# Software Development for Calculation of Fuel Consumption in Commercial Aircraft

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*Abstract:* - This work presents the development of software, implemented for Windows using Visual Studio and C#, aimed at estimating the fuel load required for a commercial aircraft prior to departure. The system is based on the operational parameters of the Boeing 777-300ER equipped with GE90-115B engines and allows the user to select departure and destination airports from a database containing major international airports and their respective geographic coordinates. The distance between airports is calculated using the WGS-84 geodetic model, a standard widely adopted in international aviation, ensuring greater accuracy in distance computation. In addition to distance, the system considers operational factors such as onboard weight, mandatory fuel reserves, and other parameters defined by civil aviation safety standards. The application also enables the inclusion of alternate airports and estimates total fuel consumption based on realistic and safe flight scenarios. The results are displayed clearly to the user, serving as a support tool for academic simulations and operational studies. Complementing the software development, the associated monograph conducts a comparative analysis between commercial aircraft from different generations, focusing on fuel efficiency. The comparison involves an older model, predominantly built with aluminium, and a more modern aircraft constructed from composite materials. The analysis highlights performance gains associated with higher cruising altitudes, reduced drag, and lighter structural weight, demonstrating the direct impact of these variables on fuel consumption.

*Key-Words:* - Flight planning, aircraft performance, fuel consumption, commercial aviation

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## 1 Introduction

The aviation industry is constantly seeking technological solutions to optimize fuel consumption, especially in long-haul flights, which represent a significant portion of operational costs and environmental impact. Accurate fuel planning is essential to ensure efficiency, safety, and regulatory compliance. However, the complexity of commercial flight planning often requires the use of costly or access-restricted software tools, which may not be accessible for academic or educational purposes. This limitation hinders the development of new methodologies and the training of future professionals. This work presents the development of custom-developed software capable of estimating fuel consumption for long-haul commercial flights based on real aircraft performance data, using the Boeing 777-300ER as a reference model. The system integrates multiple operational factors, including aircraft weight, air distance, wind component, and cruise altitude, aiming to reproduce realistic planning scenarios. The proposed tool stands out for its accessibility, flexibility, and suitability for academic environments, enabling high-fidelity simulations without the need for proprietary databases. The results demonstrate its capability to closely match real-world flight-plan data, validating its technical applicability. The developed software features an intuitive and interactive interface that allows users to simulate long-haul flights among 35 major international airports. The user can configure the aircraft payload in detail, including passengers, cargo, and catering. The great-circle distance is calculated using the WGS-84 ellipsoid, which is widely adopted for accurate geodesic computations. Based on these inputs, the system outputs the required fuel quantities in accordance with ICAO Annex 6 standards and the specific performance parameters provided by the Boeing 777-300ER Flight Crew Operating Manual (FCOM) [3].

# 2 Problem Formulation

## 2.1 Route and Distance Model

The software developed allows the user to select both origin and destination airports from a predefined list of 35 major international airports, each associated with its respective latitude and longitude. These coordinates are used to compute the great-circle distance between locations using the WGS-84 ellipsoid, known for its precision in geodesic calculations.

The geodesic distance is calculated using the Vincenty formula, as follows:

$$L = \lambda_2 - \lambda_1 \quad (1)$$

$$U_1 = \arctan\big((1-f)\tan\phi_1\big), \quad U_2 = \arctan\big((1-f)\tan\phi_2\big) \quad (2)$$

λ = L, iterating until convergence:

$$\sin\sigma = \sqrt{(\cos U_2 \sin\lambda)^2 + (\cos U_1 \sin U_2 - \sin U_1 \cos U_2 \cos\lambda)^2} \quad (3)$$

$$\cos\sigma = \sin U_1 \sin U_2 + \cos U_1 \cos U_2 \cos\lambda \quad (4)$$

$$\sigma = \arctan\left(\frac{\sin\sigma}{\cos\sigma}\right) \quad (5)$$

After convergence of λ, the geodesic distance d is given by:

$$d = bA(\sigma - \Delta\sigma) \quad (6)$$

where:

$$A = 1 + \frac{u^2}{16384}\Big(4096 + u^2\big(-768 + u^2(320 - 175u^2)\big)\Big) \quad (7)$$

$$B = \frac{u^2}{1024}\Big(256 + u^2\big(-128 + u^2(74 - 47u^2)\big)\Big) \quad (8)$$

$$\Delta\sigma = B\sin\sigma\left(\cos 2\sigma_m + \frac{B}{4}\big(\cos\sigma(-1 + 2\cos^2 2\sigma_m)\big) - \frac{B}{6}\cos 2\sigma_m(-3 + 4\sin^2\sigma)(-3 + 4\cos^2 2\sigma_m)\right) \quad (9)$$

$$u^2 = \frac{\cos^2\alpha\,(a^2 - b^2)}{b^2} \quad (10)$$

In the simulation, the result of this computation is referred to as the ground distance. While it differs from the real ground track flown by aircraft due to airway routing constraints and operational procedures—this simplification is generally acceptable in medium- and long-haul operations, as the relative difference is typically small compared with the total segment length. Modelling real-world airways would require an extensive and constantly updated route database, which was considered impractical for this version of the software.

