

Historical Domestic Flights from 2016-2020 with Estimations of Greenhouse Gas Emissions by Aircraft Type

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Data and analyses are presented on the utilization of aircraft fuel in the U.S. and the greenhouse gas emissions that they create. Aggregated commercial passenger and freight aviation flight data from 2016-2020 is captured from the Bureau of Transportation Statistics website is used to augment flight data from the Sherlock data warehouse at NASA Ames is used to determine the miles flown by major aircraft models. The corresponding fuel burn is estimated using the International Civilian Aviation Organization fuel burn tables and carbon dioxide emissions are calculated using a fuel-burn multiplicative factor. One key conclusion of this analysis is that long haul flights (i.e. >2485 statute miles) create a disproportionately large amount of carbon dioxide emissions in the U.S while short flights (i.e. < 311 statute miles) contribute less than five percent of the U.S. aviation-related carbon dioxide emission. Although these short-haul flights may not have a large impact on overall carbon dioxide emissions, they will be a critical entry point for the adoption of future, larger fuel-efficient novel vehicles and the impact to future airport and infrastructure requirements. The final paper will present some estimates of the impact of advanced technologies on fuel burn and CO₂ emissions in various scenarios.

I. Introduction

On November 9, 2021, the Federal Aviation Administration (FAA) published the United States 2021 Aviation Climate Action Plan [1]. The stated goal of this government-wide plan is to achieve net-zero life cycle greenhouse gas (GHG) emissions from aviation in the United States by 2050 in order to avoid irreversible and potentially catastrophic climate change. Although aviation accounts for a relatively small portion of GHG emissions, (currently 1.9% of the total CO₂ emitted and 3.5% effective GHG when accounting for contrails) global aviation GHG emissions are projected to triple by 2050 [1].

The FAA plan is a policy framework with government and industry goals and actions. In the near-term, the plan anticipates GHG reductions through aircraft efficiency improvements and greater use of sustainable drop in jet fuels. In the far term, advanced technologies such as cryogenic hydrogen fueled, electric and electric hybrid configurations are encouraged but are not expected to have an impact on GHG until after 2050. Paths to net zero GHG will require major reworking of the nation's aviation and energy infrastructure at great cost. Eliminating fossil fuels from aviation by 2050 is an ambitious goal, but the odds improve if decisions are made guided by science and data.

The original motivation for studying aircraft utilization and CO₂ emissions is a surprising result published by the EUROCONTROL [2], the main European flight safety and support intergovernmental organization, that shows long-haul flights are disproportionately large contributors to GHG (see Figure 1). Presented in Figure 1 are the number of European departures in 2020 (left bar) and their corresponding CO₂ emissions contributions (right bar). The data for each bar is segregated into four distance bins. The chart shows that more than half of European aviation's CO₂

emissions were emitted from just 6.2% of the flights. The data also indicates that 31% of the flights, with distance less than 500 km, accounted for only 4% of the emissions. The EUROCONTROL authors rightly see this situation as somewhat of a dilemma: while short-haul flights are those most likely to be successfully electrified, complete electrification of these flights using today’s technology would reduce total emissions by not much more than 4%. The EUROCONTROL authors concluded that increasing the supply of sustainable aviation fuels to cover just 10% of the long-haul flights would be more impactful on emissions reductions than complete electrification of the entirety of short-haul flights.

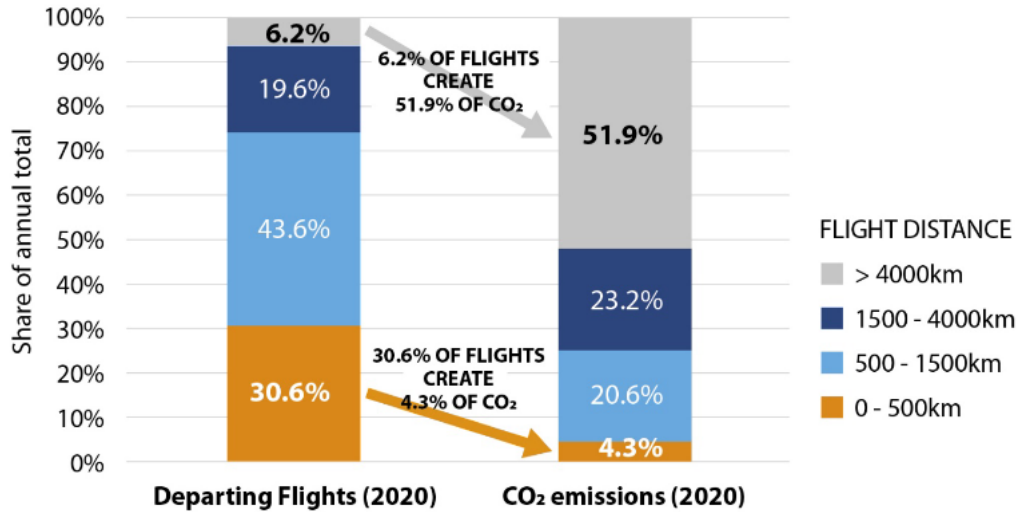


Figure 1. European flight data and aviation emissions estimates for 2020 (adapted from [2]).

