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Aerospace Structure

(AE 530)

Rocket Design

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ABSTRACT

Missiles structures are usually thin bodies of revolution. The primary structure consists of a nose cone and a cylindrical fuselage. In order to reduce weight, the fuselage skin is usually used as a fuel-tank as well. Fuselage I usually stiffened by longitudinal stiffeners, as well as lateral rings.

In this paper, we carry a dual level of design to the structure of the fuselage by approximating the fuselage as one dimensional beam in the first level and by approximating the fuselage as one a cylindrical shell in the second level.

ACKNOWLEDGEMENT

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1. INTRODUCTION

Missiles structures are usually thin bodies of revolution. The primary structure consists of a nose cone and a cylindrical fuselage. In rocket design, many criteria must be taken in consideration. The strength of the rocket structure is a primary issue in building a rocket. In order to reduce weight, the fuel tanks are usually integrated inside the main body of the rocket as shown in figure 1.
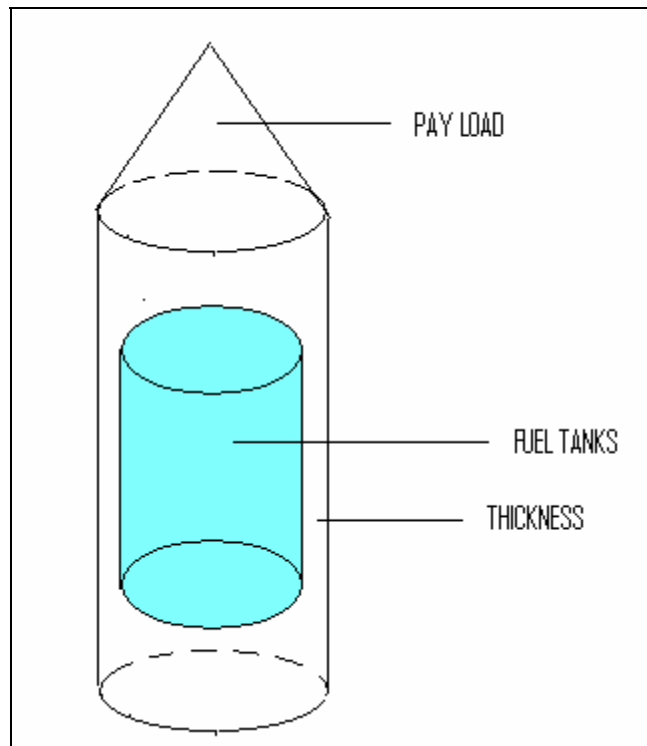
Fig.1. Fuel tanks in a rocket

The wall of the rocket must be strong enough to withstand the fuel tank pressure. Another criterion is the weight of the structure of the rocket that it has to be lowered as much as possible in order to decrease the cost in terms of fuel consumption and to use any validity of adding extra weight to the pay load.

In this paper, we are going to have a suggested design for the rocket problem declared in down in project nature part. Taking the strength of criterion as our major task that has to be satisfied for save design; and the weight and displacement due to the load as our minor criterion with making some acceptable and logical assumptions under the given conditions.

2. PROJECT NATURE:

Statement of the Problem:

Missiles structures are usually thin bodies of revolution. The primary structure consists of a nose cone and a cylindrical fuselage. In order to reduce weight, the fuselage skin is usually used as fuel-tank as well. Fuselage skin is usually stiffened by longitudinal stiffeners, as well as lateral rings.

Consider the shown missile primary structure in figure 2. The liquid fuel pressure is 100 bar. The maximum aerodynamic pressure differential between two opposite points on the fuselage surface is 20 psi. The structure is to be analyzed when the thrust provides an acceleration of 5 g's for the 2 ton missile. Structure can be made of any of the commonly used aerospace aluminum alloys (2024, 7075…etc.) Upon suggesting a design, you can analyze it using traditional mechanical approach methods, with all calculations done on MATLAB, or you can analyze it using ANSYS. If needed, reasonable assumptions may be made.

Required:

This project will be devoted to carry a dual level design to the structure of the rocket fuselage:

1. <u>First Level:</u> Approximate the fuselage as one dimensional beam supported at the adaptor plate. The beam will be subjected to the external pressure, while the internal pressure effect would be that of axial and hoop stresses only, calculated by a simple formula. Calculate the wall thickness, and the areas of any added stiffeners. At this level, do not consider the nose cone because it is not subjected to the internal pressure.

2. <u>Second Level</u>: Approximate the fuselage as a cylindrical shell and a conical shell supported at the adaptor plate. Calculate the wall thickness, and the areas of any added stiffeners.

3. Comment on the results of parts 1 and 2. Do you think this design problem is feasible under the given conditions?
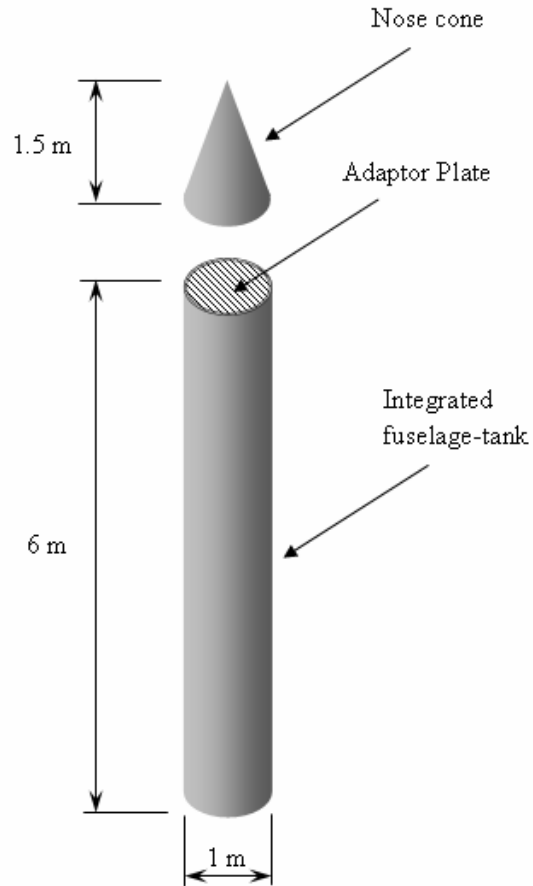
Fig.2. rocket primary structure

3. BACKGROUND INFORMATION:

In this part, all stress relations and equations used to find what is required in both levels will be investigated in details to find the best design that satisfies the strength and the minimum weight criteria.

➔ Our main target is to check whether the given default configuration (thickness) in the problem can be used or we have to modify it to come up with a new design. To do so, we need to go through sequence of steps.

Firs of all, we show the loads on the missile as shown in figure 3.
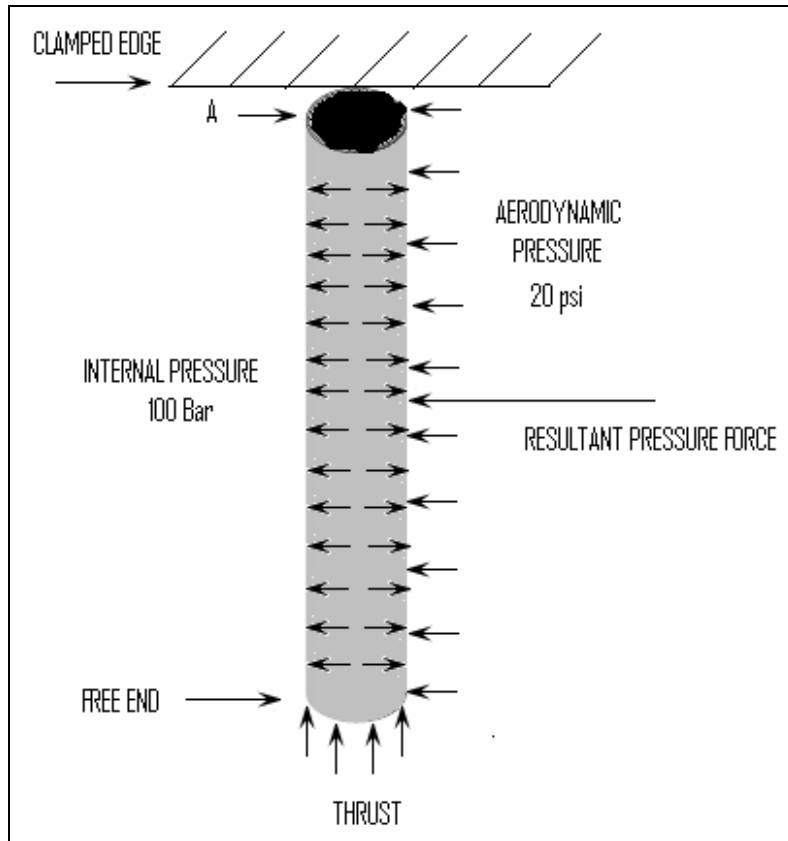
Fig.3. Loads on the rocket

➔ Given configuration data:

Table1. Given configuration data

Liquid fuel pressure (Internal pressure) (Pr)	100 bar
Max. aerodynamic pressure differential between any 2 points (P)	20 psi
Thrust force (T)	5 g
Total weight of the missile	2 ton
Material used	Aluminum 7075 T6
Length of the cylindrical part of the rocket (L)	6 meter
Length of the conical part of the rocket	1.5 meter
Diameter of the rocket (D)	1 meter

➔ Aluminum 7075 T6 properties:

Table2. Aluminum 7075 T6 properties

Maximum allowable stress	503×10^{6} Pascal
Density	2.8×10^{3} kg/m^{3}
Young Modulus (E)	10.5×10^{6} psi

➔**First level:** Approximating the fuselage as one dimensional beam supported at the adaptor plate and assuming clamped edge at the adaptor plate.

