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Operational Improvements and Changes in Aerodynamics of Aircraft to Reduce the Climate Impact of Aviation

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ABSTRACT: The aviation industry serves not only as a worldwide rapid transportation network but also as a catalyst for economic and social development across the globe. As the demand for air travel continues to expand, it's critical to address the growing concerns about its impact on climate change. While various regulatory policies have promoted the use of sustainable aviation fuels, these fuel alternatives are currently challenged by production insufficiency. Therefore, strategies such as aircraft operational improvements may help mitigate CO_2 emissions in the near term. The objective of this paper is to demonstrate that operational efficiency through optimization of longer flight paths and improved aerodynamics can reduce CO_2 emissions in commercial aviation. The impact of operational management will be evaluated by collecting aircraft performance data on an existing model and analyzing how different ranges of routes impact its emissions. The impact of aerodynamic improvements will be assessed by computing the emissions per unit distance for two different aircraft models with varying wing aspect ratios and comparing their impact on the drag force. From shortest to longest flight path, the computations of the drag-based cruise method showed about 20.9% decrease in emissions per kilometer. After a complete aerodynamic comparison, the aircraft model with lower drag force appeared to release about 2.10% lower emissions due to more efficiency. These findings suggest that longer flight path optimization and aerodynamic improvements could moderately lower the effect of aviation's CO_2 on climate change.

KEYWORDS: Aerospace Engineering; Sustainable Design; Aerodynamics; Flight Route Optimization; Wing-aspect.

Introduction

It is widely known across the world that human activity is causing rapid changes to our global climate, leading to disastrous outcomes such as severe weather, wildfires, air pollution, droughts, and intensified disease transmission.[1] According to the International Energy Agency, it was reported that the aviation industry alone is responsible for nearly 2.5% of global CO_2 emissions through the usage of fossil fuels.[2] Driven by factors such as tourism, its facilitation of international trade, generation of economic growth, and global connectivity, the air transport sector is estimated to triple in size in the coming years.[3] While the demand for air travel continues to expand, it is crucial to mitigate its reputation of being one of the most carbon-intensive activities around the globe. Despite the implementation of various CO_2 reduction measures such as new technologies, more efficient infrastructure, and prospects of sustainable aviation fuels, it is likely that the industry will not meet the sustainability goals established by the Paris Agreement, an international treaty established in 2015.[4] This is because the current growth and demand of the air transport sector is simply outstripping efforts to reach net-zero carbon emissions.

Furthermore, the prospects of sustainable aviation fuels, which are comparatively low-emission biofuels, are quite uncertain considering the fact that the industry will have to increase production up to nearly 405 billion liters of fuel every year by 2050.[5] Moreover, SAF production contributed to only 0.3% of global jet fuel in 2024 and requires heavy investments as well as policy change to replace jet fuel at the current scale.6 Therefore, achieving this ambitious goal will require stronger cooperation among airlines, more technological advancements, and collaboration between governments worldwide for the construction of a powerful supply chain that can support the production of such high capacity.[6] Therefore, other feasible strategies could be utilized to reduce the carbon emissions of aviation to a moderate level.

Improvements in aircraft configurations, such as wing structures and the implementation of sustainable operational measures, can increase aerodynamic efficiency. Recently, numerous studies have indicated that changing wing aspect ratios can lead to an improvement in the fuel efficiency of an aircraft by 10%, accounting for the fact that the lift of a thinner and longer wing can reduce the drag coefficient, which decreases fuel consumption.[7] However, elongating the wings of the aircraft can make it especially vulnerable to strong gusts, turbulence, or disruptive conditions, but adding more weight to stabilize the plane will decrease flight efficiency and defeat the purpose of this modification. NASA's X-66A Transonic Truss-Braced Wing project, for instance, is a truss-braced configuration that utilizes computational fluid dynamics to reduce the weight penalty of extended wings.[4]

Operational improvements within the aviation sector can play a critical role in advancing the long-term sustainability objectives. In the context of air travel, operational managements include a wide classification of activities such as passenger and cargo unloading, optimization of processes, formation flying, effective utilization of existing resources, and the metrics/procedures used to assess and improve aircraft efficiency.[8] As asserted by the International Civil Aviation Organization (ICAO), utilizing the opportunity to improve operational