The current study sets out to see if these same trends are observed for 2020 US departing flights and to develop additional insights into the US flights and emissions data by using the flight data aggregated in the Sherlock database [3] and ICAO fuel consumption models [4]. Additionally, the US data in the Sherlock database was interrogated to study the impact of the COVID-19 pandemic on US aviation during 2019 and 2020 and to compare those statistics with those reported by the Bureau of Transportation Statistics. Finally, the data was mined to determine other flight patterns including typical ranges flown by vehicle type and fuel economy per seat-mile, to gain a deeper understanding of fuel usage by aircraft type.

There are a couple of notable similar studies. Zeng and Rutherford [5] study the fuel use of commercial jet aircraft from 1960 to 2019. Their results show that although aircraft fuel efficiency has increased by a factor of two since 1960, aviation CO₂ emissions are continuing to increase. Quadros et al. [6] derive global civil aviation emissions estimates based on Automatic Dependent Surveillance–Broadcast (ADS-B) data coupled with a fuel use model to show that the majority of aviation fuel is consumed in North America, Europe and along the Pacific Rim. Seymour et al. [7] present a high-fidelity fuel use and CO₂ emission estimation methodology that is validated against airline fuel consumption reports for 133 aircraft models.

II. U.S. Flight Data from 2016-2020

Flight data from BTS and the Sherlock data warehouse for 2016–2020 and augmented with the ICAO fuel consumption models is used to perform an emission and distance study for comparison with the EUROCONTROL results. To conform to the EUROCONTROL study, all departures of passenger and cargo flights from U.S. airports are identified and used for the emissions calculations using the simplified ICAO distance-based fuel calculations described in reference 4. Several detailed inputs and operational considerations such as passenger load factors, airline seat layouts, taxi distances, indirect routings, engine sub-models, mail and cargo, etc. are not accounted for in the fuel consumption estimates presented in this report, as this data was not generally available for each flight. Final carbon dioxide emissions are then calculated assuming 3.16 lb of CO₂ are created for each pound of fuel consumed. Figure 2 shows the U.S. results from 2016 through 2020 using the same distance bins and coloring schema as the

EUROCONTROL study.

Figure 2 clearly shows the similarities and differences between the 2020 European and U.S. emissions results from 2016 through 2020. As in Europe, the majority of U.S. flights range between 500 and 4000 km (the light and dark blue layers), and the fractions of emissions produced by the shortest flights (orange layers) are very similar. Our calculations indicate that nearly one-third of the U.S. aviation CO₂ contribution comes from a relatively small number of long flights (grey layers), and a disproportionately small amount of CO₂ comes from a relatively large number of short flights (orange layers). Some differences include a smaller proportion of the longest U.S. flights compared to that from the EUROCONTROL data, with the emissions contribution scaling similarly. The other significant difference is that the largest portion of the U.S. emissions is produced by the longer flights under 4000 km (the dark blue layers), not the over 4000 km (grey layers) as in the EUROCONTROL data.

Pre-pandemic flight patterns in the U.S., 2016-2019, showed similar flight trends, with a few long-haul flights dominating the total fuel used. A decrease in the number of longest flights (grey slice) can be seen in the 2020 data, dropping roughly 1% as compared to flight patterns of the number of longest flights between 2016-2019 (5.2-5.4%). This was due to the decrease in international destinations starting in 2020.