If we assume the fuselage as a beam, then it is clear that the most critical point in the beam is point A as shown in figure 3 where we have maximum stress there.
So the stress at point A is:

$$\sigma_{A\_axial} = -\frac{(FL/2)}{I} - \frac{T}{2\pi rt} \quad \text{..(1)}$$

$$I = \pi r^3 t \quad \text{..(2)}$$

Where:
σ_{A_axial} is the axial stress at point A due to the axial pressure.
F is the resultant force due to the aerodynamic differential pressure.
L is the Length of the cylindrical part of the rocket.
I is the area moment of inertia for cylindrical thickness.
T is the thrust force.
r is the radius of the cylinder = D/2.
t is the thickness of the cylinder.

$$\sigma_{A\_hoop} = \frac{(Pr\,D)}{2tL} \quad \text{..(3)}$$

Where:
Pr is the Liquid fuel pressure (Internal pressure).
D is the diameter of the rocket.

Solving for thickness:

$$t_{axial} = \frac{FL + Tr^2}{2\pi r^3 \sigma\_allaw} \quad \text{..(4)}$$

$$t_{hoop} = \frac{Pr\,D}{2L\sigma\_allaw} \quad \text{..(5)}$$

Where:
σ_allaw is Maximum allowable stress.

➔ For any (n) added stiffeners, the area moment of inertia for the cross section is:

$$I_{add\ stff} = I + \sum_{i=1}^{n}(I\_stiff + A\_stiffY^2) \quad \text{..(6)}$$

Where:
I is the area moment of inertia for cylindrical cross section without stiffeners.
I_stiff is the area moment of inertia for a stiffener which equals to zero (very small).
A_stiff is the area of each stiffener.
Y is the distance of each stiffener to the middle surface of fuselage top base.

➔ For any (R) added rings and any (n) stiffeners, the area moment of inertia for the cross section is:

$$I_{\text{add ring add stiff}} = I + I_{\text{add ring}} + I_{\text{add stiff}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.(7)$$

➔ For checking wither we reach the save condition, we calculate the ratio of the maximum stress and maximum allowable stress in hic has to be more than 1(ratio>1).

$$\text{Ratio}_{\text{axial}} = \text{Maximum allowable stress} / \sigma_{A\_axial} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..(8)$$

$$\text{Ratio}_{\text{hoop}} = \text{Maximum allowable stress} / \sigma_{A\_hoop} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..(9)$$

➔ For calculating displacement we consider figure 4:
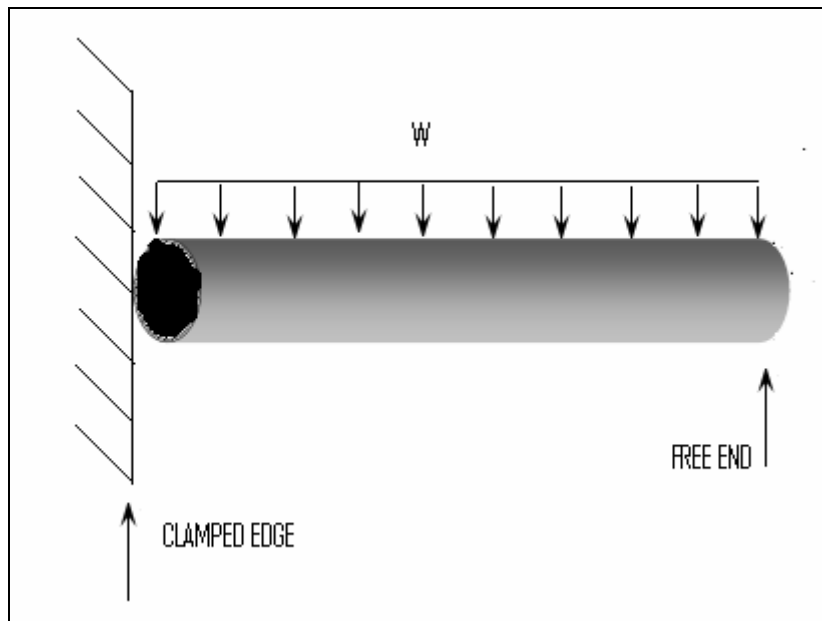
Fig.4. pressure distribution on the rocket

EI $V^{////}$ = -W...(10)

Where:

W is the force per unit length.

E is the Young Modulus of aluminum 7075 T6

I is the area moment of inertia of the cross section

Integrating eq. 10 4 times to get:

EIV = - (W/24) X^4 + (C_1/6) X^3 + (C_2/2) X^4 + (C_3) X...........................(11)

Applying the four boundary conditions:

EIV (0) = 0, $EIV^{/}$ (0) = 0

$EIV^{//}$ (L) = 0, $EIV^{////}$ (L) = 0

And substituting L = 6

The displacement is:

$$V = \frac{-162W}{EI}$$ ....(12)

➔ The structure weight percent of the total weight is calculated by using eq. (13) as follows:

Structure weight % = (Structure weight /Total weight)*100...........................(13)

➔**Second level:** Approximating the fuselage as a cylindrical shell supported at the adaptor plate and assuming clamped edge at the adaptor plate.

If we assume the fuselage as a cylindrical shell, then the relations used to calculate stress and other needed quantities are as follows:

The equilibrium equations in cylindrical coordinates are:

$$N_\theta = -P_r r$$ ....(14)

$$\frac{\partial N_{X\theta}}{\partial X} + \frac{1}{r}\frac{\partial N_\theta}{\partial \theta} = -P_\theta$$ ....(15)

$$\frac{\partial N_X}{\partial X} + \frac{1}{r}\frac{\partial N_{X\theta}}{\partial \theta} = -P_X$$ ....(16)

$$\sigma_{hoop} = N_\theta / t_{hoop} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (17)$$

$$\sigma_{axial} = N_x / t_{axial} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (18)$$

$$N_X = - \int P_X \, dx \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (19)$$

Where:
$P_\theta = 0$
$P_r = 100$ bar

$$P_X = \frac{T}{2\pi r t} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (20)$$

Substituting eq. 20 into eq. 19 and integrating it to get:

$$N_X = -\frac{T}{2\pi r t} X + C \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (21)$$

Applyng the boundary condition:

$N_X = 0$ at $x = 0$

$$N_X = -\frac{T}{2\pi r t} X \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (22)$$

Substituting eq. 22 into eq. 18 and Solve for t and substitute for $x = L$ to get:

$$t_{axial} = \sqrt{\frac{TL}{2\pi r \sigma_{allaw}}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (23)$$

4. CALCULATION AND RESULTS

➔ **Flow Chart**
The design procedure goes as it is explained in the flow chart:

```
          Calculating thickness for maximum allowable stress
                  │                                    │
                  ▼                                    ▼
              t_axial                              t_hoop
              ┌──┴──┐                              ┌──┴──┐
              ▼     ▼                              ▼     ▼
            safe  not safe                       safe  not safe
              │     │                              │     │
              ▼     ▼                              ▼     ▼
             ok   add stiffeners                  ok   add rings to
                  to support the                       support the
                  wall                                 wall
                  ┌──┴──┐                              ┌──┴──┐
                  ▼     ▼                              ▼     ▼
                safe  not safe                       safe  not safe
                  │     │                              │     │
                  ▼     ▼                              ▼     ▼
                 ok   new idea                        ok   new idea
                      of design                            of design
                        │                                    │
                        ▼                                    ▼
                        ok                                   ok
```