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measures might be the most successful and affordable way to reduce carbon emissions and minimize fuel consumption.[9] Not only is this approach beneficial to the environment in terms of the CO_2 emissions released, but it can also reduce costs that are associated with burning large amounts of fossil fuels. Since the promotion of operational measures does not require any new high-cost equipment or advancements in technology, this organization encouraged and developed major initiatives. In 2016, ICAO implemented the Global Air Navigation Plan (GANP) and the Aviation System Block Upgrades (ASBU) in efforts to optimize air traffic management.[9]

According to Eurocontrol's environmental assessment in 2020, inefficiencies in the European air traffic management (ATM) network cause flights to burn 8.6–11.2 % more fuel on average.[10] Optimization of flight paths is the process that can be utilized to produce the flight path that has the least impact on the climate based on emissions. Aircraft operations are generally classified into two groups: Landing and Take-off (LTO cycle) and the cruise phase of the plane. The LTO cycle includes the takeoff, climb, approach, and idle phases of the aircraft, while the cruise phase encompasses all the operations above the altitude of 30,000 feet.[11] Aircraft release the highest amount of CO_2 during the LTO phase, which account to over 10% of an aircraft's total carbon emissions.[12] According to various recent research studies, the adoption of flight route optimization over extended flight segments would distribute the landing and takeoff emissions over greater distances.[12]

While existing research has previously explored aerodynamic improvements, such as improving lift-to-drag ratios, and other studies have modeled the impact of optimizing operational measures, such as flight path planning, these fields have mostly been studied in isolation from one another.[13] There is limited empirical research that properly examines the direct impact of the drag coefficient on aircraft's carbon emissions and how optimization of long-haul flight paths can impact carbon emissions. The objective of this study is to investigate how the potential effects of optimizing longer-range flight paths and increasing aerodynamic efficiency could assist in reducing carbon emissions. By focusing on improving operational efficiency through flight route optimization and changes in aerodynamics, this study analyzes how they can mitigate the impact of CO_2 emissions on the environment.

■ Methods

This study uses a quantitative analytical research design, such as the utilization of performance and aerodynamic equations to calculate the fuel burn and CO_2 emissions. These computations are followed by a comparative analysis between the emissions per unit distance of two aircraft model types as a function of specific characteristics such as the drag force. The first part of this section describes the methodologies used to model the CO_2 emissions of four varying flight distances and calculate the average emissions per kilometer to examine how they balance the Landing and Takeoff Cycle (LTO) emissions and the cruise emissions of the aircraft. The purpose of this computational modeling was to showcase how optimization of longer-range flight routes can potentially reduce CO_2 emissions to a considerable extent.

Data Collection:

For the first part of this analysis, the four representative flight distances selected can be generally classified as short haul (covering 500 kilometer or less), short-medium haul (covering more than 500 but less than 1500 kilometers), medium haul (covering around 4500 kilometers), and a long haul (close to the maximum flight distance that can be covered in a flight).[14] The aircraft model A320neo with a CFM LEAP 1A engine was selected for the purpose of this study, considering the fact that it was particularly designed in efforts to decarbonize the aviation sector and offers approximately 20% of more fuel efficiency compared to previous models.[15] Table 1 displays the aircraft parameters that were utilized in this analysis, such as the values of thrust-specific fuel consumption (TSFC), cruise thrust, cruise speed, and the fuel LTO per cycle. These parameters were obtained through manufacturer specifications that were publicly available, reputable aviation databases such as the International Civil Aviation Organization (ICAO), official Airbus technical documents, and studies of credible peer-reviewed literature to ensure maximum accuracy and consistency of the technical values of this model. Furthermore, parameters such as cruise speed and cruise TSFC were collected at the standard cruise altitude of 35,000 feet, as validated by the manufacturer's spec.

Table 1: The following values are performance parameters collected for the A320neo with the CFM LEAP 1A model. These values are used as inputs for modeling CO_2 emissions over different flight distances.

Parameters	Value	Units	Source/Note
Aircraft Model	**A320neo**	**-**	**-**
Engine Type	**CFM LEAP 1A26**	**-**	**-**
Cruise TSFC	**14.43**	**g/kN-s**	16
Cruise Thrust (per engine)	**143.05**	**kN**	17
Total Cruise Thrust (both engines)	**286.10**	**kN**	18
Fuel LTO per Cycle	**304**	**kg/cycle**	19
LTO CO_2 per flight	**960.64**	**kg**	19
Cruise Speed	**840**	**Km/hr**	19

Representative flight distances include 500 kilometers (short haul), 1,500 km (short-medium haul), 4,500 km (medium haul), and 13,500 (long-haul). First and foremost, the cruise time for each distance was calculated by dividing the cruise distance by the cruise speed.

