A Design Report for the Transportation Aircraft Designed in Aircraft Systems Design E3 with a Specific Focus on the Design Aspects Covered by the Author.

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Aircraft Systems Design E3

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Abstract

Some abstract yada yada yada

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3.1 Initial Weight Estimation

Once the aircraft concept had been completed and unanimously agreed to by the design team, the first task was to estimate the weights. As a reminder, the aircraft was designed to transport specialist cargo, such as medical supplies, and crew into disaster zones. To do this, the aircraft needs to:

1. Have a high payload weight fraction and,
2. Operate from short, improvised airfields.

Therefore, the aircraft must weigh as little as possible while generating as much lift as possible with its wings. The goal of this element of the design is to tackle the first of those two characteristics.

It is well known that there is a complex relationship between aircraft range and weight. Logically, two aircraft of identical design will need different amounts of fuel depending on the distance they intend to travel. Therefore, it was quickly decided that aircraft range would not be a factor of primary concern. The aircraft is designed to transport specialty cargo into areas in need of immediate help, and it would be exceptionally useful if help cannot arrive by other methods of transportation such as road, rail or sea. The aircraft only needs to operate relatively short distances to and from a central hub or distribution centre to deliver aid to a local population.

The following parameters must be known in order to complete the weight estimation:

1. Range (km)
2. Payload (Pax and Cargo)
3. Power to Weight (P/W) Ratio of the Engine (kW/kN)

4. Specific Fuel Capacity (SFC) of the Engine ((N/s)/kW)

5. Wing Aspect Ratio

6. Fuselage Diameter/Length

7. Weight per Pax (kg)

Since the aircraft aims to primarily deliver aid supplies rather than transport people, the parameters were slightly modified to account for pallets of cargo that are one cubic meter in size, each capable of carrying 500kg. In addition to the cargo, the aircraft still aims to transport a small number of passengers; this was decided to be seven people maximum.

The parameters related to the engine (P/W and SFC) were taken from known data for the engine selected to power the aircraft, specifically the Pratt and Whitney 127G. The mass of an average person was approximated to be 90kg, and the fuselage D/L was taken to be 0.13. The two parameters not yet discussed, aspect ratio and range, were the most changeable as the design process continued. In total, 10 different initial weight estimations were conducted, with different parameters, to settle on the most acceptable outcome, which will shortly be presented, but the final value for aspect ratio was taken to be 9, and range to be taken at 1000km (it was decided that this would be sufficient to transport supplies short distances into relief areas). Table 3.1 shows the final design values for weight estimation.

Table 3.1

Final values for weight estimation

Range	**Payload**		**P/W**	**SFC**	**Aspect Ratio**	**D/L**	**Payload Masses**	
km	Pax	Pallets	kW/kN	(N/s)kW			Pax (kg)	Pallets (kg)
1000	7	4	17.1	0.00076	9	0.13	90	500

Before estimating the aircraft's weight, the fuselage's length, breadth and depth can be estimated by the following equations, where x_p is the number of passengers and x_c is the number of pallets (or crates):

$$Length = 10 + 0.237x_p + 1.2x_c\,, \tag{3.1}$$

$$Depth = Length \times \frac{D}{L}, \tag{3.2}$$

$$Breadth = Length \times \frac{D}{L}, \tag{3.3}$$

With these equations in mind, the fuselage can therefore be estimated, with the results shown in Table 3.2.

Table 3.2

This table shows the estimated values for the fuselage.

Length (m)	Breadth (m)	Depth (m)
16.62	2.2	2.2

These values can then be used as a basis when the fuselage design is considered later in the design process. The fuel fraction, however, can now be calculated by the following equation:

$$ff = 1.046 - e^{-0.3504 \times SFC \times \frac{Range}{\sqrt{AR}}}, \tag{3.4}$$

When this equation is applied to the values found in Table 3.1, the fuel fraction obtained is 0.131, rounded to 3 decimal places. This means that roughly 13% of the aircraft's weight will be taken up by only the fuel needed to fly, assuming maximum takeoff weight. Similarly, the payload weight can be found by the equation:

$$W_p(N) = g(x_p \times 90 + x_c \times 500), \tag{3.5}$$

Therefore, the payload weight is found to be 24.92kN. Next, the structural weight can be found, which uses the previously defined parameters for fuselage length, breadth and depth.

