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Environmental Benefits Assessment of the Traffic Aware Strategic Aircrew Requests Concept

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Abstract

Reduction of greenhouse gas emissions has been a focus area of the scientific community for the past several years. Specifically, the aviation industry has set goals to reduce greenhouse gas emissions, providing a sustainable transportation mechanism with minimal impacts on the environment. This reduction must be accomplished through several means, including advanced technology, sustainable propulsion, efficient air traffic management, and improved operations. A potential solution for improving operations in an efficient air traffic management system is the Traffic Aware Strategic Aircrew Requests (TASAR) concept. The TASAR concept applies onboard automation for the purpose of advising the pilot of route modifications that would be beneficial to the flight, leading to a decrease in direct operating costs through fuel burn reduction and shorter flight times. This report discusses analyses that provide an estimate of the potential environmental benefits that result from the application of the TASAR concept. The data used for this benefits assessment was gathered during an operational evaluation on revenue flights with an airline partner between July 2018 and April 2019. The analyses in this report determined that there are impactful potential environmental benefits to be realized using the TASAR concept.

1 Introduction

Earth's climate has changed throughout history. However, since the mid-20th century, humans have adversely contributed to the global warming phenomenon through emissions of greenhouse gases. Atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are at unprecedented levels in at least the last 800,000 years [1], mainly from anthropogenic[1] casual factors. To reduce the impact of anthropogenic greenhouse gas emissions on the environment, many countries signed the Paris Agreement—an international treaty on climate change with the goal to limit global warming compared to pre-industrial levels by reducing greenhouse gas emissions [2]. In 2021, President Biden reaffirmed the Paris Agreement and made climate change a focus area of his administration's policies [3].

In 2018, the transportation sector in the United States generated approximately 1,877 million metric tons, (megatons, Mt) of carbon dioxide equivalent (CO_2e)[2] of net emissions, aviation contributing approximately 9% (approximately 175.5 Mt CO_2e) of total transportation-related greenhouse gas emissions from burning jet fuel or aviation gasoline [4]. Globally in 2018, the aviation industry contributed approximately 700 Mt CO_2e [5]. Projections based on estimated fleet growth show that the global aviation industry would contribute approximately 1,800 Mt of CO_2 in the 2050 timeframe (approximately 350 Mt CO_2e emissions from the United States) without any changes to the current technological or operational paradigm [5, 6].

To provide a framework for enabling impactful changes in the aviation industry required to minimize the impact of anthropogenic greenhouse gas emissions, specifically emissions from aircraft operations and the use of jet fuel, the Air Transport Action Group (ATAG) established a series of climate change goals. These goals ultimately seek to reduce aviation's greenhouse gas emissions in 2050 to 400 Mt of CO_2 equivalent emissions. ATAG presumes that a combination of advanced technology, improved operations, efficient air traffic management, and sustainable propulsion will be required to meet the CO_2 emission goal [5].

Historically, each new generation of aircraft reduces emissions between 15-20%. Future gains in efficiency will come from novel airframe design (e.g., the blended or hybrid wing body), advanced wing design (e.g., active load alleviation, truss-braced wing, variable camber), new propulsion systems (e.g., open rotor engine, electric propulsion, geared turbofans), and new fuels (e.g., electricity, hydrogen, sustainable aviation fuel) [5]. However, the development of a new aircraft is a very lengthy and expensive endeavor.

Therefore, many airframe and engine manufacturers choose to provide retrofit solutions to progressively increase the efficiency of older airframes. These retrofit solutions may modify the airframe (e.g., new engines and wingtip devices), aircraft cabin (e.g., lightweight seats and cargo containers), or flight software (e.g., electronic flight bags, updated flight control systems, flight management systems). While not as lengthy or expensive as designing a new aircraft, these modifications are costly and only produce evolutionary reductions in emissions—not the revolutionary reduction required to achieve the ATAG goals.

Another mechanism to reduce greenhouse gas emissions by the aviation sector is by modifying how aircraft are operated. The way aircrews and engineers operate aircraft can have a significant impact on fuel consumption and emissions. In order to meet the ATAG goal, operational efficiency improvements are needed in the 8-12% of net aviation emissions range [5]. Operations such as optimized profile descents [7] have demonstrated that significant increases in operational efficiency (leading to a reduction in fuel

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[1] The term "anthropogenic," in this context, refers to greenhouse gas emissions and removals that are a direct result of human activities or are the result of natural processes that have been affected by human activities [22].

[2] Greenhouse gas emissions are quantified in literature as CO_2-equivalent (CO_2e) emissions using weightings based on the 100-year Global Warming Potentials. The 100-year Global Warming Potential of a greenhouse gas is defined as the ratio of the accumulated radiative forcing within a specific time horizon (e.g., 100 years) caused by emitting 1 kilogram of the gas, relative to that of the reference gas CO_2 [23].

consumption and greenhouse gas emissions) may be accomplished with a combination of technology and minimal changes to current operating procedures for air traffic controllers and aircrews.

A concept developed by the National Aeronautics and Space Administration (NASA) called Traffic Aware Strategic Aircrew Requests (TASAR) [8], uses cockpit automation to recommend optimized route modifications that an aircrew may request from air traffic control. TASAR provides an opportunity for a flight to significantly reduce fuel burn, leading to fewer greenhouse gas emissions. The ATAG Waypoint 2050 report specifically calls out an operational enhancement that reduces greenhouse gas emissions, called flexible tracks/free-route airspace, that is aligned with the goals of the TASAR concept:

> *Taking advantage of improved navigational capabilities such as required navigation performance, air navigation service providers can provide and accept requests for flexible routes allowing flight crews to react to changing weather patterns and fly more efficient direct routes. The systems will analyze current weather conditions and a flight's trajectory to re-route flights along a more efficient path, subject to approval from flight crew and air traffic control. Up to 500,000 tonnes of* CO_2 *a year could be saved when fully implemented over Europe alone* [5].

This paper provides an assessment of the environmental benefits of the TASAR concept by answering two research questions:

1. What are the potential quantified environmental benefits of TASAR for a representative fleet of aircraft conducting domestic U.S. operations[3]?
2. What is the impact of estimated TASAR environmental benefits relative to the 2050 ATAG goal?

Section II provides background information on the TASAR concept and operational evaluation. Section III describes the methodology used to estimate reductions in greenhouse gas emissions from TASAR, and Section IV discusses the results of the analyses. Section V presents future capabilities and functionality for TASAR to provide further reductions in greenhouse gas emissions, and Section VI concludes the paper.

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[3] Note: Only flights that originate and terminate within U.S. airspace are considered in these analyses. Flights that originate or terminate in foreign airspace are not included in these analyses.

2 Background

2.1 TASAR Concept Overview

Aircraft operating in the National Airspace System (NAS) under Instrument Flight Rules (IFR) generally must fly trajectories approved by air traffic control (ATC). The approved trajectory is the trajectory originally specified in the flight plan. This trajectory may be modified by ATC clearance received prior to takeoff or by changes issued or negotiated and approved by ATC after takeoff and throughout the flight. The approved trajectory often does not coincide with the aircraft operator's most efficient or preferred trajectory. Less-desired trajectories can be the result of non-optimal routes, altitude restrictions, and/or speed restrictions issued by ATC before or during the flight. Furthermore, changing conditions or priorities during the flight may affect the approved trajectory. Some causes of in-flight priority changes are unanticipated weather convection or turbulence development, the need to make up time as a result of an earlier reroute to avoid traffic or weather, the need to delay arrival due to fleet operator constraints or traffic congestion at the destination, and the need to increase altitude as fuel is burned to improve efficiency. As a result, the aircrew occasionally has a need or desire to change their trajectory while in flight.

Because ATC has responsibility to separate IFR aircraft, it maintains authority over the trajectories of all IFR aircraft in controlled airspace. Aircrews operating under IFR are not permitted to make changes to their approved trajectory without first receiving authorization from ATC. The operational procedure to request clearance for a trajectory change is for the aircrew to prepare the request and, when appropriate, communicate it to the air traffic controller. The controller will assess the request with respect to nearby traffic and other factors and issue an approval, an amendment, a deferral, or a denial. The aircrew then proceeds as instructed.

Aircrews may make occasional route modification requests to ATC sector controllers as they proceed enroute to their destination. Apart from weather and turbulence avoidance, these requests are typically geared towards improving flight efficiency and are often based on rules of thumb. An aircrew may ask for a "direct" i.e., a short cut directly to a downstream waypoint on their filed route to achieve a shorter ground track and therefore presumably save time and fuel. Aircrews of larger aircraft (e.g., airlines) may also ask for a change in altitude to a presumably more efficient (typically higher) altitude as the aircraft burns off fuel and becomes lighter.

However, the aircrew often makes these requests with limited situation awareness of constraints and restrictions that would affect the proposed route change [9]. While ATC generally grants these requests where local procedures allow, sometimes these requests are denied by ATC due to conflicts with nearby traffic, airspace constraints, or convective weather. Repeatedly denied requests may discourage aircrews from making future requests that could improve flight efficiency. The ability of the flight crew to make better-informed requests to optimize the flight (i.e., manage their trajectory), especially as air traffic continues to increase in volume and complexity, is an avenue for improving operations within the NAS.