$$Cruise\ Distance\ \div Cruise\ Speed = Cruise\ Time \qquad (1)$$

Since the true air cruise speed of A32neo is **840 km/hr**, the cruise time for 1500 km= **1.79 hr**

Since the main focus of this study is to analyze the CO_2 emissions released during the aircraft's cruise, the next computation in this method is to calculate the fuel flow (kg/hr) of the aircraft. The fuel mass flow rate of an aircraft refers to the rate of fuel consumption per unit of time during cruise. Fuel flow was calculated by taking the cruise thrust to be equal to the aerodynamic drag during steady-level cruise and then multiplying the drag by the thrust-specific fuel consumption, which was assumed constant for this analysis. This assumption is standard for steady level flight operations because, according to the Embry Riddle Aeronautical University, the forward thrust from an aircraft's engines must balance the total balance its total aerodynamic drag to maintain constant altitude and cruise speed. Therefore, this validates fuel flow estimations that can be calculated during cruise conditions.[20]

$$T = D \tag{2}$$

In this context, the quantity ***T*** refers to the thrust. In level cruise, the engine produces enough thrust to equal the aircraft's drag. It is important to acknowledge that the cruise thrust is only equal to the drag during steady cruise, not during climb/descent or changing payloads. Thus, the drag was then computed by utilizing the conventional drag equation.

$$F_{drag} = \frac{1}{2} \times \rho \times C_d \times A \times V^2 \tag{3}$$

In this equation, the quantity ρ represents the approximation of standard air density at an altitude of 35,000 feet according to the International Standard Atmosphere (ISA) model. The quantity V is the cruise speed of the aircraft, and the quantity C_d represents the drag coefficient. Lastly, the quantity A refers to the wing area of the aircraft. The drag force was calculated after making necessary conversions. Then, the value of the A320neo with LEAP 1A engine's representative cruise TSFC was collected from the airline's official model specification sheet and multiplied by the cruise thrust (equal to drag force in level cruise) to compute the fuel mass flow.

$$\dot{m}_f = TSFC \times T \tag{4}$$

The flight fuel flow in kg/hour is $\dot{m}_f$ x 3600. Then, this value was utilized to calculate the fuel burn for each different distance. To calculate these values, the quantity $\dot{m}_f$, the fuel mass flow rate (kg of fuel burned per hour), was multiplied by the cruise time of each distance. This computed the total fuel burned for each distance, and was again utilized to further calculate the CO_2 emissions released during the cruise.

$$\textbf{Fuel Burn} = f_{cruise} \times \textbf{Time} \tag{5}$$

Therefore, to calculate the CO_2 emissions for the amount of fuel burned for each distance, this formula was used to find the mass of CO_2 emissions (kg).

$$m_{co_2} = mt \times X_c \times \frac{MW_{co_2}}{MW_f} \tag{6}$$

In equation 6, the quantity m_{CO_2} refers to the mass of CO_2 (kg), which is what is being solved for and mt is the fuel burned, which was previously calculated. Additionally, the quantity X_c is the carbon fraction of jet fuel, which is a standard value of 0.84, and the quantity $\frac{MW_{co_2}}{MW_f}$ refers to the ratio of molar weights for carbon, which is the value of 44/12. These values were confirmed by the International Civil Aviation Organization for estimating CO_2 emissions from aviation fuel combustion.[21]

Since the focus of this study is to analyze the balance of the CO_2 emissions, including the LTO cycle, those values were separately calculated using a similar methodology. First, the parameter for the fuel mass flow rate (kg of fuel) consumed per LTO cycle for the A320neo with the CFM LEAP 1A model was collected from a credible mechanical document from the airline's database. Then, the mass of the emissions was calculated for each LTO cycle using the CO_2 conversion formula above. The value of this calculation was **LTO cycle CO_2= 960.64 kg**. While the value of the LTO emissions may vary in real life due to engine settings, airport conditions, and the weather, a fixed value was assumed for this analysis for baseline comparison. Therefore, the value of 960.64 kg was added to the varying amounts of CO_2 (kg) released during cruise for each flight path of the aircraft to calculate the approximations for total CO_2 emissions released for all the flight distances.

$$Total\ CO2\ (kg) = LTO\ Cycle\ CO2\ (kg) + CO2\ cruise\ emissions\ (kg) \tag{7}$$

Thereafter, the average CO_2 emission per kilometer (kg/km) was computed for each distance using this equation to calculate the final values and the overall factor of CO_2 that was being released for each distance.

$$Avg. CO2\ per\ km\ \left(\frac{kg}{km}\right) = \frac{Total\ CO_2}{Total\ Flight\ Distance} \tag{8}$$

This concludes the first methodology that was used to analyze the effect of optimizing flight distance on CO_2 emissions, as the emissions released for each distance were calculated accordingly.

