

A Novel Approach To The Weight and Balance Calculation for The De Haviland Canada DHC-6 Seaplane Operators

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Abstract

The main objective of this research is to provide companies operating different fleets of the De Havilland Canada Twin Otter DHC-6 seaplanes with an alternative method to the time-consuming Whizz Wheel procedure when calculating the weight and balance. Using this application, these operators can lower their aircraft turnaround, speed up the passenger boarding, dispatch the flights efficiently and save on fuel and dock expenses. Furthermore, this research shows how operators do their calculations currently and the positive impact of the application on their entire operation, including extra revenue generation amounting to \$4M per year. Most DHC-6 seaplane operators are mainly in the Maldives. Therefore, this research was conducted while piloting these seaplanes and studying the day-to-day operations. While this paper presents the implementation of this software and its design model, it also discusses how two major operators used this application in the Maldives and one in St Vincent and the Grenadines.

Keywords: Software Engineering, Android, Java, Mobile, Seaplanes, DHC-6, W&B.

1. INTRODUCTION

Aviation is an essential lifeline of the world's economy; it supports more than 65.5 million jobs worldwide and enables \$2.7 trillion in global GDP (Shewring & Stevens, 2010). The aviation sector, particularly in the Maldives, makes a significant contribution to the country's economy. The Maldives alone supports 73,000 jobs and a \$3.1 billion added contribution to the GDP. In addition, air transport and tourists arriving by air represent 58.8% of the Maldives GDP. There are five major airlines in the Maldives, and two of these airlines operate the most extensive fleet of DHC-6 seaplanes in the world, conducting 24,700 flights, 51,700 takeoffs, and landings each year. With only 14 airports, the Maldives relies heavily on their seaplane fleets to link their scattered atolls (Air Transport Action Group, 2021). With this high frequency of flights, the Maldivian airlines need to optimize their weight and balance calculations procedures to speed up each aircraft's turnaround and dispatch their fleet quicker to their destinations. Saving time on the dispatch process means that the company can conduct more flights without increasing its crew number or fleet size.

In this research, we present the overall approach we chose to use, the method we used to calculate the weight and balance accurately. Finally, we give you the results of our optimization, quantifying the time and money saved per flight.

2. OBJECTIVES

The study aims to develop an Android-based weight and balance and aircraft performance calculation app replacing the traditional whizz wheel to save time and money for seaplane operators worldwide.

3. LITERATURE REVIEW

While reviewing the literature on similar research papers, we encountered that most research focuses on transport category narrow and wide-body passenger jets with 20 seats and up. We,

however, decided to focus on the commuter category aircrafts with a maximum of 19 seats and down. These commuter aircrafts are used by small operators who benefit the most from this software implementation. This niche market is very small compared to the mainstream aviation industry. The profits from this market are very limited and this is why there is less interest from software companies or manufacturers to tackle this problem.

3.1 The Importance of The Weight and Balance

Aircraft accidents related to weight and balance issues are yearly occurrences. These accidents occur due to incorrect loading and or use of wrong weight for takeoff performance calculations (Cokorilo et al., 2010). Aircraft manufacturers offer automated systems to calculate weight and balance; however, in the case of the DHC-6 among other planes, the “whizz wheel” is the only way to perform these calculations (Figure 1).

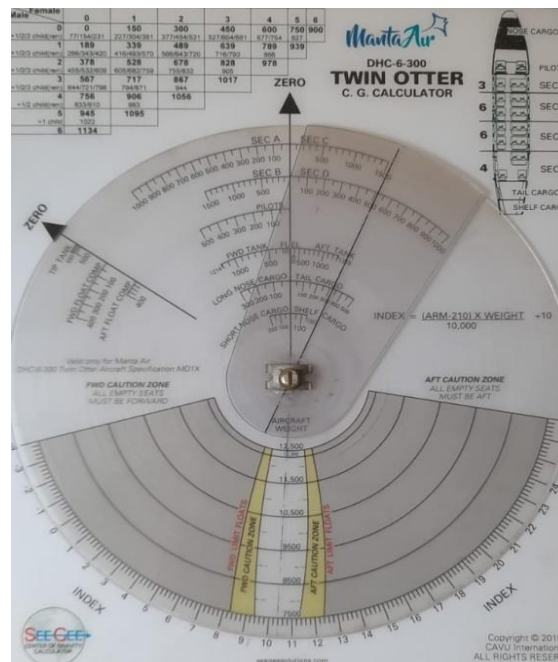


FIGURE 1: C. G. Whizz Wheel calculator for the DHC-6 aircraft.

