ENG4014 Aerospace Design Project 4M
Interim Report
Group 8

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Design Analysis and Feasibility

4.1 Safety

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4.2 Calculating new mass (Rafał)

The mass of the airplane has to be calculated in order to determine how much retardant the aircraft can take. The Maximum Payload Mass (MPM) of the aircraft prior to any modifications was calculated by subtracting the Operating Mass Empty (OME) from the Maximum Zero-Fuel Mass (MZFM). To further increase the maximum payload of the aircraft, the cabin components listed in the Table in appendix A were stripped down and removed, this further decreased the mass of the OME. The mass of the OME increases with the installation of the firefighting components listed in Table 4.1, this has the effect of reducing the total MPM. Table 3 illustrates this process.

Component	Mass of Components [kg]
Retardant Tank and Piping	2201.68
Crew Weight	180
Tank Supports	180
Total:	2561.68

Table 4.1: Components added to the aircraft

	Avro RJ100 original	Stripped cabin	Firefighter
OME [kg]	25600	18984	21546
MZFM [kg]	37875	37875	37875
Cabin Components [kg]	N/A	6616	6616
Firefighting systems [kg]	N/A	N/A	2561.68
MPM [kg]	12275	18891	16329.32

Table 4.2

4.3 Center of gravity (Fraser and Rafał)

Seeing as the RJ100 is originally a commercial aircraft, converting it to a firefighter aircraft would result in a lot of unnecessary weight, for example passenger seats, kitchen and cabin bins ect. This allows the plane to carry more retardant, meaning better performance for this specific application. However, by removing the excess weight, the center of gravity is shifted and thus will need to be recalculated. The RJ100 has an acceptable safe range for the center of gravity as a percentage of the mean aerodynamic chord is 28% to 44%. The plane cannot fly safely if the value of the center of gravity along the x-axis of the plane is outwith this range. The center of gravity also has to remain within this range before, during and after the ejection of retardant.

4.3.1 Method of Analysis

The process of calculating center of gravity is relatively trivial but can be time consuming if done if done by hand, especially in this case where there are lots of components being removed, greatly altering the mass. Using MATLAB instead of hand calculations greatly simplifies the process of changing individual values such as the mass, or the position of objects in the plane, to help achieve the safe center of gravity position.

According to Baker & Haynes (2020) the formula for the x,y and z value of the center of gravity are shown in the equation 4.1:

$$\bar{x} = \frac{\sum \bar{x}_i m_i}{\sum m_i} \; \bar{y} = \frac{\sum \bar{y}_i m_i}{\sum m_i} \; \bar{z} = \frac{\sum \bar{z}_i m_i}{\sum m_i} \tag{4.1}$$

The aircraft mass and center of gravity, before excess weight removal, can effectively be represented in equation 4.1 as a particle with known mass and position. By representing the aircraft in this way, the center of gravity after the removal of unnecessary weight can be calculated. The mass of the components to be removed are taken as negative, removing them from the original total mass. This method for calculating the new center of mass position for the x axis of the plane is shown in the equation 4.2

$$\bar{x}_{plane_{new}} = \frac{\sum_{i=1}^{n} m_i x_i - \sum_{j=1}^{m} m_j x_j}{\sum_{i=1}^{n} m_i - \sum_{j=1}^{m} m_j} \tag{4.2}$$

Where:
n = number of items total
m = number of items to be removed

Substituting:

$$\sum_{i=1}^{n} m_i x_i = m_{plane} \bar{x}_{plane} \tag{4.3}$$

and:

$$\sum_{i=1}^{n} m_i = m_{plane} \tag{4.4}$$

Into equation 4.2:

$$\bar{x}_{plane_{new}} = \frac{m_{plane} x_{plane} - \sum_{j=1}^{m} m_j x_j}{m_{plane} - \sum_{j=1}^{m} m_j} \tag{4.5}$$

4.3.2 Matlab code

Applying the method above, code was written in MATLAB to to calculate the new cg position through implementing equation 4.5, see appendix B.