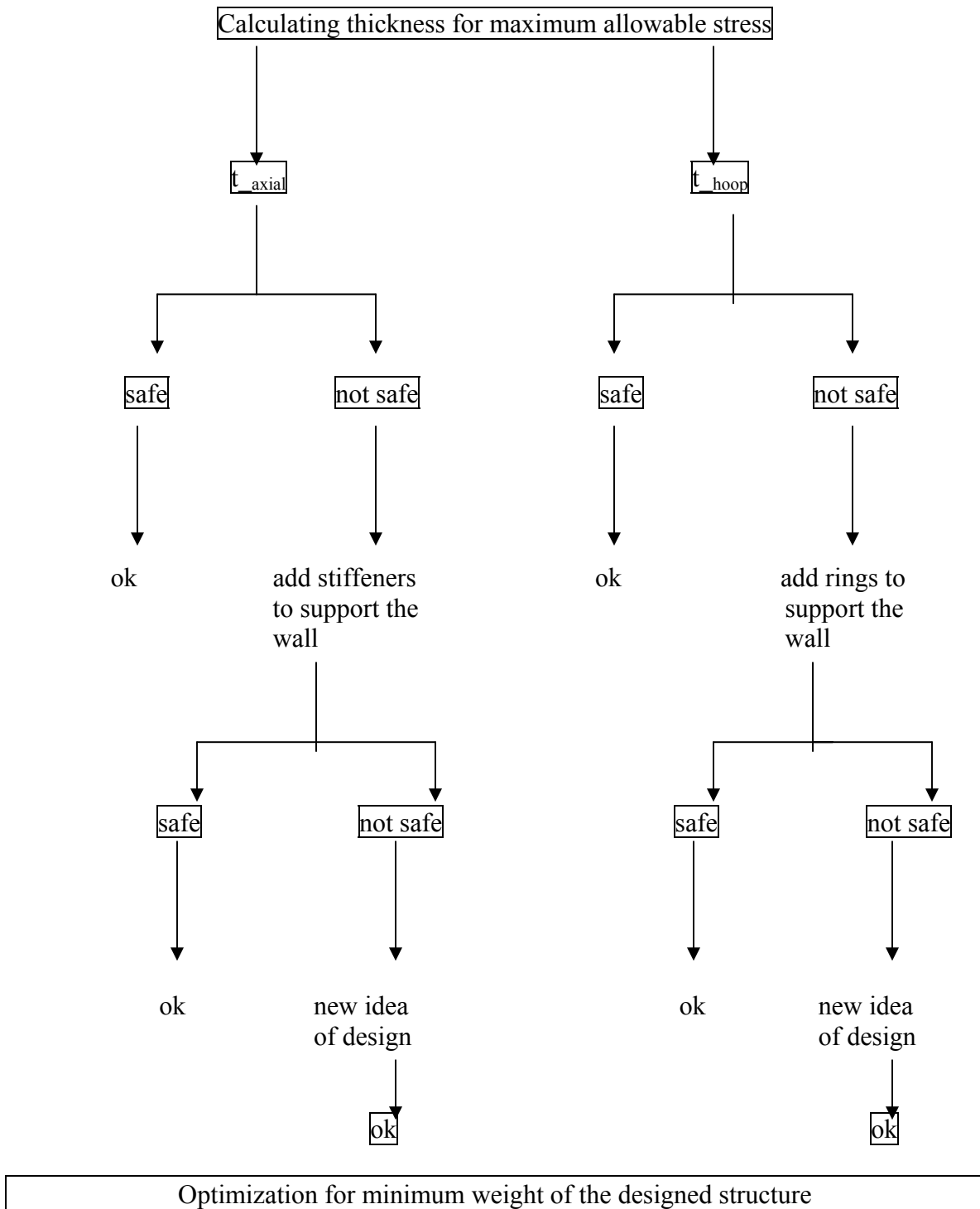| Optimization for minimum weight of the designed structure |
|---|

Fig.5. flow chart of design procedure

➔**First level:** Approximating the fuselage as one dimensional beam supported at the adaptor plate and assuming clamped edge at the adaptor plate.

Part 1:

In this part, we calculate the thickness needed due to the axial stress (t_{axial}) and due to the hoop stress (t_{hoop}):

From equations (4) and (5) the thickness needed due to the axial stress (t_{axial}) and due to the hoop stress (t_{hoop}) is calculated by Matlab program (appendix A):

t_{hoop} = 1.657 mm

t_{axial} = 12.628 mm

And displacement percent of total length (L)to be:

Disp. % = 0.0104

If we assume that the maximum sheet thickness that we could we have is about 0.25 inches which is equal to 6.25 mm, then we conclude that:

1- Thickness needed to withstand the hoop stress is safe enough since we just need 1.657 mm to carry it. So we are safe and no need to add rings to support the wall.

2- Thickness needed to withstand the axial stress is not safe enough since we need at least 12.628 mm to carry it but the possible sheet thickness is just 6.25 mm. So we need to support the wall by implementing a new design by adding stiffeners as we see in part 2.

Part 2:

In this part, we are going to add stiffeners to support the wall to carry the axial stress as follows.

The area of each stiffener is assumed to be maximum of 2.5 in^2. The stiffener has the following dimensions as shown in figure 6.
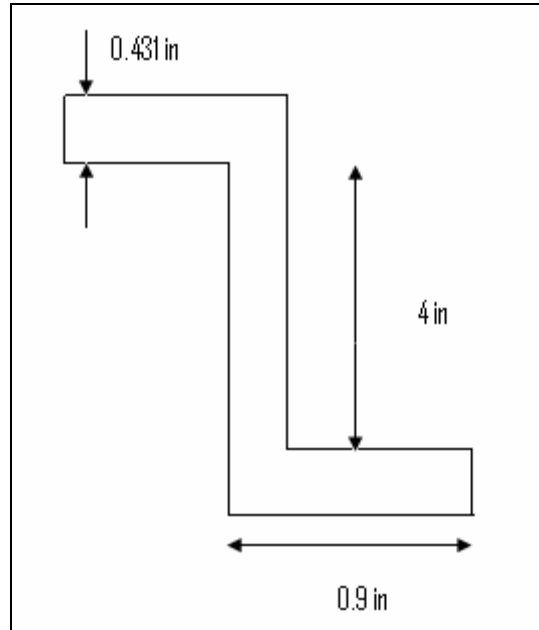

Fig.6. stiffener dimensions

By using this stiffener with the given dimensions, we can put 69 stiffeners as maximum number of stiffeners in this stage.

Now we recalculate the axial stress after we added the stiffeners by modifying equation (1) as follows:

$$\sigma_{axial} = \frac{FL/2}{I_{cross-with-stiff}} + \frac{T}{2\pi rt + nA_{stiff}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(24)$$

Where:
$I_{cross-with-siff}$ is calculated from eq. (6)
A_{stiff} is the area of each stiffner
n is the number of stiffeners

The axial stress is calculated from eq. (24) and the ratio of axial stress and the maximum allowable stress from eq. (8) by implementing the Matlab program (appendix B) to get:

$\sigma_{axial} = 6.0802 \times 10^8$ Pascal

And:

$(\sigma_{allaw-stress} / \sigma_{axial}) = 0.8273$

From above analysis, the ratio of axial stress and the maximum allowable stress doesn't reach 1 which means that even with adding maximum number of stiffeners with maximum area of each one and with putting maximum thickness (6.25 mm), still it is not safe. So we need to support the wall by implementing a new design by adding a second layer as we see in part 3.

Part 3:

In this part, we are going to add a second layer to the design implemented in part 2 to carry the axial stress as follows. The new configuration is something similar to what shown in figure 7.
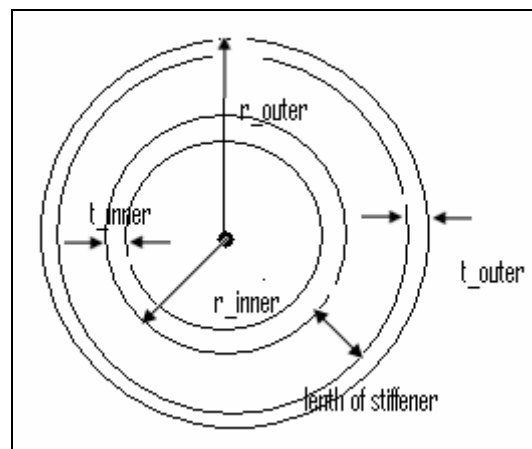The stiffener has same dimensions as it is shown in figure 6.

Fig.7. cross section with the second layer

Now we recalculate the axial stress after we added the second layer by modifying equation (24) as follows:

$$\sigma_{axial} = \frac{FL/2}{I_{cross-with-stiff-layer}} + \frac{T}{2\pi(r_{inner}t_{inner} + r_{outer}t_{outer}) + nA_{stiff}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(25)$$

Where:

$I_{cross-with-siff-layer} = I_{cross-with-siff} + \pi r^3_{inner} t_{inner}$ ....(26)

A_{stiff} is the area of each stiffener

n is the number of stiffeners

r_{inner} is the radius of the second layer

t_{inner} is the thickness of the second layer

The axial stress is calculated from eq. (25) and the ratio of axial stress and the maximum allowable stress from eq. (8) by implementing the Matlab program (appendix C) for maximum number of stiffeners (55) and maximum area of stiffener (2.5 in^2) and maximum thickness (6.25 mm) for both layers to get:

σ $_{axial}$ = 4.8885 x 10^8 Pascal

And:

(σ $_{allaw-stress}$ / σ $_{axial}$) = 1.0289

And:

The structure weight percent is calculated from equation (13) to be:

Structure weight % = 100.9585 %

And displacement percent of total length (L)to be:

Disp. % = 1.0112. it is ok.