Limitations and Assumptions:

To produce a transparent and reproducible analysis, this study adopts a small number of simplifying assumptions. First and foremost, this analysis assumes constant thrust specific fuel consumption (TSFC) for the A320neo model LEAP 1A engine, even though TSFC might vary due to changes in altitude, flight speed, atmospheric conditions, payload, and weight reduction during flight.[22] Furthermore, the aircraft's cruise thrust was taken equal to cruise drag in steady cruise conditions; thus, climb and descent phases were not modeled separately. The Landing and Takeoff (LTO) emissions are represented by a single baseline per cycle and were calculated based on the LTO mass fuel flow rate of the A320neo that was officially published in the airline's database. However, it is important to acknowledge that LTO cycle emissions are not fixed in reality and can vary considerably depending on the thrust settings, airport location/operations.[23] The assumptions explained above were made to enable a tractable comparison using publicly available aircraft data while clearly exposing where future refinement could focus.

In the next stage of this study, a drag-based approach was employed to perform a comparative analysis between two aircraft models to calculate the fuel consumption, the CO2 emissions, and assess how differences in the wing structure of aircraft can directly impact the CO_2 emissions. Hence, the first aircraft model is the same model that was utilized in the first methodology to calculate the average (kg) of CO_2 emissions per km, which was the A320neo with the CFM LEAP 1A design model. The secondary aircraft model that was compared was the Airbus 220-300 with PW1500G. To ensure full clarity on the distinction between sourced data and computed values in this analysis of aerodynamics, Table 2 and Table 3 present the performance parameters of each aircraft, such as the fuel flow rates, wing dimensions, and maximum take-off weight (MTOW) data that were collected from credible sources of the aircraft models' manuals, spec sheets, and databases. After obtaining these sourced parameters, the CO2 emissions for each of the aircraft models were computed through the methodology described above. The cruise thrust, in particular, was calculated based on the drag force and the cruise speed values, which were collected from the sources to ensure a realistic reflection of operational conditions.

Table 2: Structural and performance parameters for the A320neo with CFM LEAP 1A engine are used to calculate CO_2 emissions per flight distance. The table presents the main aerodynamic and operational parameters that directly influence fuel efficiency and emissions.

Parameter	Value	Units	Source/Note
Aircraft Model	**A320neo**	**-**	19
Engine Type	**CFM LEAP 1A26**	**-**	19
Wing Span (b)	**35.8**	**m**	19
Wing Area (S)	**122.4**	**m²**	19
Cruise Speed	**840**	**km/hr**	19
Fuel Flow	**1845.30**	**kg/hr**	19
MTOW	**79,000**	**kg**	19

Table 3: Structural and performance parameters for the Airbus 220-300 with PW1500G engine used to calculate CO_2 emissions per flight distance. The data displays the critical operational and aerodynamic parameters used in emission modeling.

Parameters	Value	Units	Source/Note
Aircraft Model	**Airbus A220**	**-**	24
Wing Span (b)	**35.1**	**m**	24
Wing Area (S)	**112.3**	**m²**	24
Cruise Speed	**871**	**km/hr**	24
Thrust (both engines)	**207.28**	**kN**	24
Engine Type	**PW1500G**	**-**	24
MTOW	**154,000**	**lbs**	24
Fuel Flow	**1850**	**kg/hr**	24

By using these precise values, the drag force for each aircraft mode was calculated, which led to varying results due to clear differences in factors such as wing area, which impacted the drag coefficient. The drag force was calculated using equation (2). The quantities in this equation, such as, F_{drag} refer to the drag force (N) while the quantity ρ is the air density at a specific altitude. According to the International Standard Atmosphere, 0.3099 is the standard value for this term at the standard cruise altitude of 35,000 feet. The quantity A is equal to the wing area in m^2 and V^2 is the velocity of the aircraft squared. While the precise values were not available, the drag coefficient C_d values that were utilized in this analysis were validated with representative values from similar aircraft configurations.

Using this equation and the varying values of the wingspan, drag coefficient for each model, it was calculated that the drag force of the A320neo with CFM LEAP 1A was approximately **35,522 N** and the drag force of the Airbus 220-300 with PW1500G was approximately **32,500 N**.