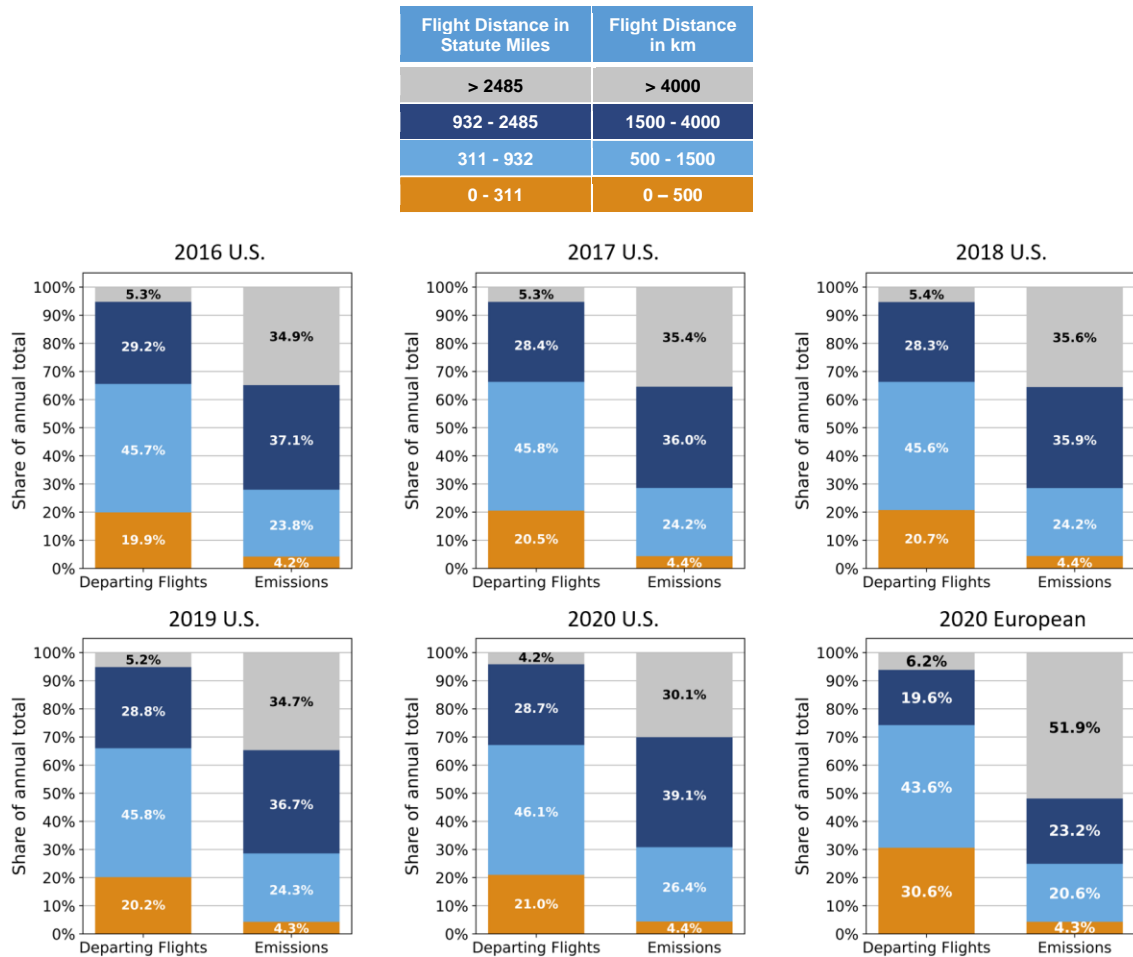


Figure 2. Comparison of 2016-2020 U.S. and European departure and emission data.

Figure 3 shows the cumulative percentage of total annual fuel used as a function of distance (in statute miles) between 2016 to 2020. The trends were very consistent from 2016 through 2019. This chart shows that roughly 30-35% of the total annual fuel burned in the years 2016-2020 occurred on flights that were less than 1000 statute miles. The relatively larger percentage reduction in longer flights due to the COVID-19 pandemic is more clearly seen by

the large deviation of the 2020 trend from those of the previous four years for flights longer than 1000 statute miles. In 2016-2019, 70% of the total annual fuel burned occurred on flights less than 3000 statute miles. In 2020, that fraction increased to 75% for flights less than 3000 statute miles, or conversely, flights greater than 3000 statute miles contributed only 25% of fuel used in 2020, compared to 30% for the years before the COVID-19 pandemic.

In the remainder of this paper, we will focus on the 2019 flight data and discuss the fuel efficiencies and missions flown by the top contributors to CO₂ emissions. Given the scaling factor of 3.16 lb of CO₂ created for each pound of fuel consumed, the remainder of this paper will report fuel usage rather than CO₂ emissions directly.