From above analysis, the design is safe with a factor of safety of (1.0289) which means that the wall is supported enough to carry the axial stress, so our first criterion in design has been satisfied. However, the weight of this suggested design is too much; so we need now to consider our second criterion which is designing for minimum possible weight. By playing with different parameters in the problem like the area of stiffener, the number

of stiffeners and the thickness of both layers, the design was optimized for the best possible weight by considering the following changes.

Table 3. Level one optimized design data

Thickness of outer layer	6.25 mm
Thickness of inner layer	6.25 mm
Area of each stiffener	2.5 in^2
Number of stiffeners	19

After we optimized the design, the final results are:

Table 4. Level one design final results

($\sigma_{allaw\text{-}stress}$ / σ_{axial})	1.0017
Structure weight %	53.7085 %
Displacement %	1.0372 %

➔Second level: Approximating the fuselage as cylindrical shell supported at the adaptor plate and assuming clamped edge at the adaptor plate.

Part 1:

In this part, we calculate the thickness needed due to the axial stress (t_{axial}) and due to the hoop stress (t_{hoop}):

From equations (17) and (23) the thickness needed due to the axial stress (t_{axial}) and due to the hoop stress (t_{hoop}) is calculated by Matlab program (appendix D):

t_{hoop} = 9.94 mm

t_{axial} = 19.29 mm

And displacement percent of total length (L)to be:

Disp. % = 0.0068

If we assume that the maximum sheet thickness that we could we have is about 0.25 inches which is equal to 6.25 mm, then we conclude that:

1- Thickness needed to withstand the hoop stress is not safe since we need 9.94 mm to carry it. So the design is not safe and we need to add rings to support the wall to withstand the hoop stress.

2- Thickness needed to withstand the axial stress is not safe enough since we need at least 19.29 mm to carry it but the possible sheet thickness is just 6.25 mm. So we need to support the wall by implementing a new design by adding stiffeners to withstand the axial stress.

To support the wall, we are going to support it to carry the axial stress first as first stage of design till we reach the save case of axial stress perspective then we add rings to support it till we reach the save case of hoop stress perspective.

Part 2:

In this part, we are going to add stiffeners first to support the wall to carry the axial stress as follows.

The area of each stiffener is assumed to be maximum of 2.5 in^2. The stiffener has the dimensions as shown in figure 6.

By using this stiffener with the given dimensions, we can put 69 stiffeners as maximum number of stiffeners in this stage.

Now we recalculate the axial stress after we added the stiffeners by modifying equation (22) as follows:

$$N_X = \frac{TL}{2\pi rt + nA_{stiff}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(27)$$

Substituting eq. (25) into eq. (18) to recalculate the axial stress.

Where:
A_{stiff} is the area of each stiffener
n is the number of stiffeners

The axial stress is calculated and the ratio of axial stress and the maximum allowable stress from eq. (8) by implementing the Matlab program (appendix E) to get:

$\sigma_{axial} = 7.3819 \times 10^8$ Pascal

And:

$(\sigma_{allaw\text{-}stress} / \sigma_{axial}) = 0.6814$

From above analysis, the ratio of axial stress and the maximum allowable stress doesn't reach 1 which means that even with adding maximum number of stiffeners with maximum area of each one and with putting maximum thickness (6.25 mm), still it is not safe. So we need to support the wall by implementing a new design by adding a second layer as we see in part 3.

Part 3:

In this part, we are going to add a second layer to the design implemented in part 2 to carry the axial stress as follows. The new configuration is something similar to what shown in figure 7.
The stiffener has same dimensions as it is shown in figure 6.

Now we recalculate the axial stress after we added the second layer by modifying equations (27) and (18) as follows:

$$N_{X\text{-with-stiff-layer}} = \frac{TL}{2\pi(r_{outer}t_{outer} + r_{inner}t_{inner}) + nA_{stiff}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(28)$$

$$\sigma_{axial\text{-with-stiff-layer}} = N_{X\text{-with-stiff-layer}} / (t_{outer} + t_{inner}) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(29)$$

Where:
A_{stiff} is the area of each stiffener
n is the number of stiffeners
r_{inner} is the radius of the second layer
t_{inner} is the thickness of the second layer

The axial stress is calculated from eq. (29) and the ratio of axial stress and the maximum allowable stress from eq. (8) by implementing the Matlab program (appendix F) for maximum number of stiffeners (55) and maximum area of stiffener (2.5 in^2) and maximum thickness (6.25 mm) for both layers to get:

$\sigma_{axial} = 3.9138 \times 10^8$ Pascal

And:

$(\sigma_{allaw\text{-stress}} / \sigma_{axial}) = 1.2852$

From above analysis, the wall can carry the axial stress and it is safe with a factor of safety of (1.2852). However, the wall needs to be supported to carry the hoop stress by adding rings as we see in part 4:

Part 4:

In this part, we are going to add rings to the design implemented in part 3 to carry the hoop stress as follows. The rings will be put around the internal layer as shown in figure 8.
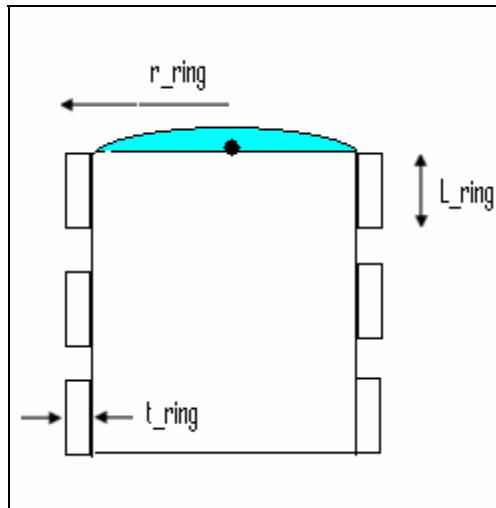

Fig.8. rings added to support the hoop stress

If we consider figure 8 and balance the forces at the shown cross section, we get:

2 σ $_{hoop}$ k t_ring L_ring + 2 L σ $_{hoop}$ t_ring = 2 (Pr) r_ring L…………………………..(30)

Solving for σ $_{hoop}$:

$$\sigma_{hoop} = \frac{P_r Lr}{t_{ring}(L + kL_{ring})}$$ …………………………………………………………………………(31)

where:
t_ring is the thickness of each ring
k is the number of rings
L_ring is the length of each ring

The axial stress is calculated from eq. (29) and the ratio of axial stress and the maximum allowable stress from eq. (8); and the hoop stress is calculated from eq. (31) and the ratio of the hoop stress and the maximum stress from eq. (9) by implementing the Matlab program (appendix G) for maximum number of stiffeners (55) and maximum area of

stiffener (2.5 in^2) and maximum thickness (6.25 mm) for both layers and (3) rings each with thickness of (4.5 mm) and length of (1.5 m) to get:

$\sigma_{axial} = 3.9196 \times 10^8$ Pascal

And:

$(\sigma_{allaw\text{-}stress} / \sigma_{axial}) = 1.2833$

And:

$\sigma_{hoop} = 4.7263 \times 10^8$ Pascal

And:

$(\sigma_{allaw\text{-}stress} / \sigma_{hoop}) = 1.0642$

And:

Structure weight % = 107.44 %

And displacement percent of total length (L) to be:

Disp. % = 1.0185. it is ok.

From above analysis, the design is safe with respect to axial stress with a factor of safety of (1.2833) and it is safe with respect to hoop stress with a factor of safety of (1.0642), which means that the wall is supported enough to carry the axial stress and the hoop stress, so our first criterion in design has been satisfied. However, the weight of this suggested design is too much (107.44 % of the total weight); so we need now to consider our second criterion which is designing for minimum possible weight. By playing with different parameters in the problem like the area of stiffener, the number of stiffeners, the thickness of both layers, the number of rings and the thickness of each ring; the design was optimized for the best possible weight by considering the following changes.

Table 5. Level two optimized design data

Thickness of outer layer	6.25 mm
Thickness of inner layer	6.25 mm
Area of each stiffener	2.5 in^2
Number of stiffeners	19
Number of rings	3
Length of each ring	1.5 m
Thickness if each ring	4.5 mm

After we optimized the design, the final results are:

Table 6. Level two design final results

($\sigma_{allaw\text{-}stress}$ / σ_{axial})	1.0160
($\sigma_{allaw\text{-}stress}$ / σ_{hoop})	1.0642
Structure weight %	86.44 %
Displacement %	1.0242 %

5. CONCLUSION

The paper was devoted to design a rocket considering to levels. In the first level, the rocket was assumed as one dimensional beam. In the second level, the rocket was assumed as a cylindrical shell. The main goal of design is to build the rocket with enough strength to carry the stresses (strength criterion) and that was achieved. The second goal of the project was to minimize the structure weight as much as possible to reach a limit of 20 % maximum of the total weight but that was not achieved and the results were very far of this limit (for first level = 53.7085 %, for second level = 86.44 %) which gives an indication that this design problem is not feasible under the given conditions. Of course we can minimize the structure weight to some lower values if we ignore our logical assumption that we have made of (0.25 inch = 6.25 mm) as maximum thickness of a layer; if we go beyond that by assuming thicker thickness of layer for example (13 mm), the results will be safer and we will lose some weight as shown in table 7 (Appendix H).