The whizz wheel is a navigation computer that can perform many calculations and have many variables as inputs such as the wind direction, wind speed, load factors, etc.

The pilot turns the wheel either right or left, aligns the wheel with different indexes, etc. Although they can do many calculations, these whizz wheels are time-consuming; it can take up to 3 minutes to finalize a weight and balance of a fully-loaded DHC-6 seaplane. Also, any change to the loading, either a passenger moved to another seat or extra suitcases loaded or unloaded, last-minute arrivals, the calculation needs to be re-done from scratch. This problem is precisely what we want to fix.

3.2 Navigation and Positioning Calculation Restrictions

The Maldivians operate these aircraft in the most remote areas in the world; the application cannot rely on assisted GPS from android OS but rather use mathematics to calculate many aspects:

- The Azimuth from the latitude and longitude of the seaplane base
- The proper heading to the destination seaplane base
- The distance and fuel consumption depicted as sector burn

3.3 Weight and Balance Calculation

The Mean Aerodynamic Chord, also known as the “Percent Mac” calculation, gives us a value of the %Mac at takeoff and landing. Having this information, the pilot knows whether the plane will be within its center of gravity or end up with an aft or forward center of gravity at any phase of the flight. Finally, we chose the average weight of passengers based on their gender and age, Female “F,” Male “M,” and Child “C.”

4. PROJECT DESIGN AND METHODOLOGY

The methodology used in this study follows the “prototyping model” software development Methodology. This model allows the software prototype to be built, tested, and refined on end-user feedback until a good working version is accomplished.

4.1 The Requirements Gathering and Analysis Phase

The requirement gathering and analysis phase consisted of being on the field gathering all the observations made by the pilots, the dispatchers, and the company management. In addition, during the study, we witnessed the problems caused by the current process, and we had the opportunity to confirm our assumptions.

4.2 The Quick Design Phase

In this section, we produced a quick and straightforward framework showing how the user interface will look.

4.3 The Build Phase

This section produced a quick and simple design that we call an MVP a “Minimum Viable Product.” This version of the software included only four or five features. This fast design was then presented to the end-user to gather more feedback integrated into future design phases.

4.4 Field Evaluation Phase

In this section, we used the application in the field and gathered valuable feedback from the end-user, allowing us to determine its strengths, weaknesses, and must-have features.

4.5 The Prototype Phase

In this section, we measured the impact of the application, we determined the nice to have features and the must-have features, and we were able to have an approved final prototype.

5. THE USER INTERFACE & NAVIGATION

We chose to develop the application on Android OS because it provides a huge selection of pre-built UI components like UI controls and structured layouts, allowing us to build a graphical user interface quickly. We also chose Android because it is based on Java which is a powerful object-oriented programming language.

5.1 Departure and Destination Selection

5.1.1 Departure and Destination UI Component

This UI section allows the pilot to select the departure and destination airport from the airport database. Each airport has the following attributes:

- Airport ICAO code
- Airport name
- Airport longitude
- Airport latitude

Once the departure and destination airports are chosen, we can launch the backend distance calculation by pressing the Globe button depicted in figure 2.



FIGURE 2: The departure and destination selection.

5.1.2 Backend Distance Calculation

The backend component is the code that runs to calculate the distance between two locations. Figure 3 shows this backend code using the Haversine formula to accomplish the calculation. This calculation is crucial to calculate and display the fuel burn to the pilot as shown in figure 4.

Formula to calculate the distance between two points on earth :

$$a = \sin^2(\Delta\varphi / 2) + \cos \varphi_1 \cdot \cos \varphi_2 \cdot \sin^2(\Delta\lambda / 2)$$

$$c = 2 \cdot \text{atan2} [\sqrt{a}, \sqrt{1 - a}]$$

$$d = R \cdot c$$

Where :

- φ_1 is the latitude of initial point (positive for N and negative for S)
- φ_2 is the latitude of the final point (positive for N and negative for S)
- λ_1 is the longitude of the initial point (positive for E and negative for W)
- λ_2 is the longitude of the final point (positive for E and negative for W)

$$\Delta\varphi = \varphi_2 - \varphi_1$$

$$\Delta\lambda = \lambda_2 - \lambda_1$$

R is the radius of the Earth in meters (R = 6371000 m)

FIGURE 3: The haversine formula to calculate the distance between two locations.



FIGURE 4: Sector Burn for the flight in pounds as well as the distance in Nautical Miles.

5.1.3 Backend Azimuth Calculation

Now that we have the distance between two points, we need to calculate the Azimuth. To do so, we use the same latitude and longitude of the departure and destination airport and input them into the azimuth formula below.