Subsequently, the system allows the inclusion of wind components, enabling the user to input a headwind or tailwind component in knots. This yields the operational air distance (ground distance adjusted by the wind component), which is the metric used in all fuel-consumption calculations. This correction reflects real flight conditions and aligns with how the Boeing 777-300ER's FCOM [3] presents performance fuel data.

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## 2.2 Aircraft Configuration and Payload Settings

The software allows detailed configuration of the aircraft's payload before flight simulation. Users can define the number of passengers, belly cargo, and catering load. For standardization, the average weight per passenger is set to 85 kg, based on typical values used by international airlines operating long-haul routes to Brazil. This estimate includes both the passenger and carry-on luggage.

The fig.1 below shows the configuration screen of the system:

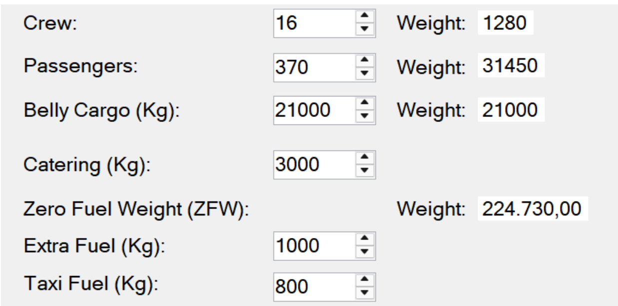


Fig. 1: Aircraft weight configuration interface

The aircraft used for simulation is the Boeing 777-300ER, with the following certified operational weight limits and fuel capacity:

- OEW (Operating Empty Weight): 167,800 kg
- MTOW (Maximum Takeoff Weight): 351,534 kg
- MTW (Maximum Taxi Weight): 352,442 kg
- MLW (Maximum Landing Weight): 251,290 kg
- MZFW (Maximum Zero Fuel Weight): 237,681 kg
- Total fuel capacity: approx. 181,280 liters (≈ 145,500 kg)

The Zero Fuel Weight (ZFW) is the key reference mass used in fuel consumption calculations and is dynamically computed by the software based on the selected payload configuration. The aircraft in the simulation is configured to accommodate up to 370 passengers and 34,000 kg of belly cargo. Although this value is below the structural cargo capacity, it closely reflects typical operational limits. In long-haul operations, this threshold is rarely exceeded due to factors such as cargo compartment layout constraints, load distribution limits, and the need to maintain compliance with maximum operational weights. The software monitors these parameters in real time. If the configured payload causes the ZFW or any other operational limit to be exceeded, such as the Maximum Takeoff Weight (MTOW) or MLW (Maximum Landing Weight), the simulation is automatically interrupted, and a warning message is displayed to the user. This ensures that all simulated scenarios remain within the realistic and certified performance envelope of the aircraft.

## 2.2 Fuel Planning Standards

The fuel planning logic adopted in this project follows the international requirements established by ICAO Annex 6 [2], specifically Section 4.3.6.3, which ensures both safety and efficiency in international commercial aviation. According to these standards, the following fuel components must be considered in any operational flight plan:

- **Taxi Fuel:** Estimated fuel consumed during ground operations prior to takeoff (e.g., APU operation, engine start, taxi to runway).
- **Trip Fuel:** Fuel required to fly from the departure airport to the destination under forecasted operational conditions, such as wind and cruising altitude.
- **Contingency Fuel:** Fuel reserved for unforeseen factors like rerouting, weather deviations, or traffic delays. While ICAO allows reduction to 3% under certain operational frameworks, this project adopts the conservative and commonly used 5% margin over Trip Fuel.
- **Alternate Fuel:** Fuel required to reach an alternate airport from the destination in case of emergency or unavailability of landing.
- **Final Reserve Fuel:** Fuel sufficient for 30 minutes of flight at 1,500 ft above the destination or alternate airport, assuming final reduced aircraft weight.
- **Additional Fuel:** Extra fuel to ensure safety under exceptional conditions (e.g., poor infrastructure, weather uncertainty).
- **Discretionary Fuel:** Optional fuel added at the dispatcher's or captain's discretion based on anticipated operational factors.