Subsequently, these values were used to calculate the fuel flow rate (mass of fuel per hour) by using the thrust specific fuel consumption (TSFC). By equation (3), a lower drag force requires less thrust and thereby reduces fuel per hour.

In this equation, the coefficient $\dot{m}_f$ is the fuel flow rate, and the TSFC refers to the thrust specific fuel consumption, while T equals to the cruise thrust. The value of an aircraft's cruise thrust is equal to its drag force if the aircraft is flying under steady conditions and constant speed without acceleration.[25] Thus, this research used the drag force that was previously calculated for both models to solve for the fuel flow rate of the aircraft.

After conversion of units, the fuel flow of the A320neo was **1845.30 kg/hr**. For the second aircraft model of Airbus 220-300 the value of fuel flow for this model is **1850 kg/hr**. Then, these values were divided by their respective cruise speeds to find the fuel burned per kilometer (kg/km).

$$\frac{\dot{m}_f}{Cruise\ Speed} = Fuel\ Burned\ (kg/km) \tag{9}$$

Then, the values of the fuel burned per km (kg/km) were multiplied by the standard CO2 emission factor per kg of jet fuel of 3.15, to collect the CO2 emissions of each different aircraft per hour.[26]

$$CO_2\ emissions\ per\ hour\ =\ Fuel\ Burned\ (kg)\ * 3.15 \tag{10}$$

Following this calculation for each of the aircraft models, the final step of the methodology involved dividing the mass of CO2 emissions per hour (kg/hr) by the cruise speed of each aircraft model, which was the main focus of the second objective of this research. The simple equation that was utilized is included below.

$$CO_2\ emissions\ per\ kilometer\ =\ \frac{CO_2\ emissions\ per\ hour}{Cruise\ Speed} \tag{11}$$

This marks the end of the methodologies that were employed to address the two main research objectives. The methodology of the primary objective involves a secondary data analysis of the A320neo with CFM LEAP 1A aircraft model by collecting publicly available performance data, such as fuel flow rates and LTO fuel cycle data, to compute emissions as a function of distance. The secondary objective of this paper was approached by performing a comparative analysis of the emissions released by two varying aircraft models and examining how differences in their wing structure affected the drag coefficient and thereby affected the amount emitted.

The results of the computations of CO2 will be described in Section 3 through various graphs and detailed tables that will contain all the calculations and parameters, allowing for quantitative comparisons as well as visual interpretations of the emission patterns.

Results

The numerical values of the computations of the CO2 emissions for the four different distances are presented in Table 4. The following values were calculated using the methodology above and will be described clearly in relation to the primary objective. For each distance, cruise time was calculated based on the cruise speed of the model. While total cruise CO2 emissions increase with distance, the average CO2 emissions per km decrease.

Table 4: Calculated values of the total and average CO_2 emissions (kg and kg/km) for the A320neo with CFM LEAP 1A engine across four representative flight distances (short, short-medium, medium, long haul). The computations indicate that the longest flight path of 13,500 kilometers produced the lowest average CO_2 emissions per kilometer.

Flight Distance (km)	Cruise Time (hr)	Fuel Burn during cruise (kg/hr)	CO_2 cruise emissions (kg)	LTO Cycle CO_2 (kg)	Total CO_2 (kg)	Average CO_2 per km (kg/km)
500	0.59	1098.39	3459.94	960.64	4420.58	8.841
1500	1.78	3295.18	10379.81	960.64	11,340.45	7.560
4500	5.35	9885.54	31139.44	960.64	32,100.08	7.133
13500	16.07	29656.6	93418.33	960.64	94,378.97	6.991

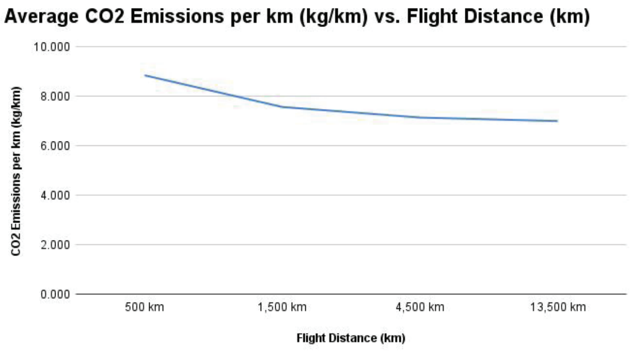

Figure 1: Average CO_2 emissions released per kilometer (kg/km) for the A320neo with CFM LEAP 1A engine across four representative flight distances (500 km, 1,500 km, 4,500 km, and 13,500 km). The results show that emissions per kilometer decrease as flight distance increases, which indicates greater efficiency on longer flights.