Table 7. Level one for new design

$(\sigma_{\text{allaw-stress}} / \sigma_{\text{axial}})$	1.0295
$(\sigma_{\text{allaw-stress}} / \sigma_{\text{hoop}})$	7.8468
Structure weight %	34.3062 %
Displacement %	0.6824 %

If we do same thing in level two and ignore our logical assumption that we have made of (0.25 inch = 6.25 mm) as maximum thickness of a layer; if we go beyond that by assuming thicker thickness of layer for example (20 mm), the results will be safer and we will lose some weight as shown in table 8 (Appendix I).

Table 8. Level two for new design

$(\sigma_{\text{allaw-stress}} / \sigma_{\text{axial}})$	1.075
$(\sigma_{\text{allaw-stress}} / \sigma_{\text{hoop}})$	2.0120
Structure weight %	52.7788 %
Displacement %	0.6548 %

From tables 7 and 8 it is clear that there was a huge decrease in weight (about 63.8 % of the weight structure was decreased for level one and about 61 % of the weight structure was decreased for level two) by implementing this simple design.

➔ Comments:

➔ The simple design mentioned above is better from all aspects, it is safer and the structure is lighter and it is simpler in manufacturing. The only problem is that the thickness is large and it is not logical in general but finding a layer with that thickness is not a big deal and it can exist.

➔ If we keep our logical assumption with maximum thickness of 0.25 inch, then we conclude the following:

- ➢ This design is not a good design or we can say that this design problem is not feasible under the given conditions.
- ➢ To be feasible, we modify the conditions of the problem like using stronger material than the used material (aluminum 7075 T6) e.g. titanium. Or we can decrease the pressurization of the fuel or simply we use a solid or liquid fuel. Or we can modify the geometry of the rocket like increasing the diameter of the rocket.
- ➢ There is no unique design for this problem and according to some simple changes as mentioned above we may come up with a good design.

However, A great knowledge was earned from this project. And high percentage of the course topics was included in this paper.

Finally for us we thank Allah for all the success in doing this paper and the success in applying the principles and knowledge of this course and contribute them to related practical beneficial application in our daily life. It was very powerful tool in learning and it helped us a lot in understanding the course contents. Lastly, we thank the person who was behind this work and who spent some of his valuable time and effort for giving us all support and great help **Dr. Wael Abdulrahman** .

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4- http://www.members.optusnet.com.au/ncrick/converters/pressure.html

5- **Dr. Wael Abdulrahman**, KSA, KFUPM, Aerospace Engineering Department.

APPENDIX A

Level one (part 1) Matlab code:

```
clc
clear all
%%%% AA 7075 (T6)
MAX_STRESS = 503E6; %the maximum stress in pascal
E_psi = 10.5e6; % the Young Modulus in psi
DENSITY = 2.8E3; % in Kg/m3
P_psi = 20; % The Aerodynamic pressure difference in psi
L = 6; % The length of cylinderical part of the rocket in meter
D = 1; % The diameter of the rocket
r = D/2; % The radius of the rocket
Pr_bar = 100; % The fuel internal pressure in bar
g = 9.8; % The earth acceleration in m/s2
m = 2E3; % The mass of the missile in Kg/m3
T = 5*g*m; % The thrust force of the rocket
% The project objectives:

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%
 % To calculate the thickness of the rocket wall that     %
 % garantee the best design by adding stiffeners and rings %
 % if it is needed                      %
 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
  % FIRST LEVEL
  PRESS_CONV_1 = 6894.763; % The pressure conversion factor from psi to pascal
  PRESS_CONV_2 = 100E3; % The pressure conversion factor from bar to pascal
  E = E_psi * PRESS_CONV_1; % the Young Modulus in pascal
```

```
W = P_psi*PRESS_CONV_1*2*r; % The force intensity in N/m

P = P_psi*PRESS_CONV_1; % The Aerodynamic pressure difference in N/m2

Pr = Pr_bar*PRESS_CONV_2; % The fuel internal pressure in N/m2

F = W*L; % The aerodynamic force in N

 %HOOP_STRESS = Pr*D/(2*L*t)


% AXIAL_STRESS = abs (-(F*L/2)/I_cross - T/(2*pi*r*t))

 % To calculate the thickness:

% We solve for thickness in terms of principal stresses to get:

% thickness in cm due to axial stress is:

t_axial = (F*L + T*r^2)/(2*pi*r^3*MAX_STRESS)*100

% thickness in cm due to hoop stress is:

t_hoop = (Pr*D)/(2*L*MAX_STRESS)*100

I_cross = pi*r^3*t_axial; % The area moment of inertia for the cylidrical rocket

% For good design, the thicness must not not excced 0.25 inch = 0.625 cm

% From calculation:

  % we need to check the displacment for each section

% for acceptable displacement, it shoud'nt excced 5% of the length (L)

disp = abs(-162*W/(E*I_cross)) % the displacement due to the load

dis_percent_axial = disp * (100/L) % the disp % of the length (L)
```

APPENDIX B

Level one (part 2) Matlab code:

```matlab
% First level
% Part 2
clc
clear all
%%%% AA 7075 (T6)
MAX_STRESS = 503E6; %the maximum stress in pascal
DENSITY = 2.8E3; % in Kg/m3
E_psi = 10.5e6; % the Young Modulus in psi
P_psi = 20; % The Aerodynamic pressure difference in psi
L = 6; % The length of cylinderical part of the rocket in meter
D = 1; % The diameter of the rocket in m
r = D/2; % The radius of the rocket in m
Pr_bar = 100; % The fuel internal pressure in bar
g = 9.8; % The earth acceleration in m/s2
m = 2E3; % The mass of the missile in Kg/m3
T = 5*g*m; % The thrust force of the rocket
% The project objectives:

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 % To calculate the thickness of the rocket wall that     %
 % garantee the best design by adding stiffeners and rings %
 % if it is needed                              %

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%
   % FIRST LEVEL
   PRESS_CONV_1 = 6894.763; % The pressure conversion factor from psi to pascal
```

```matlab
    PRESS_CONV_2 = 100E3; % The pressure conversion factor from bar to pascal
    E = E_psi * PRESS_CONV_1; % the Young Modulus in pascal
    W = P_psi*PRESS_CONV_1*2*r; % The force intensity in N/m
    P = P_psi*PRESS_CONV_1; % The Aerodynamic pressure difference in N/m2
    Pr = Pr_bar*PRESS_CONV_2; % The fuel internal pressure in N/m2
    F = W*L; % The aerodynamic force in N
% I_cross = pi*r^3*t; % The area moment of inertia for the cylidrical rocket
    %HOOP_STRESS = Pr*D/(2*L*t)
    % AXIAL_STRESS = abs (-(F*L/2)/I_cross - T/(2*pi*r*t))
    % To calculate the thickness:
    % We solve for thickness in terms of principal stresses to get:
    % thickness in cm due to axial stress is:
    t_axial = (F*L + T*r^2)/(2*pi*r^3*MAX_STRESS)*100;
    % thickness in cm due to hoop stress is:
    t_hoop = (Pr*D)/(2*L*MAX_STRESS)*100;
    % For good design, the thicness must not not excced 0.25 inch = 0.625 cm
    % From calculation:
    % t_axial = 1.2628 cm which is very larg
    % t_hoop = 0.1657 cm which is ok
    % We need to add stiffeners to support the wall


                    %%%%%%%%%%%
% We will choose the thickness to be % 0.625 cm %
                    %%%%%%%%%%%
% whic is maximum thickness that could be assumed
    t=0.625E-2; % in m
    % We assume the area of each stiffner is 2.5 in^2:
% (where we have Z-shape stiffner with dimensions:
%  leght = 4 in, arms = 0.9in each and 0.431 in thicness)
    A_stiff = 2.5*(2.5E-2)^2; % in m^2
    I_skin = pi*r^3*t; % The area moment of inertia for the cylidrical rocket
```

```matlab
    n = 69 % The number of stiffeners(where max # of stiff. is 69)
    for i=1:n
    theta_deg(i) = 180/i;
    theta_rad(i) = theta_deg(i) * pi/180;
    Dis_stiff(i) = r*sin( theta_rad(i)); % The distance from each stiffenr to the middle
axis
     end
      Y = sum(Dis_stiff.^2); % The sum of all squre distances for stiffeners

 I_cross_with_add_stiff = I_skin + A_stiff * Y ;
   A_total=2*pi*r*t+n*A_stiff;
    AXIAL_STRESS_with_add_stiff =  (F*L/2)/I_cross_with_add_stiff + T/(A_total)
   ratio = MAX_STRESS/AXIAL_STRESS_with_add_stiff

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
   disp = abs(-162*W/(E*I_cross_with_add_stiff)) % the displacement due to the load
   dis_percent_axial = disp * (100/L) % the disp % of the length (L)




 % The displacement = 0.0774 m which is =  1.2892 % OF L
   % whic is acceptable
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

 % Weight Calcultion:
   Weight = DENSITY*(2*pi*r*t*L + n*A_stiff*L) % in kg/m^3
   % The structure weight percent of the total weight is:
   Weigt_percent = (Weight/m)*100
   % for good design, the structure weight percent shoudnt ecxceed
 % 30 %.
```

% but in this part structure weight percent is 106.3961% which is

% very huge.