The data for the components to be removed were formatted into an excel file named "aircraftitems.xlsx" and then imported to be represented in the variable "Data". This data included each component's mass and it's center of gravity position. These position's were taken relative to the standard aircraft axis with the origin at the nose of the aircraft. Importing the data like this makes it easier to tweak values of masses and position of items on the aircraft to find the desired center of gravity position.

4.3.3 Consequence of result of code on design decisions

The position of the tank along the aircraft was tweaked in order to find a result from the MATLAB code that allowed the position of the center of gravity in the x axis was within the safe limits of 28% to 44% of the mean aerodynamic chord. The value of the x position of the center of gravity of the tank was found to be 16m away from the nose of the aircraft. This position of the tank results in a center of gravity position of the airplane of 44% of the aerodynamic chord with the tank full of retardant and 28% when the tank is full.

4.4 Delivery release system and Tank Pressurisation (Anton and Fraser)

Delivery system ect... here

4.5 Structural Support (Matthew)

4.5.1 Floor structure

To support the retardant tank in the aircraft selected, we initially tested the option of removing the floor of the aircraft cabin. This would release additional weight for retardant and would allow for free placement of the tank anywhere in the cabin. Through further research, however, it was discovered that the floor section of the cabin provides extra support for the frame which when removed could increase the likelihood of failure in our aircraft. Also, the floor structure is lightweight due to the use of a honeycomb structure cast from a high-density composite material as shown in Figure (Honeycomb structure in aircraft flooring). Thus, the removal will not reduce the weight significantly enough to remove it and suffer from the reduced structural strength.

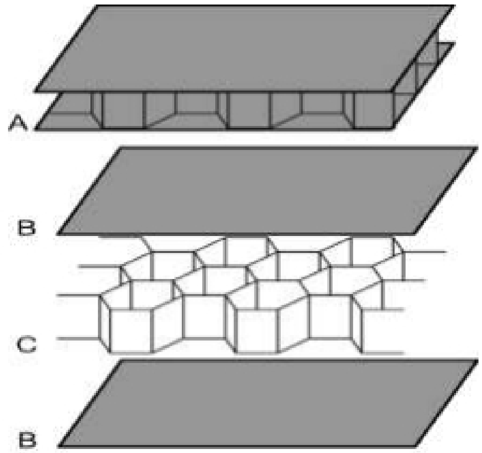

Figure 4.1: Honeycomb structure in aircraft flooring, Ganesh et al. (2015)

As the floor panel is to be kept, further structural support for the placement of the tank was considered. A consideration could be to change the material of the floor beams from aluminum to CFRP (Carbon Fibre Reinforced Plastics), these have a lower weight whilst having higher strength and durability compared to an Aluminum floor.

4.5.2 Beam calculations

The final length of the tank was estimated using a standard radius of 1.03m which would suitably fit in the aircraft cabin and using a length of 6.55m which resulted in a 15.14m^3 volume tank. To support the tank four webs were designed to calculate the resulting stresses and loads, these webs were equally spaced with one at each end as shown in Figure 4.2

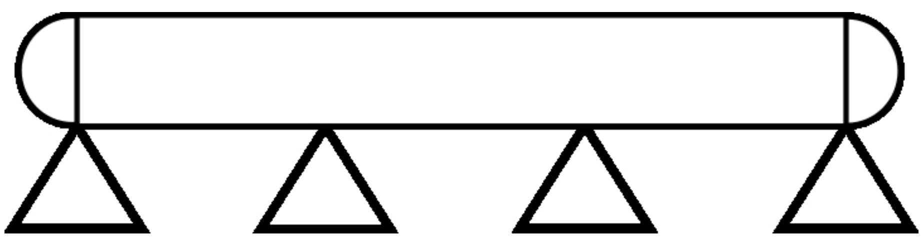

Figure 4.2: Tank supported by four equally spaced webs

For the initial calculations the web shape is simplified as shown in figure 4.3 which will be further refined using FE analysis to gather an accurate final value for the stress distribution. The structure is split into 3 sections as shown and the data representing the sections is displayed in Table 4.3