The TASAR concept introduces a new capability for in-flight trajectory management—TASAR provides an aircrew with cockpit automation that advises them of enroute trajectory modifications that best achieve the airline's specific business model and are more likely to be approved by ATC [8]. The TASAR concept is enabled by the emergence of the "connected aircraft" [10] (an industry-led initiative in which systems onboard and off the aircraft are digitally connected to each other, enabling substantial flows of information), a powerful optimization algorithm [11], the trajectory-change request procedure, and ATC approval. The TASAR concept, as illustrated in Figure 1, integrates these enablers into a progression: data flows into automation that creates optimized (e.g., time- and fuel- saving) trajectory alternatives[4], which are requested by the aircrew and usually approved by ATC. If approved by ATC, the aircrew executes the new trajectory, which ultimately reduces the direct operating costs of a flight.

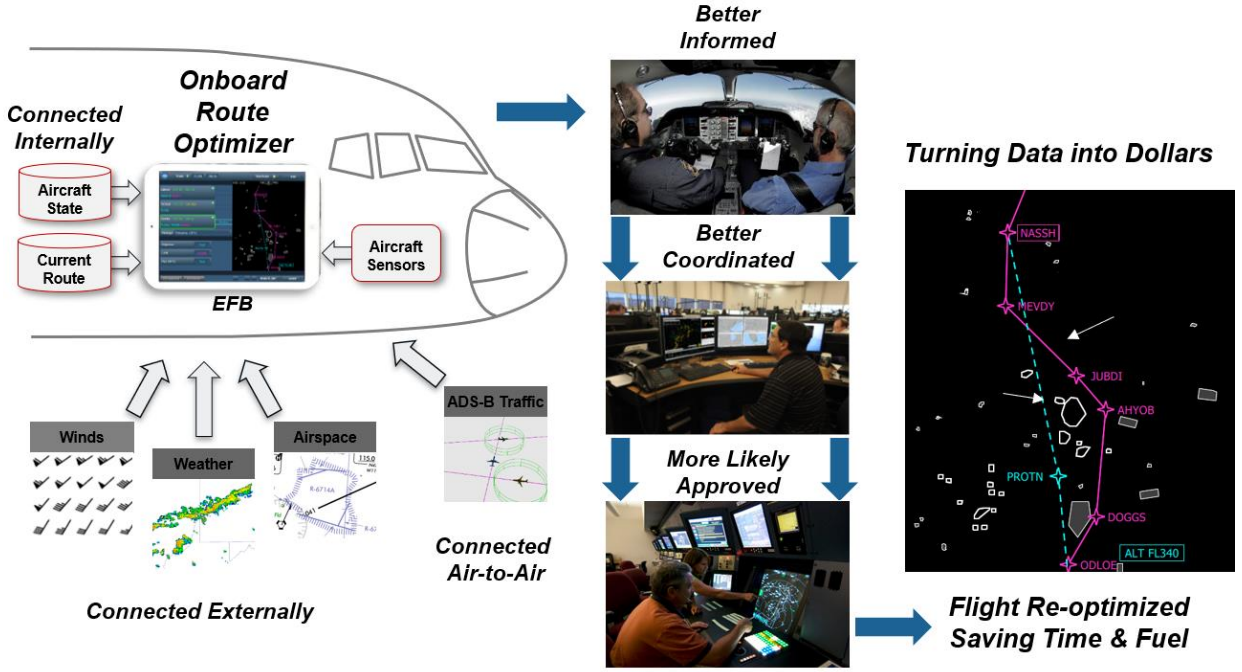

Figure 1: The TASAR Concept[8]

Regarding operational procedures for using TASAR, an aircrew monitors the automation during the flight for any displayed opportunity to optimize the flight. TASAR is expected to be used outside of terminal airspace during the climb (above 10,000 feet for jet aircraft operators) and cruise portions of the flight. Once the aircraft is airborne and the application is active, it will display route optimization opportunities when available. The aircrew consults the application as desired and reviews the options presented. As is always the case, even without TASAR, any serious consideration of a route modification must include crew coordination, cross-checking with the onboard certified systems (e.g., flight management system, weather radar), and depending on company policy, coordination with a dispatcher. The request to ATC is made using normal procedures and phraseology without reference to "TASAR." From ATC's perspective, it is simply a user request [8].

Another TASAR procedure is to use the application to assess the merits of a route modification proposed by an external source, which could be the aircrew, the dispatcher, or the air traffic controller. For instance, if ATC offers a "direct" clearance to a downstream waypoint, the aircrew could quickly enter it into the application and assess whether the maneuver is cost-effective. Depending on the wind field, the answer may be no, and the aircrew may wish to decline the offer [8].

The TASAR concept is meant for near-term implementation. It is designed as an advisory capability with no safety-critical function. This enables operators to install the TASAR automation on an Electronic Flight Bag (EFB), a low-cost onboard computing platform with connectivity to avionics and a growing number

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[4] TASAR automation provides recommended optimal solutions in three operating dimensions: lateral, vertical or combination lateral/vertical and provides fuel and time outcomes for each solution. It is at the aircrew's discretion to choose which solution they would like to request from ATC.

of information sources both within and external to the flight deck. Furthermore, by “turning data into dollars,” TASAR’s direct product is operational savings, a useful feature in motivating industry to consider adopting the technology [8].

2.2 TASAR Operational Evaluation and Benefits Analyses

In 2013, NASA solicited interest from U.S. airlines to collaborate in the development of TASAR to accelerate technology transfer to industry and subsequent adoption by the carriers for regular use in operations. In 2016, both Alaska Airlines and Virgin America committed to working with NASA on the venture, and after their subsequent merger, that NASA work continued with Alaska Airlines. An operational evaluation was conducted at Alaska Airlines with three TASAR-equipped Boeing 737-900ER aircraft [12]. The aircraft were equipped with a NASA-developed technology prototype that enables the TASAR concept known as the Traffic Aware Planner (TAP). The user interface for the TAP software application was hosted on an EFB.

A primary objective of the operational evaluation was to quantify the anticipated benefits of TASAR; namely, reduction in fuel burn and reduction in flight time, ultimately leading to a reduction in direct operating costs for a given flight [8, 9]. Data from the operational evaluation provided estimated fuel burn and flight time reduction, and these metrics were converted to direct operating cost savings [13]. The anticipated benefits were quantified, and these benefits confirmed expectations set by preliminary model-based benefit analyses.

Quantifying the benefits seen in the operational evaluation was done by comparing the operating costs of flights where TASAR-inspired requests were made by the flight crew to baseline flights, where TAP was running in the background but not seen by the crew. The TASAR flights were paired with baseline flights that had corresponding characteristics like similar flight duration and were matched based on the proximity of the flight dates to mitigate seasonal variation. For every pair of TASAR and baseline flights, an as-flown operating cost and a predicted flight cost were calculated for a specific segment in the flights. The bounds of this segment were identified as points in the flight that captured all TASAR-inspired requests from the TASAR flight. The predicted cost used to calculate savings was calculated in two ways; one method used predictions from the TAP software and the other used company generated flight plans. The savings referenced in this paper used flight plan predictions. Total cost savings were calculated by subtracting the difference in flown cost to the predicted cost for the TASAR flights from the difference in flown cost to predicted cost for the baseline flights. This calculation gives the savings due to TASAR that occur above the normal changes flight crews can make like avoiding weather for example. The detailed methodology is documented in [13].

3 Methodology

This section discusses the methodology for computing the estimated greenhouse gas emissions reduction due to the implementation of the TASAR concept. First, a representative fleet of aircraft was selected from multiple airlines using publicly available data from the Bureau of Transportation Statistics (BTS). Next, a method for estimating annualized fuel burn savings extrapolated from the 2018-2019 TASAR operational evaluation to the representative fleet is presented. Additionally, a method to account for variability in the fuel burn reduction operational trial data is discussed. Finally, a method for estimating greenhouse gas emissions reduction from fuel burn reduction is shown.

3.1 Estimation of Fuel Burn Reduction

Based on the results of the operational evaluation, annual TASAR benefits were estimated for the top 10 domestic US airlines[5]. The full methodology is presented in [13]. The estimated fuel burn reduction benefits for each airline considered the following parameters from 2018 BTS data, considered the preeminent source of statistics on commercial aviation:

- Candidate aircraft types for TASAR equipage by airline (generally, modern mainline jets)[6]
- Number of candidate aircraft by airline and aircraft type[7]
- Number of annual flights by airline, aircraft type, and flight duration (2-4 hours, 4+ hours)[8]
- Average fuel burn rate (gallons per hour) by airline, aircraft type, and flight duration[5]

Once these data were obtained, a ratio used to extrapolate the fuel reduction results to other airlines and aircraft types was determined. This ratio ($FuelBurnRatio_{ij}$) is computed based on the average fuel burn rate of the Alaska Airlines Boeing 737-900ER, the aircraft used during the operational trial, and the fuel burn rate for other aircraft types from the BTS data (see Eq. 1). For example, the Alaska Airlines Boeing 737-900ER had an average fuel burn rate of 912 gallons per hour. Based on the BTS data, an American Airlines Airbus A321 had an average fuel burn rate of 1,079 gallons per hour during the same time period (January – September 2018). Therefore, the ratio used to extrapolate the fuel burn reduction from the Alaska Airlines Boeing 737-900ER to the American Airlines Airbus A321 is (1,079/912) or 1.183.

$$FuelBurnRatio_{ij} = \left(\frac{FuelRate_{Airline\ i_{Type\ j}}}{FuelRate_{ASA737-900ER}}\right) \quad \text{Eq. 1}$$

Using data from the BTS statistics and data obtained during the operational evaluation, fuel burn reduction estimates can be made for the top 10 domestic US airlines. Eq. 2 and Eq. 3 provide the calculations used to compute the fuel reduction by flight length for aircraft type j of airline i. Eq. 4 adds the results of Eq. 2 and Eq. 3 together to obtain a total fuel reduction for aircraft type j of airline i due to the use of TASAR.

$$FuelReduction_{ij_{2-4}} = \left(FuelRedObs_{2-4} * FuelBurnRatio_{ij}\right) * numFlights_{ij_{2-4}} \quad \text{Eq. 2}$$

$$FuelReduction_{ij_{4+}} = \left(FuelRedObs_{4+} * FuelBurnRatio_{ij}\right) * numFlights_{ij_{4+}} \quad \text{Eq. 3}$$

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[5] The top 10 airlines were selected using the number of annual domestic CONUS operations in 2018.