    % From above analysis, the chosen area is larg, so we can not increase it any more

% and also the maximum number of stiffeneres was added but still we did't reach the

% save case, so a new design idea has to be made by adding an additional internal

% layer as we see in part 3.

APPENDIX C

Level one (part 3) Matlab code:

```
% First level
% Part 3
clc
clear all
%%%% AA 7075 (T6)
MAX_STRESS = 503E6; %the maximum stress in pascal
DENSITY = 2.8E3; % in Kg/m3
E_psi = 10.5e6; % the Young Modulus in psi
P_psi = 20; % The Aerodynamic pressure difference in psi
L = 6; % The length of cylinderical part of the rocket in meter
D = 1; % The diameter of the rocket in m
r_outer = D/2; % The radius of the rocket in m
 Pr_bar = 100; % The fuel internal pressure in bar
g = 9.8; % The earth acceleration in m/s2
m = 2E3; % The mass of the missile in Kg/m3
```

```
T = 5*g*m; % The thrust force of the rocket
% The project objectives:

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 % To calculate the thickness of the rocket wall that     %
 % garantee the best design by adding stiffeners and rings %
 % if it is needed                              %

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

 % FIRST LEVEL
   PRESS_CONV_1 = 6894.763; % The pressure conversion factor from psi to pascal
   PRESS_CONV_2 = 100E3; % The pressure conversion factor from bar to pascal
   E = E_psi * PRESS_CONV_1; % the Young Modulus in pascal
   W = P_psi*PRESS_CONV_1*2*r_outer; % The force intensity in N/m
   P = P_psi*PRESS_CONV_1; % The Aerodynamic pressure difference in N/m2
   Pr = Pr_bar*PRESS_CONV_2; % The fuel internal pressure in N/m2
   F = W*L; % The aerodynamic force in N
 % I_cross = pi*r^3*t; % The area moment of inertia for the cylidrical rocket
   %HOOP_STRESS = Pr*D/(2*L*t)
   % AXIAL_STRESS = abs (-(F*L/2)/I_cross - T/(2*pi*r_outer*t))

   % To calculate the thickness:
   % We solve for thickness in terms of principal stresses to get:
   % thickness in cm due to axial stress is:

 t_axial = (F*L + T*r_outer^2)/(2*pi*r_outer^3*MAX_STRESS)*100;
   % thickness in cm due to hoop stress is:
   t_hoop = (Pr*D)/(2*L*MAX_STRESS)*100;
   % For good design, the thicness must not not excced 0.25 inch = 0.625 cm
   % From calculation:
   % t_axial = 1.2628 cm which is very larg
   % t_hoop = 0.1657 cm which is ok
   % We need to add stiffeners to support the wall
                    %%%%%%%%%%%
 % We will choose the thickness to be % 0.6 cm %
                    %%%%%%%%%%%

 t_outer=0.625E-2; % in m
    t_inner=0.625E-2; % in m
    stiff_length = (4.0+2*0.431) * (2.5E-2) % The length of each siffener in m
    r_inner = (D/2)-(stiff_length + t_outer); % The inner radius in m

 % We assume the area of each stiffner is 2.5 in^2:
 % (where we have Z-shape stiffner with dimensions:
 %  leght = 4 in, arms = 0.9in each and 0.431 in thicness)
```

```matlab
    A_stiff = 2.5*(2.5E-2)^2; % in m^2
    I_skin_outer = pi*r_outer^3*t_outer; % The area moment of inertia for outer skin
    I_skin_inner = pi*r_inner^3*t_inner; % The area moment of inertia for inner skin

 n = 19 % The number of stiffeners(where max # of stiff. is 55)

 for i=1:n
    theta_deg(i) = 180/i;
    theta_rad(i) = theta_deg(i) * pi/180;

  Dis_stiff(i) = r_outer*sin( theta_rad(i)); % The distance from each stiffenr to the
middle axis

end

  Y = sum(Dis_stiff.^2); % The sum of all squre distances for stiffeners

 I_cross_with_add_stiff_add_lay = I_skin_outer + I_skin_inner + A_stiff * Y ;
   A_total=2*pi*r_outer*t_outer +  2*pi*r_inner*t_inner + n*A_stiff;

    AXIAL_STRESS_with_add_stiff_add_lay =  (F*L/2)/I_cross_with_add_stiff_add_lay
+ T/(A_total);

 ratio = MAX_STRESS/AXIAL_STRESS_with_add_stiff_add_lay




%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

 disp = abs(-162*W/(E*I_cross_with_add_stiff_add_lay)) % the displacement due to the
load

 dis_percent_axial = disp * (100/L) % the disp % of the length (L)



 % From above analysis, the chosen area of each stiffnern was 2.5 in.
 % and the number of stiffeneres were 16.
 % and we reached the safe case with this design with the following:

 % factor of afety of stress =  1.0028


 % The displacement =  0.0621 m which is =  1.0358 % OF L
```

```
% whic is acceptable


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

 % Weight Calcultion:

 Weight  =  DENSITY*(2*pi*r_inner*t_inner*L  +  2*pi*r_outer*t_outer*L  +
n*A_stiff*L) % in kg/m^3

 % The structure weight percent of the total weight is:

 Weigt_percent = (Weight/m)*100

 % for good design, the structure weight percent shoudnt ecxceed
 % 30 %
 % but for this design, the percent = 49.3105 % of the total weight
 % which is the best optimized result we got after trying different
 % options
```

APPENDIX D

Level two (part 1) Matlab code:

```
% Second level
% Part 1
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%
% In this part, we approximate the fuselage as a cylindrical   %
% shell supported at the adaptor plate               %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clc
clear all
%%%% AA 7075 (T6)
```

```matlab
MAX_STRESS = 503E6; %the maximum stress in pascal
DENSITY = 2.8E3; % in Kg/m3
E_psi = 10.5e6; % the Young Modulus in psi
P_psi = 20; % The Aerodynamic pressure difference in psi
L = 6; % The length of cylinderical part of the rocket in meter
D = 1; % The diameter of the rocket
r = D/2; % The radius of the rocket
Pr_bar = 100; % The fuel internal pressure in bar
g = 9.8; % The earth acceleration in m/s2
m = 2E3; % The mass of the missile in Kg/m3
T = 5*g*m; % The thrust force of the rocket
% The project objectives:

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 % To calculate the thickness of the rocket wall that      %
 % garantee the best design by adding stiffeners and rings %
 % if it is needed                                        %

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
  % SECOND LEVEL
  PRESS_CONV_1 = 6894.763; % The pressure conversion factor from psi to pascal
  PRESS_CONV_2 = 100E3; % The pressure conversion factor from bar to pascal
  E = E_psi * PRESS_CONV_1; % the Young Modulus in pascal
  W = P_psi*PRESS_CONV_1*2*r; % The force intensity in N/m
  P = P_psi*PRESS_CONV_1; % The Aerodynamic pressure difference in N/m2
  Pr = Pr_bar*PRESS_CONV_2; % The fuel internal pressure in pascal
  F = W*L; % The aerodynamic force in N
  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
  N_theta = - Pr*r;
  % N_x = -T*L/(2*pi*r*t)
    % To calculate the thickness:
```

```matlab
t_hoop = Pr*D/(2*MAX_STRESS)*100 % thicness in cm

t_axial = sqrt((T*L)/(2*pi*r*MAX_STRESS))*100  % thicness in cm

I_cross = pi*r^3*t_axial; % The area moment of inertia for the cylidrical rocket

   % For good design, the thicness must not not excced 0.25 inch = 0.625 cm

  % From calculation:

  % t_axial = 1.929 cm which is very larg

 % t_hoop = 0.9940 cm which is very larg

  % So, We need to add stiffeners and rings to support the wall


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%




   % we need to check the displacment for each section

  % for acceptable displacement, it shoud'nt excced 5% of the length (L)

  disp = abs(-162*W/(E*I_cross)) % the displacement due to the load

dis_percent_axial = disp * (100/L) % the disp % of the length (L)
```