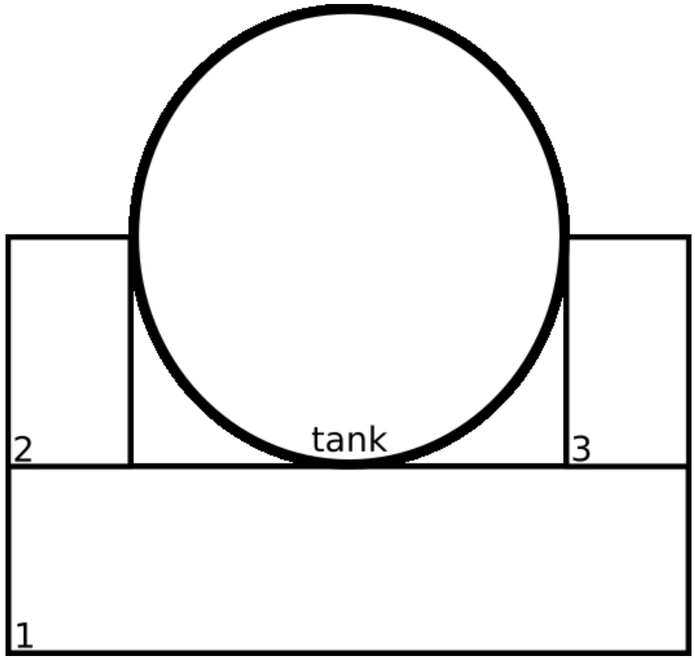

Figure 4.3: Simplified web structure

Sections	Length(m)	Height (m)
1	2.06	0.27
2	0.2	1.17
3	9.2	1.17

Table 4.3: Web Structure geometry dimensions

4.5.3 Stress distribution

The formulae used in these calculations are all standard structural equations as shown to allow for initial estimates:

$$I_{yy} = \frac{1}{12}db^3 + A(\bar{x} - x_i)^2$$

$$Z_e = \frac{I_{yy}}{(y_{top} - \bar{y})}$$

$$Z_{e_{bottom}} = \frac{I_{yy}}{(y_0 - \bar{y})}$$

$$R_y = \frac{FL}{4} \tag{4.6}$$

$$M_{C/D} = LR_y - \frac{4}{18}FL^2$$

$$Stress = \sigma = \frac{M}{Z_e}$$

$$Load = \sigma \times Length \times Thickness$$

The tank is treated as a uniformly distributed load along the length of the supports and calculations were made at the supports located centrally as these will have the maximum value of stress. The calculations can be seen in appendix C.

From these simple calculations a stress distribution plot was produced (Figure 4.4) allowing us to analyse the initial feasibility of a four-support system and estimate the total load.