Figure 1 demonstrates the slight decline in the average mass of CO_2 emissions per unit distance as a result of an increase in flight distance. According to the graph above, the rate of decline is the most pronounced over the shorter range of distance, such as from 500 kilometers to 1500 kilometers, reflecting the effect of the fixed LTO cycle emissions being balanced out over fewer kilometers. The CO_2 emissions per kilometer were reported to have a 20.9% reduction from the shortest distance (500 kilometers) to the longest distance (13,500 kilometers) on the graph.

Regarding the next objective of analyzing the effects of wing-aspect ratio on the drag coefficient and carbon emissions, the findings in the analysis of both aircraft designs indicate differences between the CO_2 released per km of each model.

Table 5: Numerical values were calculated for each aircraft model using the second methodology described in Section 2. The results indicate that the Airbus 22-300 with PW1500G engine produces slightly lower CO_2 emissions per kilometer compared to the A320neo.

Aircraft Model	Wing Aspect Ratio	Drag Force (N)	TSFC (g/kN*s)	Fuel Flow (kg/hr)	CO_2 per hr (kg/hr)	CO_2 per km (kg/km)
A320neo with CFM LEAP 1A	10.471	35,522	14.43	1845.30	5831.13	6.942
Airbus 220 with PW1500G	10.971	32,500	16.01	1873.17	5919.21	6.796

The two selected aircraft models have varying wing-aspect ratios, as the Airbus 220 with PW 1500G engines has a slightly higher value of 10.970. As a result of this value, the drag force of this aircraft is considerably lower than that of the A320neo because a higher wing-aspect ratio creates less induced drag, which, in turn, reduces the drag force of the plane according to the equation utilized in the methods section. While the fuel mass flow rate and the thrust specific fuel consumption (TSFC) of the Airbus 220 appear to be higher, the cruise speed of this aircraft model is higher, with the value of 871 km per hour, because of its longer and more slender wing structure (high aspect ratio), which reduces drag and increases the efficiency of the plane.

The following bar graph shows a 2.10% reduction of CO_2 emissions per km of the Airbus 220-300 with PW1500G. Although the Airbus 220 burns more fuel per hour than the A320neo due to its high TSFC value, it has a lower drag, which increases efficiency and yields slightly lower CO_2 emissions than the A320.

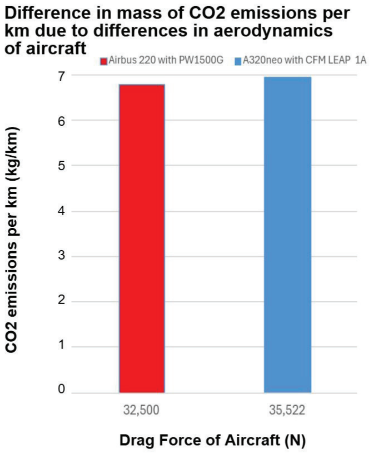

Figure 2: Comparison of CO_2 emissions per kilometer (kg/km) between the A320neo with a CFM LEAP 1A engine and Airbus 220-300 with PW1500G engine. The results show that the aircraft with a lower drag force produces slightly lower CO_2 emissions per unit distance, indicating improved efficiency.

To ensure consistency and reliability of the data, the results described in this section were verified with publicly available International Civil Aviation Organization's emission databank and were found to be within a ±10% range of reported values for similar aircraft configurations and flight profiles. While this is not a direct validation, the similarity between the values supports the credibility of this computational approach. This evidence lays the foundation for subsequent discussion and analysis, which is presented in the next section.

Discussion

Although some critics may argue that long-distance flights consume more total fuel, this study emphasizes the CO_2 emissions released per unit distance rather than just taking cruise emissions into account. According to the Intergovernmental Panel on Climate Change, landing and take-off (LTO) emissions are estimated to account for over 10% of the aviation industry's carbon emissions that contribute to climate change.27 As seen in Table 4, the impacts of LTO emissions per flight cycle are best diminished over longer distances. From the range of 500 kilometers to 13500 kilometers, there was a 20.9% reduction in the average CO_2 emissions released per kilometer (kg CO_2/km). However, it is important to interpret these results in the light of the study's assumptions that the LTO CO_2 emissions per cycle were represented by a fixed