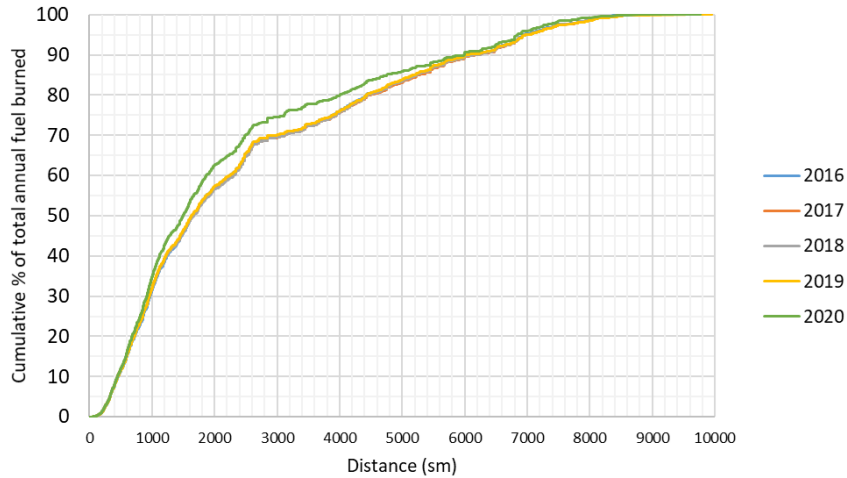


Figure 3. Cumulative percentage of total fuel used, by distance traveled, 2016-2020.

III. Aircraft Fuel Mileage

A familiar way to consider the efficiency of passenger aircraft is the statute miles travelled per U.S. gallon of fuel (MPG), viewed on a per available seat basis. Shown in Figures 4 and 5 are the MPG per available seat versus available seat statute miles for the most heavily utilized aircraft during 2019. The data points on the plot represent the fuel economy predicted for the average flight distance flown and the bars extending vertically from the data point span the range of fuel economy that the aircraft is capable of for flights between 300 statute miles and the plane’s maximum range. So, for example, airplane models that are used near their peak fuel efficiency (on average) would have a bar extending below the associated data point (see Appendix A in [9] for the aircraft type, model codes and number of seats).

IV. Aircraft Capacity, Range and Fuel Efficiency

The scatter-bubble chart in Figure 6 shows multiple dimensions of the historical flight data for the top 50 vehicles by available seat-mile in 2019. The x-axis is the average distance (in statute miles) traveled per flight, the y-axis shows the total average fuel efficiency per available seat-mile (miles per gallon per seat), the size of the bubble is the relative fuel burned as a fraction of the total fuel burned in 2019, and the color of the bubble is a partitioning by aircraft size, defined in the paper by passenger capacity: red for vehicles less than 100 passengers, green for vehicles between 100-199 passengers, teal for vehicles between 200-299 passengers, and purple for the largest vehicles (greater than 300 passengers). All flight and vehicle data have been aggregated and averaged by vehicle type to create this chart. Although these are aggregated values, the overall trends should still be informative.

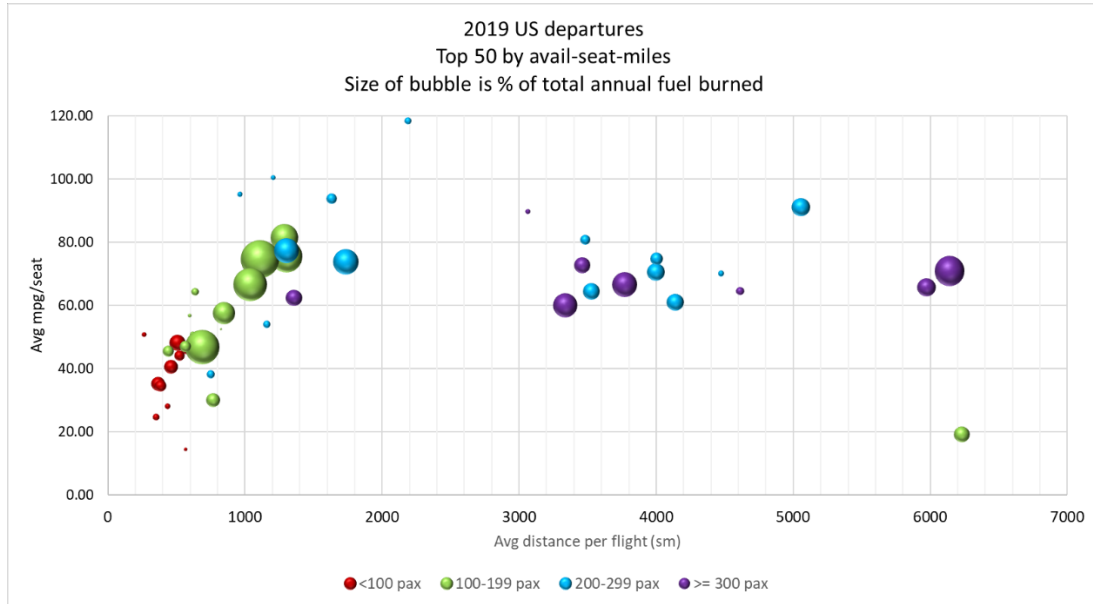


Figure 6. Scatter bubble chart showing fuel economy as a function of average flight distance, capacity and contribution to total fuel used in 2019.