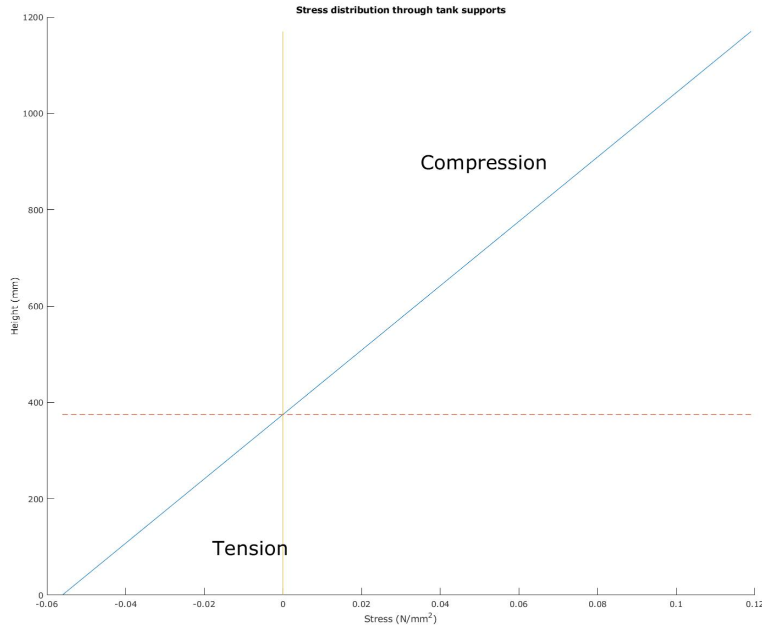

Figure 4.4: Stress distribution on central supports

We will need to consider the maximum stress at the bottom of the support to ensure the floor panels in the aircraft have the structural strength to withstand this load. To allow for enough space between the supports the thickness was estimated as $0.1m$ which will add $277.6kg$ to the overall weight of the aircraft reducing the maximum payload achievable slightly. This value of weight is if the material chosen is aluminum with a density of $2710kg/m^3$, chosen as it is regularly used in structural support of aircraft due to its high material strength properties. Using the stress displayed in figure 4.4 the total load at the bottom of each support is 18.52kN which will need to be considered when the supports are fixed to the floor. The maximum stress value is equivalent to $0.12MPa$ at the top of the structure so the chance of failure is miniscule as shown in the stress-strain curve of aluminium in figure 4.5. This value of stress is a considerable distance from failure and even yield so the number of supports could be reduced to save weight in further analysis.

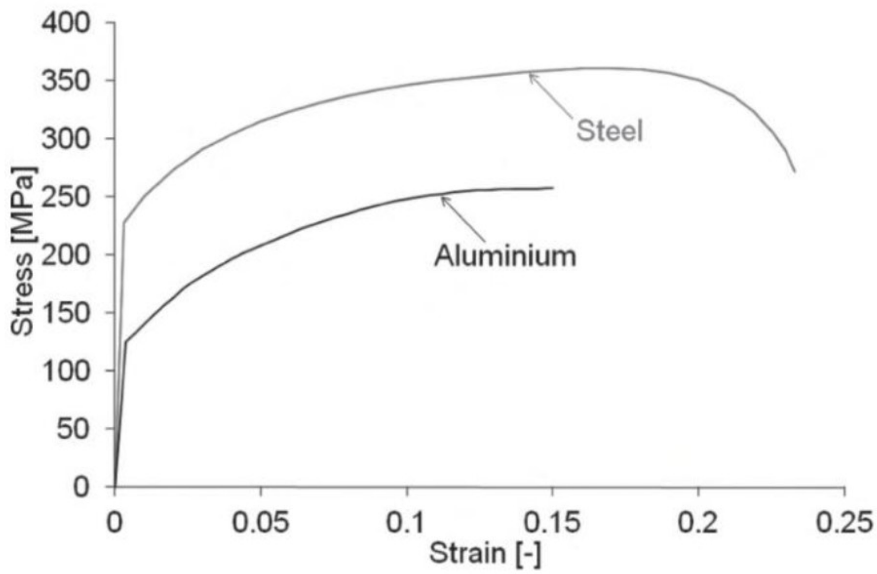

Figure 4.5: Stress-strain curve for steel and aluminum, Liu et al. (2013)

Chapter 5

Draft Plans for the Preliminary Design Stage

Draft Plans for the Preliminary Design Stage here

Chapter 6

Conclusions

Conlusions here

Chapter 7

Project Plan

project plan here

References

Baker, D. W., & Haynes, W. (2020). Engineering statics: Open and interactive.

Ganesh, B., Kumar, B. V., & Muppala, D. (2015). Design and structural analysis of aircraft floor panel. *International Journal of Advanced Engineering and Global Technology*, *3*(12), 1451–1460.

Liu, B., Villavicencio, R., & Soares, C. G. (2013). Failure characteristics of strength-equivalent aluminium and steel plates in impact conditions. *Analysis and Design of Marine Structures, vol., no*, 167.

Appendix A

Components to remove

Component	Mass of Components [kg]
Passenger Seats(triple)	1584
Passenger Seat(double)	54
Toilet	500
Kitchen	138
Insulation	250
Blankets	135
Carpeting	250
Ceiling	600
Curtains	50
Ducting	450
Elastomers	250
Emergency Slides	260
Floor Panels	260
Floor Coverings	55
Life Rafts	345
Life Vests	150
Passenger Service Units	300
Cabin Bins	550
Pillows	35
Thermoplastic Parts	250
Wall Covering	50
Window Shades	100
Total:	6616