This means that when the fuselage design has been completed, the weights can be re-estimated to find a more precise maximum takeoff weight. Structural weight is found by the following equation:

$$W_s(N) = 0.15503\left(L \times \frac{B \times D}{2}\right)^{1.3909} \tag{3.6}$$

This means that the structural weight was found to be 23.15kN. Finally, the maximum takeoff weight can now be determined by the following equation:

$$W_{to}(kN) = \frac{5 + W_p + W_s}{0.8 - ff} \tag{3.7}$$

This means that the aircraft's maximum takeoff weight is 84.59kN, which definately falls within the requirements of EASA-Part 25 to be considered a large aeroplane (greater than 5700kg). Ultimately, this is a good design weight for the aircraft as it falls at the lower end of all the aircraft previously discussed in the market survey, while still being able to carry a sufficiently large payload weight.

3.2 Centre of Gravity

Once the aircraft's wings, fuselage, and weights have been estimated, balancing the centre of gravity is an excellent way to confirm whether the design choices up to that point were suitable. In addition, EASA Part 25 sets out several key parameters in order for the aircraft to be certifiable, most notably that the centre of gravity's position must be no more than 50% of the mean aerodynamic chord or less than 25% of the mean aerodynamic chord. Furthermore, this must be true in both standard and extreme loading conditions to ensure the flight crew can fly the aircraft with relative ease.

With this in mind, while noting the aircraft's initial geometry and layout, the centre of gravity positions can be calculated; this was completed using the moment method, with the reference point taken as the aircraft's nose.

$$X_{CG} = \sum\left(\frac{m_x x}{m_{Total}}\right), \tag{3.8}$$

Where m_x is the mass of a specific component and x is the distance of that component from the datum. m_{Total} is the total mass of all components onboard the aircraft.

Table 3.2 shows the values used to calculate X_{CG} assuming maximum fuel and payload. The values given for m_x are as fractions of the aircraft's maximum takeoff weight.

Table 3.3

A table showing the weight fraction of all components onboard the aircraft and their respective position relative to the nose of the aircraft.

Component	m_x (Kg)	x (m)
Wing	0.072472	7.29
Fuselage	0.17343	6.65
Tailplane	0.01462	15.08
Fin	0.01389	14.35
Main Undercarriage	0.03586	8.04
Nose Undercarriage	0.01206	2.97
Flying Controls	0.01715	7.11
Engine Pod	0.01833	5.97
Engine Installed	0.10689	5.55
Airframe	0.14	8.31
Fuel	0.13094	7.17
Payload	0.23256	5.84

Therefore, when applying Equation 3.4, the centre of gravity position is found to be 6.93m from the aircraft's nose.

At this stage, it's important to consider how some components' mass will change in flight while others will not. For example, the mass of the aircraft's fuel tanks will decrease during the flight as fuel is burned. However, an aircraft's undercarriage will remain at a constant weight throughout the flight. This is an important consideration to make when tweaking component positions in order to gain a suitable X_{CG} position.

Once the position of the centre of gravity is known, relative to the aircraft's nose, it is vital to find the position of the centre of gravity in terms of the aircraft's mean aerodynamic chord (MAC). This can be done using the following relationship:

$$X_{CG_{MAC}} = \frac{X_{CG} - X_{MAC_{LE}}}{MAC}, \tag{3.9}$$

Where $X_{MAC_{LE}}$ is the position of the leading edge of the mean aerodynamic chord and MAC is the length of the mean aerodynamic chord. Therefore, the position of the centre of gravity, as a fraction of the mean aerodynamic chord, is given to be 0.31. This value is within the limits that were previously discussed. Yet, this calculation was only completed for one loading condition, maximum fuel capacity and maximum payload.

To remain completely compliant with EASA Part-25, this process was repeated for several loading conditions, specifically decreasing fuel by 10% until there was no fuel left for five different payload configurations. The output for these calculations are plotted on the graph shown in Figure 3.1.