These components form the basis for the fuel estimation methodology implemented in the software.

## 2.3 Fuel Calculation Methodology

The software reproduces the fuel-planning process in a modular, sequential manner, emulating real-world flight-dispatch logic while maintaining compliance with ICAO Annex 6 [2]. Each component is computed in sequence, accounting for cumulative effects on aircraft mass and on the inputs used for performance-table interpolation.

**Step 1: Determination of Estimated Zero Fuel Weight (EZFW)**

The EZFW is calculated based on:

- Operating Empty Weight (OEW)
- Passenger weight (including carry-on luggage)
- Belly cargo
- Catering

This represents the aircraft's loaded mass without fuel.

**Step 2: Final Reserve Fuel Calculation**

A fixed holding altitude of 1,500 ft above the destination or alternate aerodrome elevation is used to calculate the Final Reserve Fuel, in accordance with ICAO Annex 6 [2]. Although field-elevation variations could be modelled for additional precision, the system adopts 1,500 ft as a simplifying assumption that does not materially affect results. This choice ensures computational simplicity, provides a conservative safety margin (fuel consumption at 1,500 ft is relatively higher than at ground level), and avoids unnecessary complexity in the simulation logic. The calculation is performed via linear interpolation on a low-altitude cruise fuel table, using the estimated aircraft weight at the end of the flight (EZFW plus any discretionary fuel) as input.

**Step 3: Alternate Fuel Calculation**

Based on the distance to the alternate airport, interpolation is performed on a short-range table (up to 500 NM). The reference weight is: EZFW + Final Reserve + Discretionary Fuel.

**Step 4: Trip Fuel Calculation**

The air distance is calculated by correcting ground distance with wind input. A bilinear interpolation is applied over fuel consumption tables, considering air distance and cruise altitude. A landing weight adjustment is also included.

**Step 5: Contingency Fuel Application**

A 5% margin is added to the Trip Fuel:
Trip Fuel with Contingency = Trip Fuel×1.05

**Step 6: Taxi Fuel**

This value is manually entered by the user, based on expected APU usage, engine start, and taxi time. It is not included in the interpolation process for other fuel components, as it is assumed to be consumed entirely prior to take off.

**Step 7: Final Fuel Totals**

Minimum Fuel Required (MFR):
MFR = Final Reserve +Alternate + Trip Fuel with Contingency
Takeoff Fuel (TOF):
TOF = MFR + Discretionary Fuel
Block Fuel = TOF + Taxi Fuel

This structure reflects actual airline planning logic and ensures accurate simulation aligned with international operational standards.

As an example, the Trip Fuel is calculated by performing a bilinear interpolation on a cruise performance table below extracted from the Boeing 777-300ER FCOM [3]. Figure 2 provides fuel consumption values (in thousands of kilograms) for different combinations of air distance (NM) and cruising altitude (ft), assuming a standard landing weight of 200,000 kg.

The interpolation procedure is done in two stages:

1. Linear interpolation between the two bounding distances D1 and D2;
2. Linear interpolation between the two bounding altitudes A1 and A2.

The final interpolated fuel value F_ref (D,A) is obtained from:

$$F_{\text{ref}}(D,A) = F_{D_1,A_1} \cdot (1-\alpha)(1-\beta) + F_{D_2,A_1} \cdot \alpha(1-\beta) + F_{D_1,A_2} \cdot (1-\alpha)\beta + F_{D_2,A_2} \cdot \alpha$$