Appendix B

Center of gravity MATLAB code

```matlab
clc
clear
close all
format long g

Data = readtable("aircraft_items.xlsx"); %import data from excel file

starting_mass=37875; %starting mass in kg (Operating mass empty 25600)(Maximum zero fuel mass 37875)
absoulute_cog_to_nose=14 + 1.719; %distance from nose to the wing start + x_mgc

cg.x=-1*(absoulute_cog_to_nose+1.239056); % starting cg x position
cg.y=0; %starting cg y position
cg.z=0; %starting cg z position

%starting moment of inertia tensor values
I_convert=1.3558179619; %slug*ft^2 to kg/m

I.xx=533965*I_convert;
I.xy=0*I_convert;
I.xz=59261*I_convert;
I.yx=I.xy;
I.yy=607525*I_convert;
I.yz=0*I_convert;
I.zx=I.xz;
I.zy=I.yz;
I.zz=1019696*I_convert;

%calculating new cg
cg_sum.x=starting_mass*cg.x;
cg_sum.y=starting_mass*cg.y;
cg_sum.z=starting_mass*cg.z;

end_mass=starting_mass;

for i=1:1:height(Data)

    %extract mass,x,y and z values from file for object
    mass=Data{i,2};
    x=Data{i,3};
    y=Data{i,4};
    z=Data{i,5};

    %take away object mass
    end_mass=end_mass - Data{i,2};

    cg_sum.x=cg_sum.x - (mass*x);
    cg_sum.y=cg_sum.y - (mass*y);
    cg_sum.z=cg_sum.z - (mass*z);

end

%calculate new cg position
cg_new.x=cg_sum.x/end_mass;
cg_new.y=cg_sum.y/end_mass;
cg_new.z=cg_sum.z/end_mass;

%print new cg position
cg_new
%print new mass
end_mass

%calculate and print value of cg position in x axis as a fraction of the
%MAC
cg_from_mac = cg_new.x + absoulute_cog_to_nose;
```

```
fraction_of_mac = cg_from_mac / - 3.404
```

Appendix C

Structural MATLAB code

```
%Beam tank calculation
clc
clf
%element data
length1=2060;
height1=270;
length2=200;
height2=1170;
length3=200;
height3=1170;
thickness=200;
%area of each element
area1=length1*height1;
area2=length2*height2;
area3=length3*height3;
atotal=area1+area2+area3;

%individual cg values
ycg1=height1/2;
ycg2=height1+(height2/3);
ycg3=height1+(height3/3);
xcg1=(length1/2)+200;
xcg2=length2/2;
xcg3=(length3/2)+200+2000;
%total cg
ycg=((area1*ycg1)+(area2*ycg2)+(area3*ycg3))/atotal;
xcg=1200;
%2nd moments of inertia
inertia1=(((1/12)*length1^3*height1)+(area1*(xcg1-xcg)));
inertia2=(((1/12)*length2^3*height2)+(area2*(xcg2-xcg)));
inertia3=(((1/12)*length3^3*height3)+(area3*(xcg3-xcg)));

totalInertia=inertia1+inertia2+inertia3;

%tank data
length=6550;
F=(16623*9.81)/length;
supports=4;
sections=supports-1;
momentLength=0;
loadLength=0;


%Resultants
Ry=(F*length)/supports;

%Moment
Mmax=(Ry*length)-((F*length^2)*(4/18));

%stress positive downwards (compression)
ZEtop=totalInertia/(height2-ycg);
ZEbottom=totalInertia/(0-ycg);

stressTop=Mmax/ZEtop;
stressBottom=Mmax/ZEbottom;

totalweight=0.1*2710*(atotal*10^-6);
%total load with 0.1m thick alauminium
totalLoad=(stressBottom*(length1+length2+length3)*(thickness))/1000;
%plotting stress at top/bottom
%stress in compression at top
%stress in tension at bottom
x=[stressTop,stressBottom];
y=[height2,0];
```

```
xconstant=[0,0];
yconstant=[ycg,ycg];
hold on
%plot stress distribution
plot(x,y);
plot(x,yconstant,'--');
plot(xconstant,y);
hold off
ylabel('Height (mm)');
xlabel('Stress (N/mm^2)');
title('Stress distribution through tank supports')
txt = 'Compression';
t=text(0.035,900,txt);
t.FontSize=24;

txt2 = 'Tension';
m=text(-.018,100,txt2);
m.FontSize=24;
```