APPENDIX E

Level two (part 2) Matlab code:

```
% Second level
% Part 2
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% In this part, we approximate the fuselage as a cylindrical   %
% shell supported at the adaptor plate                %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clc
clear all
%%%% AA 7075 (T6)
MAX_STRESS = 503E6; %the maximum stress in pascal
DENSITY = 2.8E3; % in Kg/m3
E_psi = 10.5e6; % the Young Modulus in psi
P_psi = 20; % The Aerodynamic pressure difference in psi
L = 6; % The length of cylinderical part of the rocket in meter
D = 1; % The diameter of the rocket in m
r = D/2; % The radius of the rocket in m
```

```matlab
Pr_bar = 100; % The fuel internal pressure in bar

g = 9.8; % The earth acceleration in m/s2

m = 2E3; % The mass of the missile in Kg/m3

T = 5*g*m; % The thrust force of the rocket

% The project objectives:

 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

 % To calculate the thickness of the rocket wall that     %

 % garantee the best design by adding stiffeners and rings %

 % if it is needed                            %


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

     PRESS_CONV_1 = 6894.763; % The pressure conversion factor from psi to pascal

  PRESS_CONV_2 = 100E3; % The pressure conversion factor from bar to pascal

  E = E_psi * PRESS_CONV_1; % the Young Modulus in pascal

  W = P_psi*PRESS_CONV_1*2*r; % The force intensity in N/m

  P = P_psi*PRESS_CONV_1; % The Aerodynamic pressure difference in N/m2

  Pr = Pr_bar*PRESS_CONV_2; % The fuel internal pressure in N/m2

  F = W*L; % The aerodynamic force in N

    % We need to add stiffeners to support the wall


             %%%%%%%%%%%%
 % We will choose the thickness to be % 0.6 cm %
             %%%%%%%%%%%%


  % whic is maximum thickness that could be assumed


  t=0.625E-2; % in m

     % We assume the area of each stiffner is 2.5 in^2:

  % (where we have Z-shape stiffner with dimensions:

  % leght = 4 in, arms = 0.9in each and 0.431 in thicness)

    A_stiff = 2.5*(2.5E-2)^2; % in m^2
```

```matlab
I_skin = pi*r^3*t; % The area moment of inertia for the cylidrical rocket



n = 69 %  The number of stiffeners(where max # of stiff. is 69)
        for i=1:n
    theta_deg(i) = 180/i;


  theta_rad(i) = theta_deg(i) * pi/180;


  Dis_stiff(i) = r*sin( theta_rad(i)); % The distance from each stiffenr to the middle axis

end
    Y = sum(Dis_stiff.^2); % The sum of all squre distances for stiffeners


 I_cross_with_add_stiff = I_skin + A_stiff * Y ;


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


   N_x_with_add_stiff = T*L/(2*pi*r*t + n*A_stiff);
    AXIAL_STRESS_with_add_stiff = N_x_with_add_stiff / t;
   ratio = MAX_STRESS / AXIAL_STRESS_with_add_stiff
    % in this level 2, it is clear that the number of stiffeners is more
  % dominant in changing the stress than increasing the area which is
  % the reverse of what was there in the level 1 where the area of stiffener
  % was more dominant than incraesing the number of siffeners




%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
     disp = abs(-162*W/(E*I_cross_with_add_stiff)) % the displacement due to the load
```

```
    dis_percent_axial = disp * (100/L) % the disp % of the length (L)
      % The displacement =  0.0774 m which is =  1.2892 % OF L
     % whic is acceptable


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


 % Weight Calcultion:
   Weight = DENSITY*(2*pi*r*t*L + n*A_stiff*L) % in kg/m^3
   % The structure weight percent of the total weight is:
   Weigt_percent = (Weight/m)*100
   % for good design, the structure weight percent shoudnt ecxceed
  % 30 %.
 % but in this part structure weight percent is  106.3961% which is
 % very huge.




%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
   % From above analysis, the chosen area is larg, so we can not increase it any more
 % and also the maximum number of stiffeneres was added but still we did't reach
 % the save case,so a new design idea has to be made by adding an additional internal
layer as
 % we see in part 3.
```

APPENDIX F

Level two (part 3) Matlab code:

```
% Second level
% Part 3

```

```matlab
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% In this part, we approximate the fuselage as a cylindrical   %
% shell supported at the adaptor plate                         %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clc
clear all
%%%% AA 7075 (T6)
MAX_STRESS = 503E6; %the maximum stress in pascal
DENSITY = 2.8E3; % in Kg/m3
E_psi = 10.5e6; % the Young Modulus in psi
P_psi = 20; % The Aerodynamic pressure difference in psi
L = 6; % The length of cylinderical part of the rocket in meter
D = 1; % The diameter of the rocket in m
r_outer = D/2; % The radius of the rocket in m
Pr_bar = 100; % The fuel internal pressure in bar
g = 9.8; % The earth acceleration in m/s2
m = 2E3; % The mass of the missile in Kg/m3
T = 5*g*m; % The thrust force of the rocket
% The project objectives:
 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 % To calculate the thickness of the rocket wall that      %
 % garantee the best design by adding stiffeners and rings %
 % if it is needed                                         %
 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    PRESS_CONV_1 = 6894.763; % The pressure conversion factor from psi to pascal
  PRESS_CONV_2 = 100E3; % The pressure conversion factor from bar to pascal
  E = E_psi * PRESS_CONV_1; % the Young Modulus in pascal
  W = P_psi*PRESS_CONV_1*2*r_outer; % The force intensity in N/m
  P = P_psi*PRESS_CONV_1; % The Aerodynamic pressure difference in N/m2
  Pr = Pr_bar*PRESS_CONV_2; % The fuel internal pressure in N/m2
```

```matlab
  F = W*L; % The aerodynamic force in N
   % We need to add stiffeners to support the wall
                %%%%%%%%%%%
 % We will choose the thickness to be % 0.6 cm %
                %%%%%%%%%%%
   % whic is maximum thickness that could be assumed
 % for each layer


 t_outer=0.625E-2; % in m
   t_inner=0.625E-2; % in m
   stiff_length = (4.0+2*0.431) * (2.5E-2) % The length of each siffener in m
   r_inner = (D/2)-(stiff_length + t_outer); % The inner radius in m
    % We assume the area of each stiffner is 2.5 in^2:
 % (where we have Z-shape stiffner with dimensions:
 %  leght = 4 in, arms = 0.9in each and 0.431 in thicness)
   A_stiff = 2.5*(2.5E-2)^2; % in m^2
   I_skin_outer = pi*r_outer^3*t_outer; % The area moment of inertia for outer skin
   I_skin_inner = pi*r_inner^3*t_inner; % The area moment of inertia for inner skin
    n = 41 % The number of stiffeners(where max # of stiff. is 55)
   for i=1:n
   theta_deg(i) = 180/i;
   theta_rad(i) = theta_deg(i) * pi/180;
   Dis_stiff(i) = r_outer*sin( theta_rad(i)); % The distance from each stiffenr to the
middle axis
 end
   Y = sum(Dis_stiff.^2); % The sum of all squre distances for stiffeners


 I_cross_with_add_stiff_add_lay = I_skin_outer + I_skin_inner + A_stiff * Y ;


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```matlab
    N_x_with_add_stiff_add_lay  =  T*L/(2*pi*r_outer*  t_outer  +  n*A_stiff  +
2*pi*r_inner* t_inner);

    AXIAL_STRESS_with_add_stiff_add_lay = N_x_with_add_stiff_add_lay / (t_outer +
t_inner);

    ratio = MAX_STRESS / AXIAL_STRESS_with_add_stiff_add_lay

     % in this level 2, it is clear that the number of stiffeners is more
  % dominant in changing the stress than increasing the area which is
  % the reverse of what was there in the level 1 where the area of stiffener
  % was more dominant than incraesing the number of siffeners


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    disp = abs(-162*W/(E*I_cross_with_add_stiff_add_lay)) % the displacement due to
the load
   dis_percent_axial = disp * (100/L) % the disp % of the length (L)
     % From above analysis, the chosen area of each stiffnern was 2.5 in.
  % and the number of stiffeneres were 41.
  % and we reached the safe case with this design with the following:
   % factor of afety of stress =  1.0036
   % The displacement =   0.0604 m which is =  1.0075 % OF L
   % whic is acceptable


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
   % Weight Calcultion:
   Weight   =   DENSITY*(2*pi*r_inner*t_inner*L   +   2*pi*r_outer*t_outer*L   +
n*A_stiff*L) % in kg/m^3
   % The structure weight percent of the total weight is:
   Weigt_percent = (Weight/m)*100
   % for good design, the structure weight percent shoudnt ecxceed
  % 30 %
  % but for this design, the percent = 82 % of the total weight
  % which is the best optimized result we got after trying different
```

```
% options
```