[6] Data obtained from BTS Form 41, Schedule P5.2

[7] Data obtained from BTS Airline On-Time Performance Data

[8] Data obtained from BTS Air Carrier Statistics T-100 Domestic Segment database

$$FuelReduction_{ij_{Total}} = FuelReduction_{ij_{2-4}} + FuelReduction_{ij_{4+}} \quad \text{Eq. 4}$$

Constants used in Eq. 1, Eq. 2, and Eq. 3 based on data obtained from the operational evaluation can be found in Table 1. The observed fuel burn reduction for each flight length was the mean fuel burn reduction aggregated over all flights of a given duration (2-4 hours, 4+ hours) observed during the operational evaluation (Table 10 of reference [13]).

Table 1: Constants used in TASAR Fuel Burn Reduction Estimates

Constant	Variable	Value
Average fuel burn rate ASA 737-900ER	$FuelRate_{ASA737\text{-}900ER}$	912 gal/hr
Observed fuel burn reduction during the ASA operational trial, flight length 2-4 hours	$FuelRedObs_{2\text{-}4}$	29.28704 gal
Observed fuel burn reduction during the ASA operational trial, flight length 4+ hours	$FuelRedObs_{4+}$	57.06980 gal

The observed fuel burn reduction values shown in Table 1 should be considered a conservative estimate of benefits that may be achieved during regular operational use of TASAR. For example, during the operational evaluation, only 24% of evaluated flights featured a TASAR-trained Alaska Airlines Technical Pilot operating the technology from the front seat of the aircraft. The remaining 76% of evaluated flights used a combination of Alaska Airlines interns, NASA researchers, and Alaska Airlines technical pilots operating the TASAR technology from the jump seat and providing input to the aircrew flying the vehicle. When analyzing the data from the operational trial by the technology operator, the benefits for the Alaska Airlines Technical Pilot operating the technology from the front seat were higher than the aggregated benefits for all operators, as seen in Table 2. These findings demonstrate that, in regular operations, pilots may use TAP differently when they are responsible for its use as compared to taking input from technology operators located in the jump seat. This may lead to higher realized benefits for the TASAR concept. Other limitations and the effects on the benefits estimates are presented in Table 8 of reference [13].

Table 2: Difference in Fuel Burn Reduction Estimates based on TASAR Operator

TASAR Technology Operator and Location	**Fuel Burn Reduction Estimate** ***2-4 hour flights***	**Fuel Burn Reduction Estimate** ***4+ hour flights***	**Fuel Burn Reduction Estimate** ***All 2+ hour flights***
Alaska Tech Pilot *Front Seat*	67.84 gal/flight	130.96 gal/flight	74.48 gal/flight
All Operators *All locations*	29.29 gal/flight	57.07 gal/flight	38.90 gal/flight

In addition to the conservative estimate of fuel burn reduction computed using all TASAR operators (as opposed to only trained pilots operating the technology in the front seats), there are other limitations to determining accurate fuel burn reduction estimates for specific aircraft types of a given airline (discussed further in reference [13]). For example:

- Candidate Fleet Considerations: This estimation method assumes that modern mainline jets were considered candidates for TASAR equipage. Regional jets and older aircraft were assumed to not be candidates for TASAR for the purpose of this calculation. The fleet size should be considered approximate since new aircraft regularly enter airline fleets, and older aircraft are retired. Benefits for aircraft types that have recently been introduced by an airline were not quantified due to insufficient historical cost and flight frequency data.
- Extensibility of Benefits: This estimation method assumes that the city pairs used by Alaska Airlines during the operational evaluation would provide the same benefits to other city pairs of similar flight length for other airlines. More data, ideally from another airline conducting an operational trial of TASAR, would be needed to validate this assumption.
- Flight Duration: This estimation method used fuel reduction benefits that were generalized by coarse flight-duration categories (e.g., 2-4 hours, 4+ hours). More refined estimates may be provided if the benefits were binned into more granular categories.
- Competitive Effect: This estimation method did not account for any competitive effect if all aircraft were simultaneously using the TASAR technology and potentially competing for ATC approval. It is not yet fully understood whether or to what degree this phenomenon would affect observed benefits.

Given these limitations, the method provides a first cut estimation of annual fuel burn reduction benefits for airlines based on candidate fleet size and flight lengths. Table 3 shows the estimated potential reduction in fuel burn due to the use of the TASAR concept for the top 10 US airlines. This estimate is based on the conservative fuel burn reduction data from the operational evaluation (presented in Table 1), the airline data from the BTS statistics (provided in reference [13] and Appendices A-J), and the results of applying the methodology discussed above. The number of aircraft that were considered candidates to be equipped with TASAR were estimated and are shown in the middle column. The per-airline fuel burn reduction estimates, shown in the right column, were computed by adding the estimated fuel burn reduction for each aircraft type j. Appendices A through J provide data tables that present estimated TASAR fuel burn reductions for aircraft types of each airline.

Table 3: Estimated TASAR Fuel Burn Reduction for Top 10 US Airlines

Airline	Number of TASAR Candidate Aircraft	Annual TASAR Fuel Burn Reduction (gal)
Alaska Airlines	180	4,685,060
Allegiant Air	37	487,093
American Airlines	831	16,146,610
Delta Airlines	466	7,700,796
Frontier Airlines	62	1,480,925
JetBlue Airways	63	2,338,170
Southwest Airlines	754	12,982,870
Spirit Airlines	61	1,755,733
Sun Country	30	455,737
United Airlines	562	7,618,480
Total	**3,046**	**55,651,472**

3.2 Estimation of Greenhouse Gas Emissions Reduction from Fuel Burn Reduction

Using the estimated potential fuel burn reduction for aircraft type *j* of airline *i* from Eq. 4, an estimate of greenhouse gas emissions reduction was computed for aircraft type *j* of airline *i*. First, fuel burn reduction estimates were converted to greenhouse gas emissions reduction estimates (carbon dioxide, methane, nitrous oxide) in units of kilograms of emissions per gallon of burned jet fuel using published conversion factors [14], as seen in Eq. 5–Eq. 7.

$$emissions_{ij_{red_{CO_2}}} = FuelReduction_{ij_{Total}} * 9.75 \qquad \text{Eq. 5}$$

$$emissions_{ij_{red_{CH_4}}} = FuelReduction_{ij_{Total}} * 0.00041 \qquad \text{Eq. 6}$$

$$emissions_{ij_{red_{NO_2}}} = FuelReduction_{ij_{Total}} * 0.00008 \qquad \text{Eq. 7}$$

Next, the methane and nitrous oxide emissions reduction estimates were converted to carbon dioxide equivalent values using published 100-year global warming potential (GWP) factors following Eq. 8 – Eq. 9. Reference [4] was used to determine the 100-year GWP for methane and nitrous oxide.

$$emissions_{ij_{red_{conv_{CH_4}}}} = emissions_{ij_{red_{CH_4}}} * 25 \qquad \text{Eq. 8}$$

$$emissions_{ij_{red_{conv_{NO_2}}}} = emissions_{ij_{red_{NO_2}}} * 298 \qquad \text{Eq. 9}$$

Finally, the carbon dioxide emissions reduction estimate was added to the methane and nitrous oxide carbon dioxide equivalent values (Eq. 10) to obtain the total carbon dioxide equivalent greenhouse gas emissions reduction estimate for aircraft type *j* of airline *i*. The total carbon dioxide equivalent greenhouse gas emissions reduction estimate for an airline was computed by summing the emission reductions estimates for each aircraft type.

$$emissions_{ij_{red_{total}}} = emissions_{ij_{red_{CO_2}}} + emissions_{ij_{red_{conv_{CH_4}}}} + emissions_{ij_{red_{conv_{NO_2}}}} \qquad \text{Eq. 10}$$

3.3 Variability Analyses

The emissions calculated in the previous section are based on the average fuel savings from the TASAR operational evaluation benefits results. There was a wide range of calculated benefits and this variability can be extended to the emissions estimates as well. Typically, confidence intervals are constructed around the means, however, assumptions about the distributions must be made. The data from the operational evaluation do not conform to known distributions. Figure 2 shows the histogram of gallons of fuel saved for flights in the TASAR operational evaluation. The distribution is right-skewed and has a large peak at zero gallons.

When assumptions of normality fail, one common alternative is the bootstrap method. Bootstrapping uses simulation to obtain measures of uncertainty. The basic idea is to resample new datasets of the same size from the original data, with replacement. If the Alaska Airlines operational evaluation had been repeated many times, different fuel savings would have been reported. Bootstrapping simulates that repetition based on the available data. Ten thousand bootstrap samples were simulated using R version 3.6.3. The process described above in 3.1 and 3.2 to compute emissions was carried out for each bootstrap sample. A 95% confidence interval was calculated for a given grouping of flights (by airline, aircraft family, flight duration, or all flights) using the percentile method where the bounds of the interval are the 2.5th and 97.5th percentiles of the bootstrap emissions.