Formula to calculate the Azimuth between two sets of coordinates :

$$\theta = \text{atan2} [(\sin \Delta\lambda \cdot \cos \varphi_2), (\cos \varphi_1 \cdot \sin \varphi_2 - \sin \varphi_1 \cdot \cos \varphi_2 \cdot \cos \Delta\lambda)]$$

FIGURE 5: The haversine formula to calculate the Azimuth between two locations.

5.1.4 Backend Bearing Degree Calculation

Before using the azimuth radian, we need to convert it to a positive degree bearing that the pilots can use as their flight heading as illustrated in figure 6.

Formula to convert radians to degrees :

$$\theta = \text{rad} \times 180^\circ \div \pi = \text{Bearing degree}$$

FIGURE 6: The formula to convert radians to degrees.

If the resulting bearing degree is negative, we must convert it to a positive bearing degree. To do that, we add 360 to the negative result to get a positive bearing degree as illustrated in figure 7. The bearing we also call the true heading, in this case, is displayed in the heading box of the UI as depicted in figure 8.

Converting negative bearing degree to positive bearing degree :
negative bearing degree + 360 = positive bearing degree

FIGURE 7: Convert negative bearing degree to positive bearing degree.

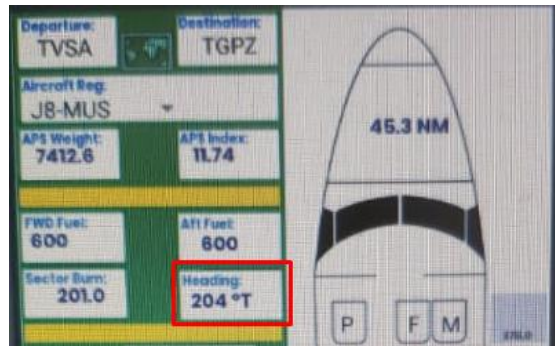


FIGURE 8: The true heading displayed for the pilots.

5.2 Aircraft Registration Selection

5.2.1 Aircraft Registration UI Component

This section of the UI allows the pilot to select the aircraft that will conduct the flight. Although it can be the same model of aircraft, each plane has its subtle differences. For example, three airplanes of the same model can have a different APS weight, Basic weight, or Horizontal arm. The aircraft numbers we will be using are:

- APS Weight or OEW weight
- Horizontal Arm
- Center of Gravity
- Moment

The **APS** “**Aircraft Prepared for Service**” and the **OEW** “**Operating Empty Weight**” describe an empty aircraft with non-useable fuel, engine oil, and equipment required to conduct the flight, excluding any useable fuel cargo and people.

The Horizontal ARM is the distance from the reference datum to the center of gravity of an item.

The center of gravity CG is the point at which the weight of a body is assumed to be concentrated. In other words, for an aircraft is the point over which the aircraft would maintain balance. If the weight is focused forward of the CG, we call this a Forward C of G, meaning the aircraft will pitch down while an Aft C of G means that the weight is concentrated Aft of the CG. The CG must stay within limits throughout all the phases of flight for the aircraft to maintain its flight characteristics.

The Moment is the force that causes an object to rotate, and it is used to calculate the center of gravity.

5.3 Fuel Quantity Input

This UI section allows the pilot to enter how much fuel is in the forward and the aft fuel tanks. Each tank has its ARM, which is the distance from the reference datum. The fuel weight in pounds is multiplied by its corresponding arm depending on which tank it resides in and gives us a Moment. Thus, the sum of the fuel weight in the two tanks is instantaneously added to the total aircraft weight as shown below in figure 9.



FIGURE 9: Fuel quantity input in forward and aft tank.

5.4 Passenger Loading

This section of the UI allows the pilot to set up the passenger loading and move passengers around, allowing the aircraft to stay within its center of gravity limit at all phases of the flight. This is an advantage since the calculations are made instantaneously while the pilot is setting up the loading. In this section, each seat has its corresponding ARM. To simplify the math, we assumed the average weight of females, males, and children as per ICAO regulations. Therefore, each seat can be one of the following states:

- **P** as in “Passenger”: The seat is vacant.
- **M** as in “Male”: The seat is occupied by a male.
- **F** as in “Female”: The seat is occupied by a female.
- **C** as in “Child”: The seat is occupied by a child.

Each row has its sector weight as well. The importance of each sector has its arm and will be added to the total weight and the C of G calculation as shown in the figure below.