APPENDIX G

Level two (part 4) Matlab code:

```
% Second level
% Part 4
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% In this part, we approximate the fuselage as a cylindrical   %
% shell supported at the adaptor plate                %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% we add ring to support the wall against the hoop stress
clc
clear all
%%%% AA 7075 (T6)
MAX_STRESS = 503E6; %the maximum stress in pascal
DENSITY = 2.8E3; % in Kg/m3
E_psi = 10.5e6; % the Young Modulus in psi
P_psi = 20; % The Aerodynamic pressure difference in psi
L = 6; % The length of cylinderical part of the rocket in meter
D = 1; % The diameter of the rocket in m
r_outer = D/2; % The radius of the rocket in m
Pr_bar = 100; % The fuel internal pressure in bar
g = 9.8; % The earth acceleration in m/s2
m = 2E3; % The mass of the missile in Kg/m3
T = 5*g*m; % The thrust force of the rocket
```

```matlab
% The project objectives:
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
To calculate the thickness of the rocket wall that     %
% garantee the best design by adding stiffeners and rings %
% if it is needed                          %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
   PRESS_CONV_1 = 6894.763; % The pressure conversion factor from psi to pascal
 PRESS_CONV_2 = 100E3; % The pressure conversion factor from bar to pascal
 E = E_psi * PRESS_CONV_1; % the Young Modulus in pascal
 W = P_psi*PRESS_CONV_1*2*r_outer; % The force intensity in N/m
 P = P_psi*PRESS_CONV_1; % The Aerodynamic pressure difference in N/m2
 Pr = Pr_bar*PRESS_CONV_2; % The fuel internal pressure in N/m2
 F = W*L; % The aerodynamic force in N
   % We need to add stiffeners to support the wall
                  %%%%%%%%%%%
% We will choose the thickness to be % 0.625 cm %
                  %%%%%%%%%%%
 % whic is maximum thickness that could be assumed
% for each layer

 t_outer=0.625E-2; % in m
   t_inner=0.625E-2; % in m
   stiff_length = (4.0+2*0.431) * (2.5E-2) % The length of each siffener in m
   t_ring = 0.45e-2; % the thickness of each ring in m
   r_inner = (D/2)-(stiff_length + t_outer)-t_ring; % The inner radius in m
     r_ring = r_inner + t_ring; % the raduis of each ring
    k= 3  % the number of rings
    L_ring = 1.5% the length of each ring
        % We assume the area of each stiffner is 2.5 in^2:
 % (where we have Z-shape stiffner with dimensions:
 %  leght = 4 in, arms = 0.9in each and 0.431 in thicness)
```

```matlab
    A_stiff = 2.5*(2.5E-2)^2; % in m^2

    I_skin_outer = pi*r_outer^3*t_outer; % The area moment of inertia for outer skin

    I_skin_inner = pi*r_inner^3*t_inner; % The area moment of inertia for inner skin

     n = 39 % The number of stiffeners(where max # of stiff. is 55)

    for i=1:n

    theta_deg(i) = 180/i;

    theta_rad(i) = theta_deg(i) * pi/180;

    Dis_stiff(i) = r_outer*sin( theta_rad(i)); % The distance from each stiffenr to the
middle axis

  end

    Y = sum(Dis_stiff.^2); % The sum of all squre distances for stiffeners


 I_cross_with_add_stiff_add_lay = I_skin_outer + I_skin_inner + A_stiff * Y ;
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
       N_x_with_add_stiff_add_lay  =  T*L/(2*pi*r_outer*  t_outer  +  n*A_stiff  +
2*pi*r_inner* t_inner);

    AXIAL_STRESS_with_add_stiff_add_lay = N_x_with_add_stiff_add_lay / (t_outer
+ t_inner);

    HOOP_STRESS_with_add_ring = Pr*r_ring*L/(t_ring*(L+k*L_ring))

    ratio_axial = MAX_STRESS / AXIAL_STRESS_with_add_stiff_add_lay

    ratio_hoop = MAX_STRESS / HOOP_STRESS_with_add_ring

    % in this level 2, it is clear that the number of stiffeners is more

  % dominant in changing the stress than increasing the area which is

  % the reverse of what was there in the level 1 where the area of stiffener

  % was more dominant than incraesing the number of siffeners

        %%%%%%%%%%%%%%%%%%%%%%%%

    disp = abs(-162*W/(E*I_cross_with_add_stiff_add_lay)) % the displacement due to
the load

  dis_percent_axial = disp * (100/L) % the disp % of the length (L)

    % From above analysis, the chosen area of each stiffnern was 2.5 in.

 % and the number of stiffeneres were 41.
```

```
% and we reached the safe case with this design with the following:
% factor of afety of stress =  1.0036
 % The displacement =   0.0604 m which is =  1.0075 % OF L
 % whic is acceptable
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 % Weight Calcultion:
 Weight   =   DENSITY*(2*pi*r_inner*t_inner*L   +   2*pi*r_outer*t_outer*L   +
n*A_stiff*L + k*L_ring*2*pi*r_ring*t_ring) % in kg/m^3
 % The structure weight percent of the total weight is:
 Weigt_percent = (Weight/m)*100
% for good design, the structure weight percent shoudnt ecxceed
% 30  % but for this design, the percent = 82 % of the total weight
% which is the best optimized result we got after trying different options
```

APPENDIX H

New design (level one) Matlab code:

```
% NEW DESIG (LEVEL 1)
clc
clear all
%%%% AA 7075 (T6)
MAX_STRESS = 503E6; %the maximum stress in pascal
E_psi = 15.5e6; % the Young Modulus in psi
DENSITY = 2.8E3; % in Kg/m3
P_psi = 20; % The Aerodynamic pressure difference in psi
L = 6; % The length of cylinderical part of the rocket in meter
D = 1; % The diameter of the rocket
r = D/2; % The radius of the rocket
Pr_bar = 100; % The fuel internal pressure in bar
g = 9.8; % The earth acceleration in m/s2
m = 2E3; % The mass of the missile in Kg/m3
T = 5*g*m; % The thrust force of the rocket
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
PRESS_CONV_1 = 6894.763; % The pressure conversion factor from psi to pascal
    PRESS_CONV_2 = 100E3; % The pressure conversion factor from bar to pascal
```

```
    E = E_psi * PRESS_CONV_1; % the Young Modulus in pascal
    W = P_psi*PRESS_CONV_1*2*r; % The force intensity in N/m
    P = P_psi*PRESS_CONV_1; % The Aerodynamic pressure difference in N/m2
    Pr = Pr_bar*PRESS_CONV_2; % The fuel internal pressure in N/m2
    F = W*L; % The aerodynamic force in N
  t = 13e-3 % in m
```

```
I_cross = pi*r^3*t; % The area moment of inertia for the cylidrical rocket
% for acceptable displacement, it shoud'nt excced 5% of the length (L)
HOOP_STRESS = Pr*D/(2*L*t)
AXIAL_STRESS = (F*L/2)/I_cross + T/(2*pi*r*t)
ratio_axial = MAX_STRESS/AXIAL_STRESS
ratio_hoop = MAX_STRESS/HOOP_STRESS
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
disp = abs(-162*W/(E*I_cross)) % the displacement due to the load
dis_percent_axial = disp * (100/L) % the disp % of the length (L)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Weight Calcultion:
Weight = DENSITY*(2*pi*r*t*L) % in kg/m^3
% The structure weight percent of the total weight is:
Weigt_percent = (Weight/m)*100
```

APPENDIX I

New design (level two) Matlab code:

```
% NEW DESIG (LEVEL 2)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% In this part, we approximate the fuselage as a cylindrical   %
% shell supported at the adaptor plate                 %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clc
clear all
%%%% AA 7075 (T6)
MAX_STRESS = 503E6; %the maximum stress in pascal
DENSITY = 2.8E3; % in Kg/m3
E_psi = 10.5e6; % the Young Modulus in psi

P_psi = 20; % The Aerodynamic pressure difference in psi
L = 6; % The length of cylinderical part of the rocket in meter
D = 1; % The diameter of the rocket
r = D/2; % The radius of the rocket
Pr_bar = 100; % The fuel internal pressure in bar
g = 9.8; % The earth acceleration in m/s2
m = 2E3; % The mass of the missile in Kg/m
T = 5*g*m; % The thrust force of the rocket
PRESS_CONV_1 = 6894.763; % The pressure conversion factor from psi to pascal
PRESS_CONV_2 = 100E3; % The pressure conversion factor from bar to pascal
E = E_psi * PRESS_CONV_1; % the Young Modulus in pascal

W = P_psi*PRESS_CONV_1*2*r; % The force intensity in N/m
P = P_psi*PRESS_CONV_1; % The Aerodynamic pressure difference in N/m2
```

```matlab
        Pr = Pr_bar*PRESS_CONV_2; % The fuel internal pressure in pascal
        F = W*L; % The aerodynamic force in N

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

        t = 20e-3 % in m
      I_cross = pi*r^3*t; % The area moment of inertia for the cylidrical rocket

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
        N_x = T*L/(2*pi*r*t);
       N_theta =  Pr*D/2;
        AXIAL_STRESS = N_x / t;
        HOOP_STRESS = N_theta / t
      ratio_axial = MAX_STRESS/AXIAL_STRESS
      ratio_hoop = MAX_STRESS/HOOP_STRES
       %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
      % we need to check the displacment for each section
      % for acceptable displacement, it shoud'nt excced 5% of the length (L)
      disp = abs(-162*W/(E*I_cross)) % the displacement due to the load
      dis_percent_axial = disp * (100/L) % the disp % of the length (L)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
        % Weight Calcultion:
      Weight = DENSITY*(2*pi*r*t*L) % in kg/m^3
      % The structure weight percent of the total weight is
      Weigt_percent = (Weight/m)*100
```