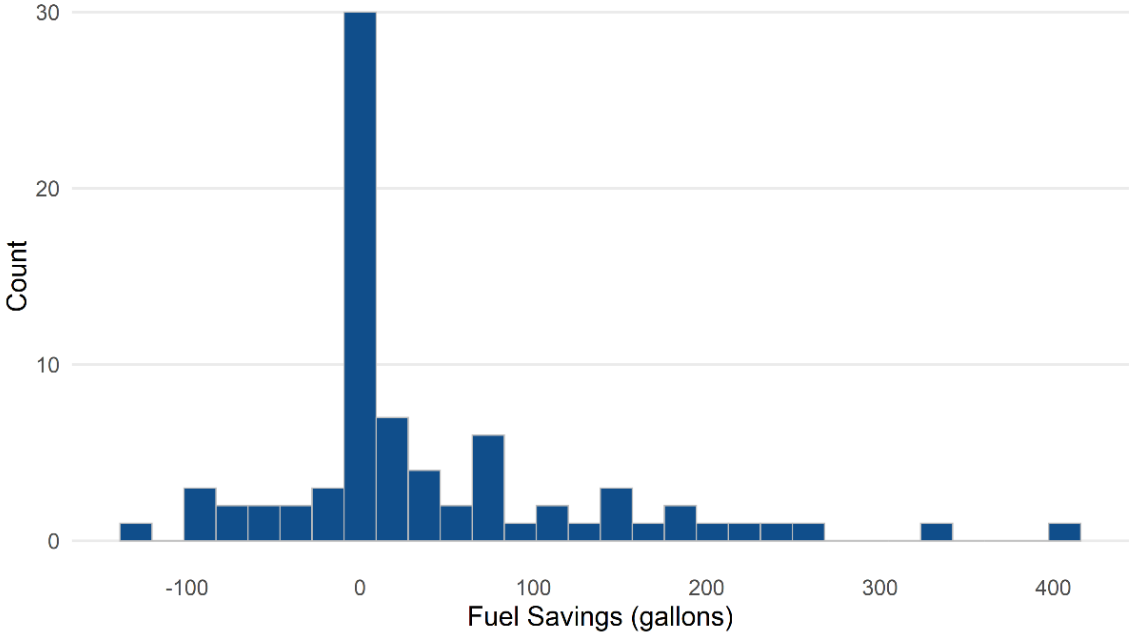

Figure 2. Distribution of TASAR Fuel Savings from Alaska Airlines Operational Evaluation.

These 95% confidence intervals provide a range of values where the calculated emissions benefits would likely fall if the same operational evaluation were repeated. The lower limit of the confidence interval will be considered the "low" estimate in the emissions results in the following section, while the upper limit of the interval will be considered the "high" estimate. The calculations described in the previous sections using the current data will be considered the "mid" estimate, although it is not the exact midpoint between the upper and lower bounds because the bootstrap method does not guarantee symmetry.

4 Results and Discussion

This section of the paper discusses the results of the analyses performed to estimate the reduction in fuel burn and greenhouse gas emissions for a representative portion of the United States domestic aircraft fleet. A summary of the anticipated greenhouse gas emission reduction resulting from the application of the TASAR concept are presented, and those results are compared to the ATAG goals for operational efficiency. Additionally, potential greenhouse gas emission reduction data are discussed per airline, per vehicle type, and by flight duration.

4.1 Summary of Greenhouse Gas Emissions Reduction Estimates

To investigate potential greenhouse gas emissions reduction due to operational improvements, ATAG developed three operational efficiency scenarios. These scenarios illustrate potential pathways for operational efficiencies to contribute to reducing overall greenhouse gas emissions. Scenario O_2, considered a "mid improvement," represents a 0.1% annual reduction in net CO_2e emissions, which translates to a 3% overall reduction of emissions in 2050. Scenario O_3, considered a "high improvement," represents a 0.2% annual reduction in net CO_2e emissions, which translates to a 6% overall reduction of greenhouse gas emissions in 2050 for scenario. In order to meet the ATAG goals, operational efficiency improvements are needed in the 8-12% range for overall reduction of net aviation greenhouse gas emissions [5].

Based on the analyses conducted for the TASAR concept discussed in Section 3.2, approximately 545,000 metric tons of CO_2e greenhouse gas emissions (Mid Estimate, Table 4) could be eliminated annually by implementing the TASAR concept across a fleet of appropriate vehicles conducting domestic operations in the United States. This fleet is comprised of approximately 3,000 vehicles across ten domestic airlines (as shown in Table 3).

Table 4: Summary of Estimated TASAR Annual CO_2e Emissions Reduction

	Annual Fleet Emissions Reduction from TASAR (metric tons CO_2e)	**Annual Emissions Reduction Percentage from TASAR**	**Cumulative Emissions Reduction from TASAR by 2050 vs. 2021**[9]	**Percent Improvement over ATAG Operational Efficiency Scenario Goals**
Low Estimate	228,499.6	0.13%	3.9%	30% greater than Scenario O_2
Mid Estimate	544,936.7	0.31%	9.3%	55% greater than Scenario O_3
High Estimate	902,499.7	0.51%	15.3%	155% greater than Scenario O_3

Using the estimate of 175.5 Mt CO_2e produced by aviation operations in the United States and the "mid" estimate for CO_2e greenhouse gas emissions reduction, use of the TASAR concept would create a 0.31% annual reduction in annual greenhouse gas emissions, translating to a 9.3% overall reduction in emissions in 2050. This surpasses the "high improvement" benchmark set by ATAG. The low-end of the range of estimated benefits (Low Estimate, Table 4) provides a 0.13% reduction in annual greenhouse gas emissions, which is slightly better than the ATAG "mid improvement" operational scenario (0.1% annual reduction). The high end of the range of estimated benefits (High Estimate, Table 4) provides a 0.51% reduction in annual greenhouse gas emissions, significantly exceeding the ATAG "high improvement" operational scenario (0.2% annual reduction).

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[9] This value is a cumulative reduction based on multiplying the annual emissions reduction percentage by the years remaining until 2050, per the methodology performed in the ATAG report. This value represents the emissions reduction due to TASAR concept compared to the emissions projection in 2050 without the TASAR concept (i.e., if TASAR was not implemented, emissions in 2050 may be approximately 9.3% higher for the "Mid" estimate).

4.2 Greenhouse Gas Emissions Reduction Estimates by Airline

Following a similar approach to the TASAR Benefits study based on the operational evaluation [13], greenhouse gas emissions reduction estimates were computed for each of the top 10 domestic airlines. Results (including a low, mid, and high estimate) are shown in Table 5. Detailed data for each airline are provided in Appendices A through J.

Table 5: Estimated TASAR Annual CO_2e Emissions Reduction by Airline

Airline	Number of TASAR Candidate Aircraft	Estimated Annual CO_2e Emissions Reduction		
		Low Estimate	Mid Estimate	High Estimate
		metric tons CO_2e	*metric tons CO_2e*	*metric tons CO_2e*
Alaska Airlines	180	23,354.20	45,878.29	70,125.63
Allegiant Air	37	939.49	4,761.83	9,159.29
American Airlines	831	68,925.56	158,464.34	258,378.40
Delta Airlines	466	33,509.21	75,299.08	122,611.77
Frontier Airlines	62	3,928.88	14,496.33	26,537.64
JetBlue Airways	63	11,289.79	22,778.68	35,068.05
Southwest Airlines	754	38,611.74	126,893.34	228,631.49
Spirit Airlines	61	5,149.36	17,144.90	30,957.87
Sun Country	30	876.95	4,471.30	8,571.44
United Airlines	562	32,580.03	74,748.65	121,899.04

Results in Table 5 are generally dependent on the number of candidate aircraft for TASAR equipage selected for analysis in each airline's fleet. For example, American Airlines has a much larger potential TASAR candidate fleet than Sun Country Airlines. Therefore, the estimated potential reduction in annual CO_2e emissions for American Airlines is much larger than for Sun Country Airlines.

Another consideration that may affect these results is the fuel burn ratio used in the calculations to extrapolate the fuel savings from Alaska Airlines to other airlines. For example, the candidate fleet size for Delta Airlines and United Airlines is comparable. However, based on the data in the BTS statistics, Delta Airlines had higher fuel burn ratios than United Airlines for the same type of aircraft. Therefore, it could be surmised that Delta Airlines was starting with more "potential" savings than United Airlines.

However, TASAR candidate fleet size and fuel burn ratio are not the only factors that influences these estimates. For example, consider JetBlue Airways, Frontier Airlines, and Spirit Airlines, which have similar candidate fleet sizes (63, 62, and 61 aircraft in their fleets, respectively) and similar fuel burn ratios for the same types of aircraft. Frontier Airlines and Spirit Airlines have comparable estimated potential reduction in annual CO_2e emissions. JetBlue Airways has a larger potential reduction in annual CO_2e emissions than either Frontier Airlines or Spirit Airlines. Figure 3 shows the results when normalizing the total potential reduction in annual CO_2e emissions for each airline by the main effect—the number of aircraft in that airline's candidate fleet. The error bars indicate 95% confidence intervals around the estimates.