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numerical value of 960.64 kg. It should be noted that these values might vary due to factors such as take-off and landing conditions (often determined by the airport), meteorological conditions, and other operations. It was estimated that a ±20% variation in the LTO CO_2 emissions would noticeably affect the emissions per kilometer of shorter flights but have a minimal impact on longer flights, which would still preserve the observed trend of the analysis.[28]

While analyzing the values of CO_2 emissions over longer paths and the effects of a lower drag coefficient, it has become clear that the trends and patterns of the data support the paper's hypothesis and align with its two main research objectives by showing that moderate reductions in CO_2 emissions could be achieved through operational and aerodynamic strategies. Figure 1 explicitly shows the declining trend of the average mass of CO_2 emissions per km for short-haul flights, which reflects the disproportionate contribution of LTO cycles to shorter flight routes. This supports the paper's implication that short-haul flights are less efficient in terms of carbon emissions per kilometer. For longer flight distances (4500 km -13,500 km), the curve flattens slightly because the fixed CO_2 emissions of the LTO cycle and the cruise CO_2 emissions are more proportionate. A report by the International Council on Clean Transportation validates this trend and explains that the carbon intensity (grams of CO_2 per passenger kilometer) is significantly higher for short-haul flights (< 1000 km) and gradually starts to decline from around 1500 km to 2000 km due to the balance between cruise CO_2 emissions and LTO cycle CO_2 emissions. This underscores the importance of modeling cruise and LTO cycle emissions separately when assessing operational strategies to decrease CO_2 emissions because improvements that specifically target LTO cycles could yield higher emission reduction rates for shorter flight paths.

An in-depth analysis of previous studies has indicated that aircraft emissions efficiency can substantially vary based on differences in aircraft configurations, passenger occupancy, and flight conditions.[28] This means that even small percentage improvements at the aircraft level can translate into meaningful cumulative emission savings when applied across larger fleets. To account for factors such as passenger loads while studying the impact of transportation on the environment, CO_2 emissions are also frequently measured in grams of carbon dioxide per passenger-kilometer (gCO_2/pax-km). While a detailed normalized passenger analysis was beyond the scope of this study, it represents an important direction for future work on this topic.

The secondary objective of this research was to compare the CO_2 emissions as a function of the drag coefficient of the Airbus 220-300 and the A320neo, which had differing wing aspect ratios. According to Embry-Riddle Aeronautical University, the wing-aspect ratio of an aircraft wing is the most important factor of aerodynamic analysis because it directly affects the vortex, which is also known as the drag coefficient.[29] The wing-aspect ratio of an aircraft refers to the ratio of its wing span to its mean chord, and it can be calculated by squaring the wingspan and dividing it by the wing area. High aspect ratio wings are considered to be more efficient as they generate more lift and reduce the induced drag at the wingtips of a plane.[30] By performing a comparative analysis using parameters, aspect ratios, and wing area, the CO_2 emissions per km of each aircraft model were calculated. Table 5 displays the calculations for various parameters of the two aircraft models collected through their official airline spec sheets. As shown in the table, the Airbus 220-300 has a slightly higher wing aspect ratio than the A320neo model, which resulted in a lower drag force and reduced thrust requirements to overcome air resistance. Although the fuel flow rate of the Airbus 220-300 was higher than that of the A320 due to its larger capacity, it still released fewer CO_2 emissions per km as it had a higher cruise speed. The increased cruise speed of the Airbus 220-300 was a result of superior aerodynamic efficiency because a lower drag enables the plane to maintain a higher speed at the same input of energy.

Figure 2 models the difference in the amount of CO_2 emission per km of both aircraft models and indicates a reduction of about 2.10% in the mass of the emissions. While seemingly minor, it is acknowledged by the government agency of the National Oceanic and Atmospheric Administration that even small reductions in CO_2 accumulate across fleets over time.31 It is important to mention that even just a 2.1% reduction in emissions per aircraft can represent a rough estimate of about 60 to 70 metric tons of CO_2 saved per aircraft per year when scaled to thousands of flights annually. This demonstrates how the collective impact of small operational improvements can considerably help minimize aviation's emissions that contribute to climate change.

Despite the relatively modest percentage change, these findings overall suggest that operational optimization can be important as a component of broader aviation emission reduction strategies. In the context of the aviation industry, incremental efficiency improvements remain a critical pathway for reducing emissions in the near term. Along with other emission reduction measures such as sustainable aviation fuels, improved air traffic management, and advanced aircraft structural modifications, the implementation of operational strategies such as flight route optimization and aerodynamic efficiency can lead to cumulative environmental benefits across commercial aviation fleets.