This chart displays the expected clustering of the different vehicle passenger capacities as a function of average distance travelled per flight. The small vehicles (less than 100 passenger capacity) typically fly the shorter distances (less than 600 statute miles), while the larger vehicles fly the longer distances, with a clustering of the 100-199 passenger vehicles flying typical distances of 6800-1400 statute miles. The two largest passenger capacity vehicles (greater than 200 passengers) are flown for distances greater than 2000 statute miles, with clusters for the 3200-3400 statute miles and another for > 5000 statute miles.

Typical fuel efficiency values per available seats ranged between 40 and 80 miles-per-gallon-per-available-seat (mpg/seat), with most fuel-efficient vehicles in terms of mpg/seat appearing at the top of this chart. Some newer aircraft are shown with higher fuel efficiency, estimated to be as much as 120 mpg/seat, with significantly lower contribution to overall fuel usage (size of bubble). This small contribution to total fuel consumed occurs not only because they are more fuel efficient, but also because these vehicles were recently introduced to the U.S. fleet and have fewer total flights and mileage as of 2019. Most interesting is the linear trend seen between fuel economy per available seats and distance flown per flight for distances less than 1400 statute miles. For longer flights, the current vehicle fleet appears to reach a plateau in terms of fuel efficiency per available seat, in the range of 60-80 mpg/seat, regardless of distance flown.

There are multiple vehicle classes for flights between 400 and 1400 statute miles, with representation from all four vehicle capacity categories. The largest contributor in terms of fuel burned in this flight range comes from vehicles with capacities between 100-199 passengers (large green bubbles) and flying 600-1400 statute miles. Although the vehicles with less than 100 passengers (small red bubbles) contribute a small amount to total annual fuel burned

because of their shorter distances and capacities, these vehicles dominate the shorter ranges (less than 600 statute miles) and it would not be practical to replace this market segment with fewer large vehicles.

V. Summary

An analysis of U.S. flight departure patterns from 2016 to 2020 and their contribution to greenhouse gas emissions was done using combination of publicly available aircraft, airport, and flight data primarily from the BTS website and the Sherlock data warehouse, maintained by NASA Ames Research Center, was used. The Sherlock flight data and data from the BTS website were augmented with additional calculated parameters, including estimates for distance, fuel usage, and available seat-miles. No attempt was made to introduce the impact of actual passenger load factors, seating layouts, cargo, and other operational considerations on the fuel usage estimates, however, load factors exist in the BTS dataset and an update to the current analysis will be done for the final manuscript.

A comparison of 2020 U.S. passenger and cargo departures and emissions shows similar trends to the ones found by the 2020 EUROCONTROL data. Based on the number of U.S. departures in 2020:

- Long-haul flights (those traveling more than 2485 statute miles) create 30% of aviation related CO₂ emissions but make up only 4% of the total number of U.S. departures.
- Short-haul flights (those traveling less than 311 statute miles) make up 21% of the total number of U.S. departures yet create less than 5% of aviation-related CO₂ emissions.

The 2020 analysis was extended to cover U.S. departure flights between 2016 and 2019. Key findings from the five-year timeframe include:

- The annual CO₂ travel and emission trends were relatively consistent over the timeframe from 2016 to 2020.
- In 2020, the COVID-19 pandemic caused a significant reduction in total air traffic, with a proportionally larger reduction in long-haul flights caused by cancellation of relatively more international than domestic flights.
- The very long-haul flights (those traveling more than 2485 statute miles), while few in terms of number of flights (less than 5%), generate a large fraction (30–36%) of CO₂ emissions.
- The greatest portion of U.S. aviation CO₂ emissions (36–39%) are created by flights traveling 932 to 2485 statute miles. A reduction of 10% in fuel use in the vehicles flying these missions has the potential to result in a 4% emissions reduction. This is the same amount to which all the short-haul flights contribute annually.
- Flights ranging from 932 to 2485 statute miles also account for the greatest portion (40–44%) of U.S. available seat-miles.
- Flights between 500 and 2000 statute miles generated approximately half of total 2020 emissions.

Future work will include mining data in other ways to understand flight patterns such as seasonal variations and network connectivity, and to quantify the potential benefits of fleet substitution, flown both domestically and internationally, to support future sustainable aviation studies. This data can also be used to assess the potential of new technologies (e.g., electric aircraft) on projected GHG emission and to help inform future climate-related decision making by both governments and industry.

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