$$\alpha = \frac{D - D_1}{D_2 - D_1}, \quad \beta = \frac{A - A_1}{A_2 - A_1}$$

| AIR DIST (NM) | PRESSURE ALTITUDE (1000 FT) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 27 | | 29 | | 31 | | 33 | | 35 | |
| | FUEL (1000 KG) | TIME (HR:MIN) | FUEL (1000 KG) | TIME (HR:MIN) | FUEL (1000 KG) | TIME (HR:MIN) | FUEL (1000 KG) | TIME (HR:MIN) | FUEL (1000 KG) | TIME (HR:MIN) |
| 800 | 13.3 | 2:02 | 13.0 | 2:00 | 12.8 | 1:57 | 12.6 | 1:54 | 12.4 | 1:52 |
| 1200 | 19.3 | 2:58 | 18.9 | 2:54 | 18.5 | 2:50 | 18.2 | 2:46 | 17.9 | 2:43 |
| 1600 | 25.5 | 3:53 | 24.9 | 3:49 | 24.4 | 3:42 | 23.9 | 3:37 | 23.4 | 3:33 |
| 2000 | 31.6 | 4:49 | 30.8 | 4:43 | 30.2 | 4:35 | 29.6 | 4:28 | 28.9 | 4:23 |
| 2400 | 38.0 | 5:43 | 37.1 | 5:35 | 36.3 | 5:26 | 35.5 | 5:18 | 34.6 | 5:13 |
| 2800 | 44.4 | 6:37 | 43.3 | 6:28 | 42.3 | 6:17 | 41.4 | 6:08 | 40.4 | 6:03 |
| 3200 | 51.0 | 7:30 | 49.7 | 7:19 | 48.5 | 7:07 | 47.4 | 6:58 | 46.2 | 6:53 |
| 3600 | 57.7 | 8:23 | 56.2 | 8:11 | 54.9 | 7:58 | 53.5 | 7:47 | 52.2 | 7:42 |
| 4000 | 64.4 | 9:15 | 62.7 | 9:02 | 61.2 | 8:48 | 59.7 | 8:37 | 58.2 | 8:32 |
| 4400 | 71.4 | 10:06 | 69.5 | 9:52 | 67.8 | 9:37 | 66.1 | 9:26 | 64.5 | 9:22 |
| 4800 | 78.4 | 10:58 | 76.3 | 10:42 | 74.3 | 10:26 | 72.4 | 10:16 | 70.7 | 10:11 |
| 5200 | 85.5 | 11:48 | 83.2 | 11:31 | 81.0 | 11:16 | 79.0 | 11:05 | 77.2 | 11:01 |
| 5600 | 92.8 | 12:38 | 90.3 | 12:20 | 87.9 | 12:04 | 85.7 | 11:54 | 84.0 | 11:51 |
| 6000 | 100.1 | 13:28 | 97.4 | 13:10 | 94.7 | 12:53 | 92.3 | 12:43 | 90.7 | 12:41 |
| 6400 | 107.7 | 14:17 | 104.7 | 13:58 | 101.8 | 13:42 | 99.4 | 13:33 | 98.0 | 13:30 |
| 6800 | 115.3 | 15:06 | 112.0 | 14:47 | 109.0 | 14:31 | 106.5 | 14:22 | 105.4 | 14:20 |
| 7200 | 123.1 | 15:55 | 119.5 | 15:36 | 116.3 | 15:20 | 113.9 | 15:11 | 113.1 | 15:10 |
| 7600 | 131.0 | 16:43 | 127.2 | 16:24 | 123.8 | 16:09 | 121.5 | 16:01 | 121.3 | 16:00 |
| 8000 | 138.9 | 17:31 | 134.8 | 17:12 | 131.3 | 16:58 | 129.2 | 16:50 | 129.4 | 16:50 |

Fig. 2: Long Range Cruise Trip Fuel and Time

Although the table above (Fig.2) is based on a fixed landing weight of 200,000 kg, the software applies a correction in the next calculation step to account for the actual estimated landing weight. A secondary table is used to adjust the Trip Fuel by adding or subtracting fuel based on the difference between the real landing weight and the reference value.

# 3 Results and Discussion

## 3.1 Simulation Based on a Real Flight Plan

To validate the results of the software, a simulation was carried out based on a real long-haul international flight plan from a commercial airline operating the Boeing 777-300ER equipped with GE90-115B engines. For compliance and confidentiality reasons, neither the flight number nor the airline is disclosed. However, all operational data used were authentic and current.

The chosen route was from São Paulo/Guarulhos (SBGR) to New York–JFK (KJFK). In the simulation, the aircraft was configured to match the Estimated Zero Fuel Weight (EZFW) of the real flight plan, set at 215,660 kg. The air distance used in the real dispatch release was 4,309 NM. In the software, the closest achievable match was 4,312.88 NM, obtained by fine-tuning the headwind component until the air distance matched within 0.1%.

The comparison between the simulation and the real flight plan revealed a high level of accuracy across most parameters. The final Block Fuel calculated by the software was 83,338.82 kg, while the real plan indicated 84,013 kg, an absolute difference of 674.18 kg (≈ 0.80%).