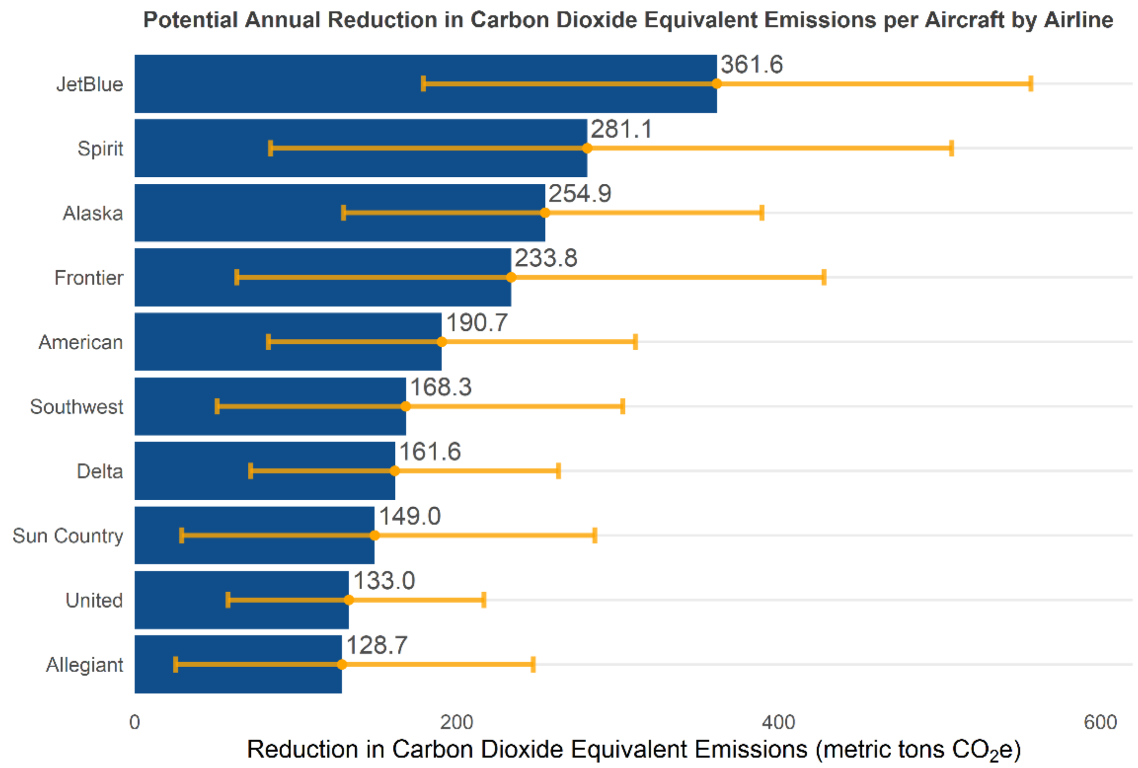

Figure 3: Potential TASAR Annual CO_2e Emissions Reduction per Aircraft by Airline

When reviewing the data on a per-aircraft basis, some interesting trends manifest. For example, JetBlue Airways, which has the fifth smallest candidate fleet for TASAR equipage, has the highest potential reduction in annual CO_2e emissions on a per-aircraft basis. This is most likely because the aircraft that comprise the JetBlue Airways candidate fleet fly mainly long flights. JetBlue Airways has approximately a 2:1 ratio of 4+ hour flights to 2-4 hour flights. No other airline has a ratio greater than 1, and the mean of all other airlines is approximately a 1:5 ratio of 4+ hour flights to 2-4 hour flights. Conversely, Allegiant Air, which has the second smallest candidate fleet for TASAR equipage, has the lowest potential reduction in annual CO_2e emissions on a per-aircraft basis. Allegiant Air flies mainly short flights (2-4 hours); their ratio of 4+ hour flights to 2-4 hour flights is approximately 1:100.

These findings imply that the flight duration, discussed in Section 4.3, influences the potential annual reduction in CO_2e emissions. This makes operational sense—on a longer flight, there is more opportunity to realize fuel burn reduction through a more optimal routing. Short duration flights do not typically spend much time in the en route phase of flight and, depending on the location of the flight (e.g., the east coast), the en route phase of flight may be highly constrained for air traffic management reasons.

4.3 Greenhouse Gas Emissions Reduction Estimates by Flight Duration

As discussed in the previous section, flight duration influences the potential annual reduction in CO_2e emissions. To understand this influence better, the data for each airline was aggregated, binned into groups of 2-4 hours and 4+ hours, and analyzed by flight duration. Table 6 presents low, mid, and high estimates of potential annual reduction in CO_2e emissions by flight duration.

Table 6: Estimated TASAR Annual CO_2e Emissions Reduction by Flight Duration

Flight Duration	Number of Candidate Operations	Estimated Annual CO_2e Emissions Reduction		
		Low Estimate	**Mid Estimate**	**High Estimate**
		metric tons CO_2e	*metric tons CO_2e*	*metric tons CO_2e*
2-4 Hours	1,227,770	65,083.84	358,260.86	694,670.60
4+ Hours	304,572	77,416.41	186,675.88	303,416.60

Results in Table 6 are dependent on the number of operations in each flight duration category. However, the number of operations conducted in each flight duration bin is not the only factor that influences these estimates. The estimates were normalized by the main effect, the number of operations (per 1,000 flights), to determine if the conclusions drawn in Section 4.3 hold true (longer flight durations have greater potential annual reductions in CO_2e emissions than shorter flights). The normalized values are presented in Figure 4 and the error bars indicate 95% confidence intervals around the estimates. These values support the conclusions from Section 4.2.

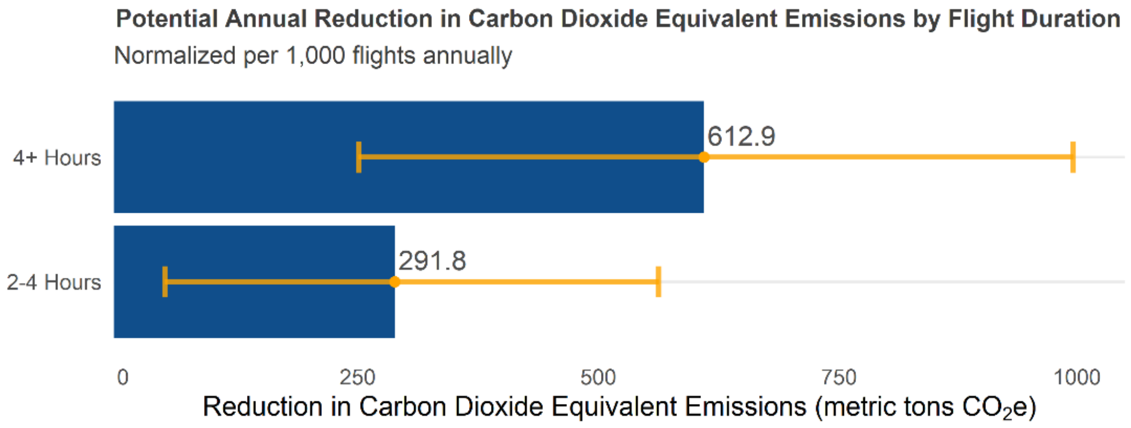

Figure 4: Potential TASAR Annual CO_2e Emissions Reduction by Flight Duration

Longer duration flights (4+ hours) have approximately twice the potential annual reduction in CO2e emissions for the "Mid" estimate than flights compared to flights of 2-4 hours. The confidence intervals around those estimates show that if the study were repeated, the average reduction may not be twice as much for 4+ hour flights due to randomness. However, it was generally found that the longer duration flights saw higher benefits, and specifically they had twice the reduction or more compared to 2-4 hour flights in about 50% of the simulations.

4.4 Greenhouse Gas Emissions Reduction Estimates by Aircraft Type

Many airline fleets examined in this analysis were comprised of several different types of aircraft that were suitable candidates for TASAR equipage. As mentioned in Section 3.1, the vehicle types considered for these analyses were modern mainline jets. Regional jets and older aircraft were assumed to not be candidates for TASAR equipage, and are therefore not included in these analyses. To understand the influences of fleet composition on the potential annual reduction in CO_2e emissions, the data for each airline was aggregated, binned into groups of aircraft type families, and analyzed. Table 7 shows the mapping of specific vehicle types to vehicle type families. Table 8 presents low, mid, and high estimates of potential annual reduction in CO_2e emissions by aircraft type family.

Table 7: Aircraft Type Mapping to Aircraft Family

Aircraft Type Family	Specific Aircraft Type(s)
Airbus A320 Family	Airbus A319, Airbus A320, Airbus A321
Airbus A330 Family	Airbus A330-200, Airbus A330-300
Airbus A350 Family	Airbus A350-900
Boeing 737 Family	Boeing 737-700/700LR, Boeing 737-800, Boeing 737-900/900ER, Boeing 737-Max 7/Max 8/Max 9
Boeing 767 Family	Boeing 767-300/300ER
Boeing 777 Family	Boeing 777-200ER/200LR/233LR, Boeing 777-300ER/300LR/333LR
Boeing 787 Family	Boeing 787-800, Boeing 787-900

Table 8: Estimated TASAR Annual CO_2e Emissions Reduction by Aircraft Type

Aircraft Type Family	Number of Candidate Aircraft	Estimated Annual CO_2e Emissions Reduction		
		Low Estimate	Mid Estimate	High Estimate
		metric tons CO_2e	*metric tons CO_2e*	*metric tons CO_2e*
Airbus A320 Family	789	86,435.91	190,941.78	308,301.28
Airbus A330 Family	66	1,591.09	3,211.03	4,910.00
Airbus A350 Family	13	16.02	31.46	47.73
Boeing 737 Family	1824	128,274.21	332,253.90	565,397.91
Boeing 767 Family	117	3,889.33	7,805.01	12,055.09
Boeing 777 Family	158	4,545.82	8,844.74	13,410.32
Boeing 787 Family	79	610.04	1,848.82	3,268.86

Results shown in Table 8 are largely dependent on the number of TASAR candidate vehicles in the aircraft type family. Most (86%) of the vehicle types analyzed were in the Boeing 737 and Airbus A320 families. As a result, the Boeing 737 and Airbus A320 families had the largest estimates of potential annual reduction in CO_2e emissions. Those vehicle families account for approximately 96% of the potential annual reduction in CO_2e emissions across all airline fleets.

