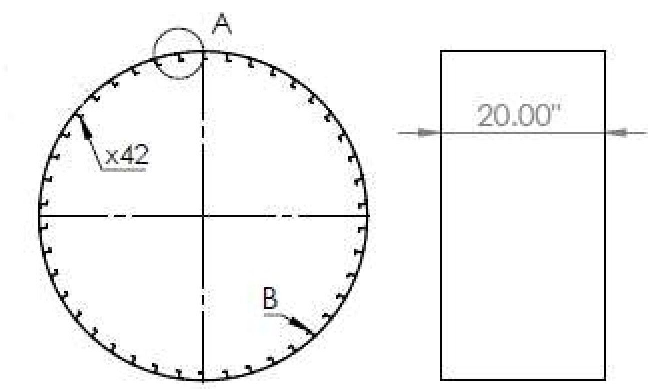
3.5 Sketch of the Final Composite Design:

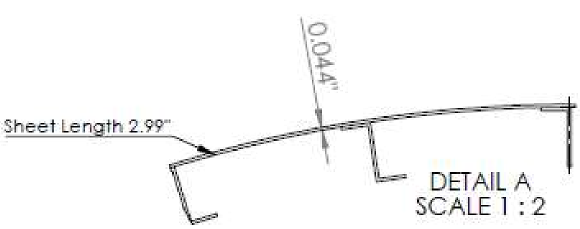
1. Complete Structure:

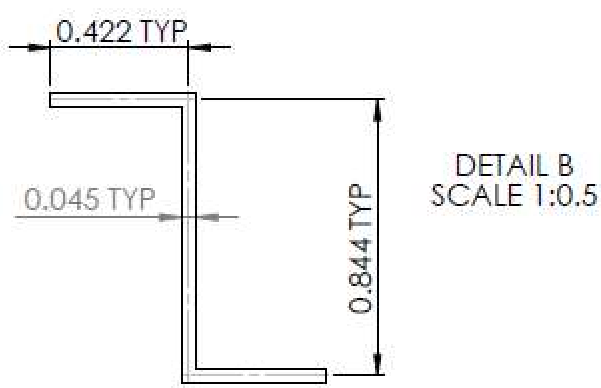


2. Details of Complete Structure:









RESULTS SUMMARY:

Attribute	Metallic Design	Composite Design
Material for Stiffeners	8090 Aluminium T8151	Carbon Fiber Reinforced Plastic (CFRP)
Stiffener Section Type	Z-section	Z-section
Stiffener Cross Section Area (A_f)	0.08	0.076
Stiffener Flange Length (b_f)	0.4651 inches	0.422 inches
Stiffener Total Web Length (b_w)	0.9302 inches	0.844 inches
Stiffener Thickness (t)	0.043 inches	0.045 inches
Stiffener Spacing (b)	3.142 inches	2.99 inches
Compression Buckling Safety Factor	2.05	3.949
Number of Stiffeners	40	42
Total weight of Stiffeners	5.504 lbs	3.447 lbs
Material for Skin	8090 Aluminium T8151	Carbon Fiber Reinforced Plastic (CFRP)
Skin Thickness (t skin)	0.042 inches	0.044 inches
Shear Buckling Safety Factor (Skin)	1.016	1.0037
Weight of Skin	9.0779 lbs	5.972 lbs
Total Weight	14.582 lbs	9.419 lbs

The final dimensions of stiffeners are generally rounded off to their nearest two decimal places. However, for showing the exact dimensions obtained through optimization, we have kept the decimal places as they are.