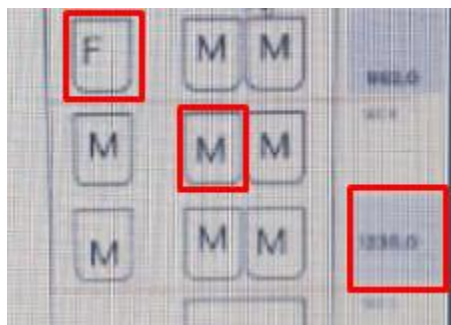


FIGURE 10: Passenger loading and sector weight.

5.5 Luggage Loading

This section of the UI allows the pilot to input the luggage weight in pounds in the luggage area at the back of the aircraft. Like any other position in the aircraft cabin, the luggage area also has its ARM value. Therefore, the luggage weight will be multiplied by its corresponding arm to give us a Moment to calculate the index and be added to the total aircraft weight as shown in the figure below.



FIGURE 11: Luggage Loading and sector weight.

5.6 Aircraft Index

The aircraft index is the Moment divided by a constant in our case, 10.000 as per the aircraft operating manual. We use the index to simplify computations of aircrafts' long arms, resulting in a sizeable unmanageable number. We use the index formula illustrated in figure 12 and display the result in the takeoff index box as shown in figure 13.

Formula to find the index of an aircraft :

$$\text{Index} = 10 + \frac{\text{Basic Weight (Horizontal Arm - 210)}}{10000}$$

FIGURE 12: Formula to calculate the aircraft's index.



FIGURE 13: Index on takeoff and landing.

5.6.1 Aircraft Index Landing

The landing index is calculated by factoring in the only variable changing with time, fuel consumption, and re-doing the same index calculation.

5.7 %MAC Calculation

The %Mac "Percent Mean Aerodynamic Chord" is a calculation showing the center of gravity over the wing. It is mandatory to have the aircraft %MAC within the limit during all flight, takeoff, cruise, and landing phases.

5.7.1 Takeoff %MAC

The formula to calculate the %MAC in figure 14 involves three different parameters:

- LEMAC: The inches aft of the datum of the leading edge of the MAC
- ARM: The distance from the reference datum to the center of gravity of an item
- MAC: The actual length of the MAC

Formula to calculate the %MAC of an aircraft :

$$\%MAC = \frac{ARM - LEMAC \times 100}{MAC}$$

FIGURE 14: Index on takeoff and landing.

5.7.2 Landing %MAC

The formula to calculate the landing %MAC is the same. The only difference is that we account for the fuel consumption rate and multiply it by flight time. Both takeoff and landing %MAC are shown to the pilots on the UI as you can see on figure 15.

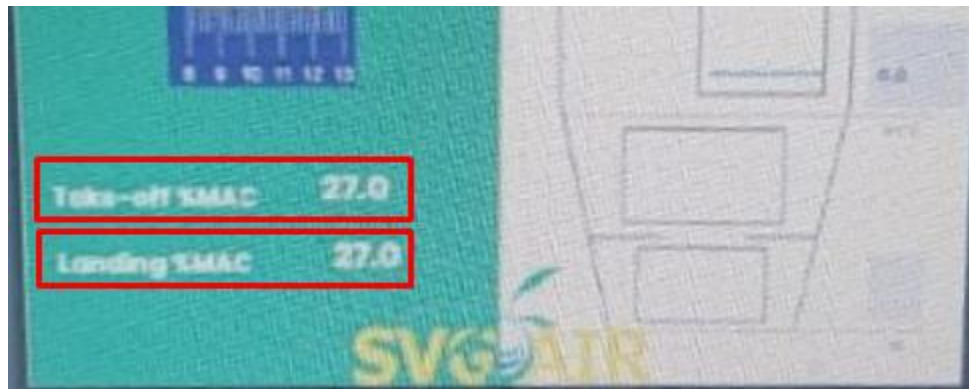


FIGURE 15: Index on takeoff and landing.

6. CONCLUSIONS

The developed application helped two operators speed up their dispatch rate. Before having this solution, the operators spend 3 minutes using the whizz wheel, assuming no errors are made. The process took even longer on average due to last-minute unloading, last-minute passenger boarding, and extra luggage loaded. This solution allowed them to finish all calculations in under 1 minute and without errors. To quantify the financial benefits of using this app, we can multiply the 2 minutes saved per flight multiplied by 50, which is the number of flights per day, giving us 1.61 hours saved each day. These savings equate to 1 full revenue-generating flight, meaning the airline can conduct their current flights without extra planes and add one additional flight to their schedule. Each hour of a revenue flight generates approximately 7000\$ dollars. We then can assume that the company can generate an extra 11,316\$ every day, which amounts to \$4M of revenue per year. Although we could quantify the financial benefits of adopting this application, the main unquantifiable benefits are the convenience for the flight crew that has less workload and, most importantly, the enhanced safety of the flights.

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