Slightly higher discrepancies were noted in two components. First, contingency fuel: the simulation applied a 5% margin (per ICAO guidance), whereas the airline used a 3% policy, so the simulated value was higher. Second, alternate fuel: the software assumes a direct geodesic distance from the destination to the alternate, while the actual flight plan likely included allowances for go-around, climb and descent segments, ATC vectors, and holding patterns; consequently, the simulated value was lower.

Despite these expected differences, the remaining parameters, including Block Fuel, Trip Fuel, Final Reserve, take off Fuel (TOF), and Estimated Take off Weight (ETOW), matched closely between the simulation and the real dispatch. The slight variation in Landing Weight is attributed to the lower overall fuel usage in the simulation due to simplified assumptions, such as a constant cruise altitude and the absence of step climbs.

These results confirm the robustness of the methodology, especially considering it relies solely on FCOM-derived performance tables and user-defined configuration inputs. The system demonstrated high operational fidelity, producing outputs within practical margins of real-world values and validating its application for planning and academic purposes.

Table 2. Comparison between Real Flight Plan and Simulation

| Parameter | Real Plan (kg) | Simulation (kg) |
|---|---|---|
| Zero Fuel Weight (EZFW) | 215,660 | 215,660 |
| Landing Weight (ELDW) | 227,137 | 226,812.77 |
| G/C Distance (NM) | 4,123 | 4,123.31 |
| Ground Distance (NM) | 4,246 | - |
| Air Distance (NM) | 4,309 | 4,312.88 |
| Fuel Trip | 71,843 | 71,493.05 |
| Contingency | 2,156 | 3,574.65 |
| Alternate Fuel | 6,222 | 4,586.52 |
| Final Reserve | 3,099 | 2,991.60 |
| MFR | 83,320 | 82,645.82 |
| TOF | 83,320 | 82,645.82 |
| Taxi | 693 | 693 |
| Block | 84,013 | 83,338.82 |
| Take off Weight (ETOW) | 298,980 | 298,305.82 |
| Estimated Flight Time | 09:32 | 09:21 |

## 3.2 Comparative Consumption Analysis: Boeing 777-300ER vs 787-8

In order to illustrate the operational impact of structural efficiency across aircraft generations, a comparative simulation was conducted between the Boeing 777-300ER and the Boeing 787-8 on a 4,000 NM route. Both aircraft were configured with realistic payloads, and Trip Fuel values were interpolated from official FCOM tables.

After adjusting for estimated landing weight, the Trip Fuel per passenger was calculated as:

- B787-8: 149.80 g/100 km/pax
- B777-300ER: 218.47 g/100 km/pax

This represents a fuel savings of 31.4% per passenger for the 787 compared to the 777, highlighting the aerodynamic and structural efficiency gains of newer-generation aircraft using composite materials.

Additionally, the optimum cruise altitudes were estimated using manufacturer tables and interpolated based on weight at cruise midpoint. The 787 achieved a higher altitude (≈39,754 ft) versus the 777 (≈36,511 ft), leading to:

- 14.4% reduction in drag due to lower air density;
- Greater engine efficiency and true airspeed at altitude;
- Slightly lower gravitational force (≈86 kgf less), translating into a lifetime fuel saving of ~226 tons, assuming continuous long-haul operation over 20 years.

This comparative study underscores how altitude performance, structural design, and materials innovation contribute significantly to fuel efficiency in modern commercial aircraft.

# 4 Conclusions

From table 2 the development and validation of the software demonstrated that it is possible to accurately reproduce key fuel-consumption parameters for long-haul commercial flights using real-world aircraft performance data. A comparison with an actual flight plan from an international airline operating the Boeing

777-300ER equipped with GE90-115B engines revealed a Block Fuel deviation of less than 1%, confirming the reliability of the interpolation methods and the consistency of the FCOM-derived performance tables.

This high level of accuracy validates the core objective of the project: to provide an accessible, reliable, and technically robust simulation tool tailored for academic and professional applications. The system was designed to support students, educators, and aviation enthusiasts in understanding operational variables such as weight, air distance, wind, and fuel consumption through a simple and intuitive interface.

Beyond matching real-world data, the software also enables simulations of edge cases and next-generation aircraft performance, as evidenced by the comparative study between the 777 and the 787, offering a versatile environment for analysing structural efficiency, the effects of altitude, and mission performance under various conditions.

In conclusion, this software represents a meaningful contribution to the field of aeronautical education, fostering the integration of theoretical knowledge with practical application while promoting critical thinking and data-driven technical analysis.

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**Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)**

Alexandre Montovavi and Dr. Luiz Carlos Gadelha both carried out the simulation and both wrote the article.

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**Conflict of Interest**

The authors declare no.