To understand the relationship between the number of TASAR candidate vehicles in the aircraft type family and the emissions reduction benefit estimates, the data in Table 8 were normalized by the main effect—the number of aircraft in each family. The resulting data are shown in Figure 5. The error bars indicate 95% confidence intervals around the estimates. These results show that the Airbus A320 and Boeing 737 aircraft type families have the highest per-aircraft emissions reduction benefit.

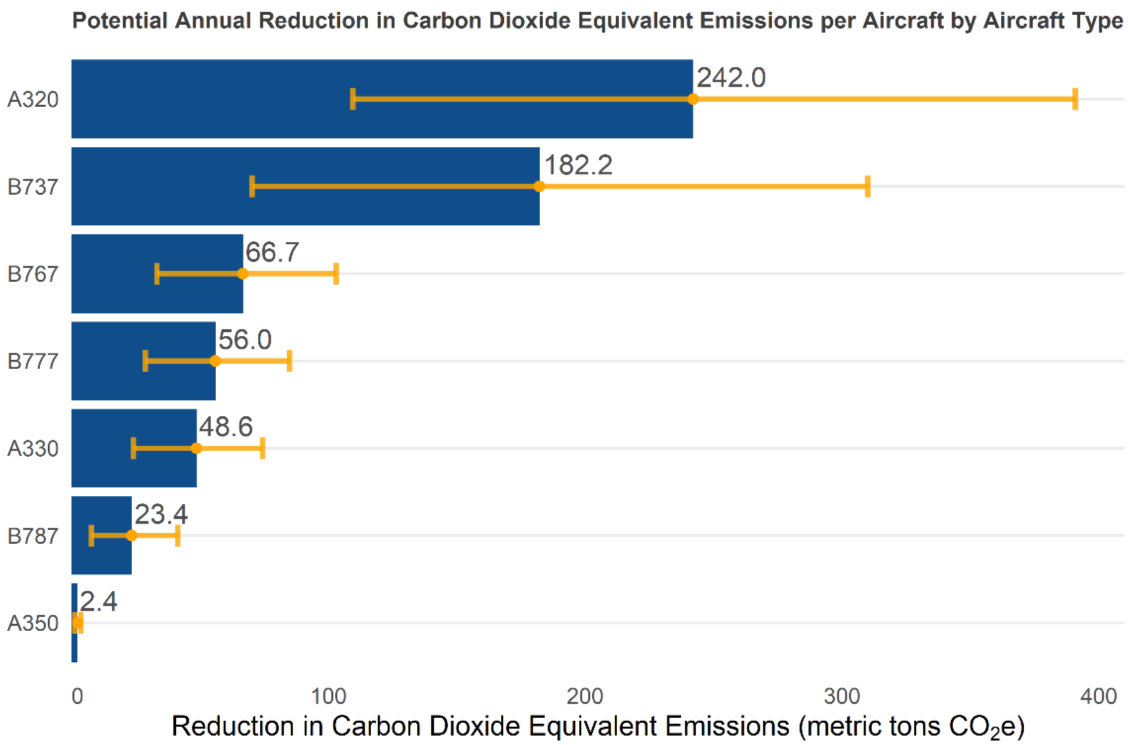

Figure 5: Potential TASAR Annual CO_2e Emissions Reduction per Aircraft by Aircraft Family

To determine why the Airbus A320 and Boeing 737 aircraft type families had higher per-capita potential annual reductions in CO_2e emissions than other aircraft type families, a series of secondary analyses were conducted. These analyses were inconclusive. However, the trends in these analyses demonstrate an apparent, but not quantifiable, interaction between the fuel burn ratio and the flight duration that causes the Airbus A320 and Boeing 737 aircraft type families to have higher per-capita potential annual emissions reductions. Of interesting note is that both factors are dependent on the airline. However, no accessible data provide per-aircraft fuel loading, nor is there data that specifies the durations of each flight for a specific aircraft.

5 Future Work

Emissions savings calculated in the previous section were based on fuel savings from the TASAR operational evaluation that included various operators. The original benefits analysis found that Alaska Airlines technical pilots in the front seat saw the most fuel savings. A natural extension of the work presented in this report would be to conduct environmental benefit analyses using only the subset of flights where Alaska Airlines technical pilots in the front seat use the TAP software. However, the current sample size for that subset of is too small to provide an accurate estimate of the environmental benefits. As industry commercialization efforts for TASAR progress, there may be an opportunity to gather more data on TASAR benefits when used by trained pilots in the front seats of the aircraft. If those data are provided to NASA, these environmental benefit analyses may be redone with an updated set of fuel reduction estimates due to the use of TASAR. These data, especially if they are from multiple airlines using different technologies that enable the TASAR concept, would provide a more accurate assessment of the environmental benefits.

Furthermore, this report discusses the benefits as they are related to commercial, passenger-carrying operations conducted in the domestic United States. Analyses may be conducted that expand the scope of this report. For example, analyses could consider including large domestic cargo operations (e.g., FedEx, UPS, Amazon Prime Air) and domestic business and general aviation. Additional analyses may expand the scope to consider a global perspective, including data from international operations. Caution must be taken to validate the assumptions of this report (presented in Section 3.1) when including global operations.

Additionally, TASAR represents a starting point on a roadmap of concepts and technologies leading towards autonomous Airborne Trajectory Management (ABTM). These concepts, introduced in [15], mature different facets of the TASAR concept. The steps in that Roadmap are listed below, along with the references that describe them further.

1. TASAR. Uses flight deck automation to compute optimized lateral and vertical trajectory changes to be requested via voice exchange between pilots and controllers [8].
2. Digital TASAR. Replaces the voice exchange for trajectory request and re-clearance of Basic TASAR with FAA Data Comm permitting the use of more flexible, complex, and lengthier trajectory definitions for greater savings; to facilitate simpler and faster request procedures by reducing pilot and controller workload as well as frequency congestion; and to eliminate sources of error and misunderstanding [16].
3. Four-dimensional (4D) TASAR. Extends the optimization dimensions of Basic and Digital TASAR to include the speed/time dimension to consider time of arrival constraints in the optimization routine and permit along-path speed optimization in the absence of time constraints [17].
4. Strategic Airborne Trajectory Management (SATM). Integrates the Digital and 4D TASAR capabilities with ANSP automation to provide user authority to update the strategic trajectory in downstream ANSP control sectors automatically, removing the time- and workload-intensive coordination process with downstream ANSP facilities [18].
5. Full Airborne Trajectory Management. Extends Strategic Airborne Trajectory Management to include airborne separation responsibility in the current sector and the authority to make tactical trajectory changes without prior ANSP approval, by operating under Autonomous Flight Rules [19].

Each concept provides its own benefit mechanisms that build upon the previous concepts. TASAR has proven benefits (direct operating cost reduction) that has enabled business case approval for airlines and avionics companies to invest in the requisite technology. Digital TASAR enables the optimization technology to find more complex solutions using simpler request/approval procedures, increasing potential direct operating cost benefits. 4D TASAR adds a new dimension for optimization (speed) and makes constrained flights candidates for trajectory optimization, further increasing potential direct operating cost benefits. SATM could significantly increase the opportunities to routinely realize the potential benefits of Digital TASAR and 4D TASAR on extended trajectories through implementing an automated approval process involving intelligent autonomous agents that augment or replace human decision makers at key facilities (e.g., Airline Operations Center, Air Route Traffic Control Centers, Air Traffic Control System Command Center).

As benefit analyses for each of these future concepts are conducted, attention should be taken to account for the potentially significant greenhouse gas emissions reductions in addition to the direct operating cost benefits. It is hypothesized that as the direct operating cost benefits increase (i.e., more cost savings due to reduced fuel burn and flight time), so will the greenhouse gas emissions reduction. Further research and analysis are required to confirm this hypothesis and provide estimated potential greenhouse gas emissions reduction values.

6 Conclusions

The reduction of anthropogenic greenhouse gas emissions is a key focus area of the scientific community around the world. Specifically, the aviation community has created a framework and established goals to reduce greenhouse gas emissions from aircraft operations. One area identified that will contribute to a reduction in greenhouse gas emissions is improved operations, and a specific example of an operational enhancement calls for flexible tracks and free-route airspace. NASA's TASAR concept provides an example of this operational enhancement, allowing aircrews to request trajectory modifications that save fuel or reduce the flight time.

The TASAR concept and its associated technology were developed at NASA and tested in an operational evaluation on revenue service flights with Alaska Airlines. The results from that operational evaluation validated the benefit estimates for the concept and provided researchers with real-world data to be used in subsequent analyses. This report focused on analyzing those data to determine estimated greenhouse gas reduction benefits across a representative portion of the domestic United States airline fleet due to the application of the TASAR concept.

Methods for converting the fuel burn reduction data from the operational evaluation to estimated greenhouse gas emission reductions were presented, and a novel approach to account for the variability in the operational evaluation data was described. Based on these methods, there is the potential for significant emission reductions by applying the TASAR concept in operations. The low-end of the range of estimated benefits (approximately 0.13% reduction in annual greenhouse gas emissions) aligns with the ATAG "mid improvement" operational scenario (0.1% annual reduction), the middle of the estimated benefits (approximately 0.31%) exceeds the ATAG "high improvement" operational scenario (0.2% annual reduction), and the high end of the range of estimated benefits (approximately 0.51% reduction annually) significantly exceeds the ATAG "high improvement" operational scenario.