■ Conclusion

This paper assessed how optimizing longer flight paths and improving aerodynamic efficiency can help mitigate the impact of aviation's carbon emissions on the climate. By utilizing the officially published aircraft parameters of a reputable aircraft model, secondary analysis was conducted to compute the average CO_2 emissions per unit distance of four selected flight distances with varying ranges. Secondly, a comparative study was conducted between two aircraft models after the collection of their respective aerodynamic performance data to analyze the impact of the drag coefficient on the CO_2 emissions. With the trends of the data indicating a 20.9% decline in the average mass of CO_2 emissions per kilometer from the shortest flight distance to the longest flight distance, and a modest difference of about 2.10% reduction in average CO_2 emissions as a result of reduced drag and increased aerodynamic efficiency, the results aligned with the paper's initial proposition. While the benefits of flight path optimization are more apparent over shorter ranges, CO_2 reductions through aerodynamic efficiency prove to be consistent through all ranges. These findings indicate potential benefits of implementing operational efficiency improvements that encourage a decrease in CO_2 emissions through longer flight paths and increased aerodynamic efficiency. However, they should not be interpreted as direct policy changes because implementing these measures in the real world would require further advanced system-level studies that consider factors such as cost, route demand, and fleet compositions. Within these limitations, this paper provides a quantitative illustration of how longer route optimization and drag reduction could possibly contribute to aviation's ongoing efforts to achieve a greener future.

Future research in this field could aim to extend this study by analyzing the effects of both the operational strategies on the same emissions in a unified approach, while also exploring the application of these principles to a wider range of fleets to examine variations. In addition to this, there remains a significant gap in research in understanding the process of how flight management systems can integrate operational strategies and changes in aerodynamics under varying atmospheric and air traffic conditions.

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References

1. European Commission. *Causes of Climate Change*; https://climate.ec.europa.eu/climate-change/causes-climate-change_en (accessed Aug 15, 2025).
2. International Energy Agency. *Aviation*; https://www.iea.org/energy-system/transport/aviation (accessed Aug 14, 2025).
3. Braun, M.; Grimme, W.; Oesingmann, K. Pathway to Net Zero: Reviewing Sustainable Aviation Fuels, Environmental Impacts and Pricing. *J. Air Transp. Manag*. 2024, *117*, 102580. https://doi.org/10.1016/j.jairtraman.2024.102580.
4. Ting, E.; Reynolds, K. W.; Nguyen, N. T.; Totah, J. Aerodynamic Analysis of the Truss-Braced Wing Aircraft Using Vortex-Lattice Superposition Approach. In *32nd AIAA Applied Aerodynamics Conference*; American Institute of Aeronautics and Astronautics: Atlanta, GA, 2014. https://doi.org/10.2514/6.2014-2597.
5. Brueckner, J. K.; Kahn, M. E.; Nickelsburg, J. How Do Airlines Cut Fuel Usage, Reducing Their Carbon Emissions? *Econ. Transp*. 2024, *38*, 100358. https://doi.org/10.1016/j.ecotra.2024.100358.
6. International Air Transport Association. *SAF Volumes Growing but Still Missing Opportunities*; https://www.iata.org/en/pressroom/2023-releases/2023-12-06-02/ (accessed Aug 14, 2025).
7. Harrison, N. *Primary Funding Opportunities: High Aspect Ratio Wings and Dry Wings*; Aerospace Technology Institute; https://www.ati.org.uk/news/primary-funding-opportunities-high-aspect-ratio-wings-and-dry-wings/ (accessed Aug 14, 2025).
8. *Operational Improvements to Reduce the Climate Impact of Aviation—A Comparative Study from EU Project ClimOP*; https://www.mdpi.com/2076-3417/13/16/9083 (accessed Aug 14, 2025).
9. International Civil Aviation Organization. *Operational Measures*; https://www.icao.int/operational-measures (accessed Aug 15, 2025).
10. EUROCONTROL. *Inefficiency in the European Air Traffic Management Network Resulting in an Average Additional Fuel Burn of 8.6–11.2%*; https://www.eurocontrol.int/press-release/inefficiency-european-atm-network-resulting-additional-fuel-burn (accessed Aug 15, 2025).
11. Moniruzzaman, C. G.; Bowden, J.; Arunachalam, S. Aircraft Landing and Takeoff Emission Impacts on Surface O3 and PM2.5 through Aerosol Direct Feedback Effects Estimated by the Coupled WRF-CMAQ Model. *Atmos. Environ*. 2020, *243*, 117859. https://doi.org/10.1016/j.atmosenv.2020.117859.

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