Figure 3.1

The change in CG Position as Fuel Load Decreases

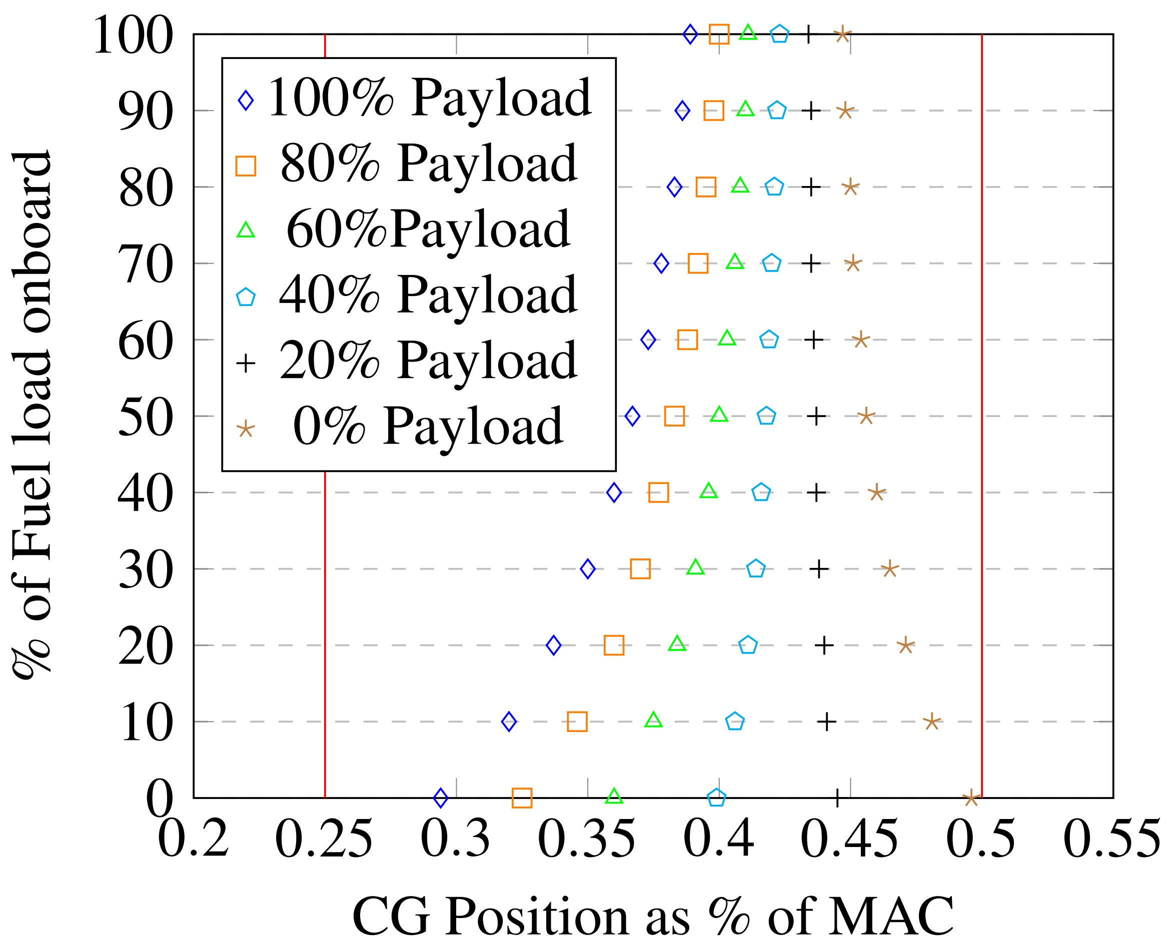

Figure 3.1 ultimately shows that no matter the aircraft's loading configuration, the CG position remains within the acceptable limits imposed in EASA Part-25. This means that the aircraft has been successfully balanced and that the initial aircraft configuration is acceptable and can be built on in further elements, such as the design of the tailplane and undercarriage.

Throughout the design process, the CG was constantly tweaked. For example, after completing the fin and tailplane design, more accurate values for tailplane weight and position could be used and implemented in the CG balancing method. This meant that the overall aircraft balancing was constantly being tweaked by slightly moving components with constant weight throughout the flight. The values discussed in this report represent the final values once the design had been completed.

3.3 Environmental Control Systems

4 Secondary Tasks

4.1 Aircraft Drag Prediction

4.2 Tail and Fin Design

5 Design Review

6 Group Work Evaluation

7 Conclusions

8 Appendix