Results were presented on a per-airline basis. These results are dependent on the number of TASAR candidate aircraft in each airline's fleet, the fuel loading ratio that is used to extrapolate the fuel savings from Alaska Airlines to other airlines, and the flight duration for aircraft in that airline's fleet. The results, when analyzed by flight duration, support the conclusion that flight duration plays a large role in estimating the environmental benefits of TASAR. Flights longer than four hours have approximately twice the potential annual reduction in CO2e emissions for the "Mid" estimate compared to flights of 2-4 hours when normalized per 1,000 flights. Finally, the results by aircraft type indicate that the Airbus A320 and Boeing 737 aircraft type families have the highest per-aircraft emissions reduction benefit. Secondary analyses to determine the cause of the results were inconclusive, but there is an apparent, but not quantifiable, interaction between the fuel burn ratio and the flight duration that causes the Airbus A320 and Boeing 737 aircraft type families to have higher per-capita potential annual emissions reductions.

Data from other airline's operational trials using commercial versions of the TASAR technology may refine the estimates provided in these reports. These analyses may be extended to include other types of operations, such as domestic cargo operations and business aviation / general aviation operations. Additionally, these analyses may also include global operations. Finally, there is an opportunity for the TASAR concept (and follow-on concepts such as Digital TASAR, Four-dimensional TASAR, and Strategic Airborne Trajectory Management) to significantly reduce aviation greenhouse gas emissions. While commercialization activities are on-going for the TASAR concept, further research and development is required to determine the exact benefits for these TASAR roadmap applications.

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Appendix A. Alaska Airlines Data Tables

Table A-1: Alaska Airlines Annual Fuel Reduction Data

TASAR Candidate Aircraft Type	Number of Annual Flights		Ratio to Observed Fuel Burn	Fuel Reduction per Flight		Annual Fuel Reduction by Flight Duration		Total Annual Fuel Reduction
	2 - 4 hours	4+ hours		2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
				gal	*gal*	*gal*	*gal*	*gal*
Boeing 737-700/700LR/Max 7	1,367	99	0.91996	26.94279	52.50171	36,830.80	5,197.67	42,028.47
Boeing 737-800	15,098	8,888	0.97149	28.45210	55.44281	429,569.84	492,775.70	922,345.54
Boeing 737-900	6,203	276	1.04605	30.63579	59.69801	190,033.78	16,476.65	206,510.43
Boeing 737-900 ER	31,468	18,575	1.00000	29.28704	57.06980	921,604.57	1,060,071.54	1,981,676.11
Airbus A319	8,661	11,355	1.38377	40.52658	78.97159	351,000.74	896,722.37	1,247,723.12
Airbus A321	806	3,836	1.19079	34.87470	67.95812	28,109.01	260,687.34	288,796.34
Totals	**63,603**	**43,029**				**1,957,148.741**	**2,731,931.263**	**4,689,080.004**

Table A-2: Alaska Airlines Annual Carbon Dioxide Emissions Reduction Data

TASAR Candidate Aircraft Type	Number of Annual Flights		Annual Fuel Reduction by Flight Duration		Annual Carbon Dioxide Emissions Reduction by Flight Duration		Total Annual Carbon Dioxide Emissions Reduction
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Boeing 737-700/700LR/Max 7	1,367	99	36,830.80	5,197.67	791,679.64	111,724.14	903,403.78
Boeing 737-800	15,098	8,888	429,569.84	492,775.70	9,233,623.10	10,592,235.76	19,825,858.87
Boeing 737-900	6,203	276	190,033.78	16,476.65	4,084,784.57	354,166.38	4,438,950.94
Boeing 737-900 ER	31,468	18,575	921,604.57	1,060,071.54	19,809,931.81	22,786,285.35	42,596,217.15
Airbus A319	8,661	11,355	351,000.74	896,722.37	7,544,776.76	19,275,087.77	26,819,864.53
Airbus A321	806	3,836	28,109.01	260,687.34	604,204.38	5,603,486.04	6,207,690.42
Totals	**63,603**	**43,029**	**1,957,148.741**	**2,731,931.263**	**42,069,000.26**	**58,722,985.44**	**100,791,985.70**

Table A-3: Alaska Airlines Annual Methane Emissions Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Annual Fuel Reduction by Flight Duration**		**Annual Methane Emissions Reduction by Flight Duration**		**Total Annual Methane Emissions Reduction**
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Boeing 737-700/700LR/Max 7	1,367	99	36,830.80	5,197.67	33.29	4.70	37.99
Boeing 737-800	15,098	8,888	429,569.84	492,775.70	388.29	445.42	833.70
Boeing 737-900	6,203	276	190,033.78	16,476.65	171.77	14.89	186.66
Boeing 737-900 ER	31,468	18,575	921,604.57	1,060,071.54	833.03	958.19	1,791.23
Airbus A319	8,661	11,355	351,000.74	896,722.37	317.27	810.54	1,127.81
Airbus A321	806	3,836	28,109.01	260,687.34	25.41	235.63	261.04
Totals	**63,603**	**43,029**	**1,957,148.741**	**2,731,931.263**	**1,769.06**	**2,469.38**	**4,238.43**

Table A-4: Alaska Airlines Annual Nitrous Oxide Emissions Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Annual Fuel Reduction by Flight Duration**		**Annual Nitrous Oxide Emissions Reduction by Flight Duration**		**Total Annual Nitrous Oxide Emissions Reduction**
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Boeing 737-700/700LR/Max 7	1,367	99	36,830.80	5,197.67	6.50	0.92	7.41
Boeing 737-800	15,098	8,888	429,569.84	492,775.70	75.76	86.91	162.67
Boeing 737-900	6,203	276	190,033.78	16,476.65	33.52	2.91	36.42
Boeing 737-900 ER	31,468	18,575	921,604.57	1,060,071.54	162.54	186.96	349.51
Airbus A319	8,661	11,355	351,000.74	896,722.37	61.91	158.15	220.06
Airbus A321	806	3,836	28,109.01	260,687.34	4.96	45.98	50.93
Totals	**63,603**	**43,029**	**1,957,148.741**	**2,731,931.263**	**345.18**	**481.83**	**827.01**

Table A-5: Alaska Airlines Annual Carbon Dioxide Equivalent Emissions Reduction Data

TASAR Candidate Aircraft Type	Annual Fuel Reduction	Annual Carbon Dioxide Emissions Reduction	Annual Methane Emissions Reduction	Annual CO$_2$ Equivalent Methane Emission Reduction	Total Annual Nitrous Oxide Emissions Reduction	Annual CO$_2$ Equivalent Nitrous Oxide Emission Reduction	Annual Reduction in Carbon Dioxide Equivalent Reduction	
	gal	lbs	lbs	lbs	lbs	lbs	lbs	Mt C0$_2$e
Boeing 737-700/700LR/Max 7	42,028.47	903,403.78	37.99	949.73	7.41	2,208.94	906,562.45	411.21
Boeing 737-800	922,345.54	19,825,858.87	833.70	20,842.57	162.67	48,476.77	19,895,178.20	9,024.29
Boeing 737-900	206,510.43	4,438,950.94	186.66	4,666.59	36.42	10,853.80	4,454,471.34	2,020.51
Boeing 737-900 ER	1,981,676.11	42,596,217.15	1,791.23	44,780.64	349.51	104,153.21	42,745,151.00	19,388.86
Airbus A319	1,247,723.12	26,819,864.53	1,127.81	28,195.24	220.06	65,578.01	26,913,637.78	12,207.81
Airbus A321	288,796.34	6,207,690.42	261.04	6,526.03	50.93	15,178.60	6,229,395.05	2,825.60
Totals	**4,689,080.00**	**100,791,985.70**	**4,238.43**	**105,960.81**	**827.01**	**246,449.33**	**101,144,395.83**	**45,878.29**

Appendix B. Allegiant Air Data Tables

Table B-1: Allegiant Airlines Annual Fuel Reduction Data

TASAR Candidate Aircraft Type	Number of Annual Flights		Ratio to Observed Fuel Burn	Fuel Reduction per Flight		Annual Fuel Reduction by Flight Duration		Total Annual Fuel Reduction
	2 - 4 hours	4+ hours		2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
				gal	*gal*	*gal*	*gal*	*gal*
Airbus A319	16,741	207	0.97	28.39	55.32	475,241.44	11,450.76	486,692.20
Totals	**16,741**	**207**				**475,241.44**	**11,450.76**	**486,692.20**

Table B-2: Allegiant Airlines Annual Carbon Dioxide Emissions Reduction Data

TASAR Candidate Aircraft Type	Number of Annual Flights		Annual Fuel Reduction by Flight Duration		Annual Carbon Dioxide Emissions Reduction by Flight Duration		Total Annual Carbon Dioxide Emissions Reduction
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	gal	lbs	lbs	lbs
Airbus A319	16,741	207	475,241.44	11,450.76	10,215,336.15	246,134.49	10,461,470.64
Totals	**16,741**	**207**	**475,241.44**	**11,450.76**	**10,215,336.15**	**246,134.49**	**10,461,470.64**

Table B-3: Allegiant Airlines Annual Methane Emissions Reduction Data

TASAR Candidate Aircraft Type	Number of Annual Flights		Annual Fuel Reduction by Flight Duration		Annual Methane Emissions Reduction by Flight Duration		Total Annual Methane Emissions Reduction
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	gal	lbs	lbs	lbs
Airbus A319	**16,741**	**207**	**475,241.44**	**11,450.76**	**429.57**	**10.35**	**439.92**
Totals	**16,741**	**207**	**475,241.44**	**11,450.76**	**429.57**	**10.35**	**439.92**

Table B-4: Allegiant Airlines Annual Nitrous Oxide Emissions Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Annual Fuel Reduction by Flight Duration**		**Annual Carbon Dioxide Emissions Reduction by Flight Duration**		**Total Annual Carbon Dioxide Emissions Reduction**
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Airbus A319	16,741	207	475,241.44	11,450.76	83.82	2.02	85.84
Totals	**16,741**	**207**	**475,241.44**	**11,450.76**	**83.82**	**2.02**	**85.84**

Table B-5: Allegiant Airlines Annual Carbon Dioxide Equivalent Emissions Reduction Data

TASAR Candidate Aircraft Type	**Annual Fuel Reduction**	**Annual Carbon Dioxide Emissions Reduction**	**Annual Methane Emissions Reduction**	**Annual CO$_2$ Equivalent Methane Emission Reduction**	**Total Annual Nitrous Oxide Emissions Reduction**	**Annual CO$_2$ Equivalent Nitrous Oxide Emission Reduction**	**Annual Reduction in Carbon Dioxide Equivalent Reduction**	
	gal	lbs	lbs	lbs	lbs	lbs	lbs	Mt C0$_2$e
Airbus A319	486,692.20	10,461,470.64	439.92	10,997.96	85.84	25,579.64	10,498,048.23	4,761.83
Totals	**486,692.20**	**10,461,470.64**	**439.92**	**10,997.96**	**85.84**	**25,579.64**	**10,498,048.23**	**4,761.83**

Appendix C. American Airlines Data Tables

Table C-1: American Airlines Annual Fuel Reduction Data

TASAR Candidate Aircraft Type	Number of Annual Flights		Ratio to Observed Fuel Burn	Fuel Reduction per Flight		Annual Fuel Reduction by Flight Duration		Total Annual Fuel Reduction
	2 - 4 hours	4+ hours		2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
				gal	*gal*	*gal*	*gal*	*gal*
Boeing 737-Max 8	5,378	929	0.90132	26.39687	51.43791	141,962.38	47,785.82	189,748.20
Boeing 737-800	158,855	30,127	1.04386	30.57156	59.57286	4,856,445.05	1,794,751.60	6,651,196.65
Boeing 767-300/300ER	4,049	1,102	1.82456	53.43600	104.12735	216,362.38	114,748.34	331,110.72
Boeing 777-200ER/200LR/233LR	1,268	565	2.59211	75.91509	147.93093	96,260.33	83,580.97	179,841.31
Boeing 777-300ER/300LR/333LR	64	36	2.99671	87.76478	171.02167	5,616.95	6,156.78	11,773.73
Boeing 787-800	518	168	1.88048	55.07376	107.31876	28,528.21	18,029.55	46,557.76
Boeing 787-900	797	0	2.08004	60.91833	118.70769	48,551.91	0.00	48,551.91
Airbus A319	38,749	2,135	1.01425	29.70451	57.88329	1,151,020.01	123,580.83	1,274,600.85
Airbus A321	103,244	54,919	1.18311	34.64991	67.52008	3,577,395.11	3,708,135.35	7,285,530.46
Airbus A330-200	148	1052	2.07456	60.75776	118.39480	8,992.15	124,551.33	133,543.48
Airbus A330-300	218	226	2.26645	66.37753	129.34570	14,470.30	29,232.13	43,702.43
Totals	**313,288**	**91,259**				**10,145,604.77**	**6,050,552.71**	**16,196,157.48**

Table C-2: American Airlines Annual Carbon Dioxide Emissions Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Annual Fuel Reduction by Flight Duration**		**Annual Carbon Dioxide Emissions Reduction by Flight Duration**		**Total Annual Carbon Dioxide Emissions Reduction**
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Boeing 737-Max 8	5,378	929	141,962.38	47,785.82	3,051,487.65	1,027,158.35	4,078,646.00
Boeing 737-800	158,855	30,127	4,856,445.05	1,794,751.60	104,389,504.94	38,578,266.31	142,967,771.25
Boeing 767-300/300ER	4,049	1,102	216,362.38	114,748.34	4,650,718.99	2,466,520.83	7,117,239.82
Boeing 777-200ER/200LR/233LR	1,268	565	96,260.33	83,580.97	2,069,120.23	1,796,576.82	3,865,697.04
Boeing 777-300ER/300LR/333LR	64	36	5,616.95	6,156.78	120,736.51	132,340.27	253,076.77
Boeing 787-800	518	168	28,528.21	18,029.55	613,215.16	387,546.02	1,000,761.18
Boeing 787-900	797	0	48,551.91	0.00	1,043,625.43	0.00	1,043,625.43
Airbus A319	38,749	2,135	1,151,020.01	123,580.83	24,741,226.92	2,656,375.60	27,397,602.52
Airbus A321	103,244	54,919	3,577,395.11	3,708,135.35	76,896,268.85	79,706,536.18	156,602,805.02
Airbus A330-200	148	1052	8,992.15	124,551.33	193,286.65	2,677,236.53	2,870,523.18
Airbus A330-300	218	226	14,470.30	29,232.13	311,039.80	628,345.90	939,385.71
Totals	**313,288**	**91,259**	**10,145,604.77**	**6,050,552.71**	**218,080,231.12**	**130,056,902.80**	**348,137,133.93**

Table C-3: American Airlines Annual Methane Emissions Reduction Data

TASAR Candidate Aircraft Type	Number of Annual Flights		Annual Fuel Reduction by Flight Duration		Annual Methane Emissions Reduction by Flight Duration		Total Annual Methane Emissions Reduction
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Boeing 737-Max 8	5,378	929	141,962.38	47,785.82	128.32	43.19	171.51
Boeing 737-800	158,855	30,127	4,856,445.05	1,794,751.60	4,389.71	1,622.27	6,011.98
Boeing 767-300/300ER	4,049	1,102	216,362.38	114,748.34	195.57	103.72	299.29
Boeing 777-200ER/200LR/233LR	1,268	565	96,260.33	83,580.97	87.01	75.55	162.56
Boeing 777-300ER/300LR/333LR	64	36	5,616.95	6,156.78	5.08	5.57	10.64
Boeing 787-800	518	168	28,528.21	18,029.55	25.79	16.30	42.08
Boeing 787-900	797	0	48,551.91	0.00	43.89	0.00	43.89
Airbus A319	38,749	2,135	1,151,020.01	123,580.83	1,040.40	111.70	1,152.10
Airbus A321	103,244	54,919	3,577,395.11	3,708,135.35	3,233.59	3,351.76	6,585.35
Airbus A330-200	148	1052	8,992.15	124,551.33	8.13	112.58	120.71
Airbus A330-300	218	226	14,470.30	29,232.13	13.08	26.42	39.50
Totals	**313,288**	**91,259**	**10,145,604.77**	**6,050,552.71**	**9,170.55**	**5,469.06**	**14,639.61**

Table C-4: American Airlines Annual Nitrous Oxide Emissions Reduction Data

TASAR Candidate Aircraft Type	Number of Annual Flights		Annual Fuel Reduction by Flight Duration		Annual Nitrous Oxide Emissions Reduction by Flight Duration		Total Annual Nitrous Oxide Emissions Reduction
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Boeing 737-Max 8	5,378	929	141,962.38	47,785.82	25.04	8.43	33.47
Boeing 737-800	158,855	30,127	4,856,445.05	1,794,751.60	856.53	316.54	1,173.07
Boeing 767-300/300ER	4,049	1,102	216,362.38	114,748.34	38.16	20.24	58.40
Boeing 777-200ER/200LR/233LR	1,268	565	96,260.33	83,580.97	16.98	14.74	31.72
Boeing 777-300ER/300LR/333LR	64	36	5,616.95	6,156.78	0.99	1.09	2.08
Boeing 787-800	518	168	28,528.21	18,029.55	5.03	3.18	8.21
Boeing 787-900	797	0	48,551.91	0.00	8.56	0.00	8.56
Airbus A319	38,749	2,135	1,151,020.01	123,580.83	203.00	21.80	224.80
Airbus A321	103,244	54,919	3,577,395.11	3,708,135.35	630.94	654.00	1,284.95
Airbus A330-200	148	1052	8,992.15	124,551.33	1.59	21.97	23.55
Airbus A330-300	218	226	14,470.30	29,232.13	2.55	5.16	7.71
Totals	**313,288**	**91,259**	**10,145,604.77**	**6,050,552.71**	**1,789.38**	**1,067.13**	**2,856.51**

Table C-5: American Airlines Annual Carbon Dioxide Equivalent Emissions Reduction Data

TASAR Candidate Aircraft Type	Annual Fuel Reduction	Annual Carbon Dioxide Emissions Reduction	Annual Methane Emissions Reduction	Annual CO$_2$ Equivalent Methane Emission Reduction	Total Annual Nitrous Oxide Emissions Reduction	Annual CO$_2$ Equivalent Nitrous Oxide Emission Reduction	Annual Reduction in Carbon Dioxide Equivalent Reduction	
	gal	lbs	lbs	lbs	lbs	lbs	lbs	Mt C0$_2$e
Boeing 737-Max 8	189,748.20	4,078,646.00	171.51	4,287.81	33.47	9,972.81	4,092,906.62	1,856.51
Boeing 737-800	6,651,196.65	142,967,771.25	6,011.98	150,299.45	1,173.07	349,574.53	143,467,645.23	65,075.78
Boeing 767-300/300ER	331,110.72	7,117,239.82	299.29	7,482.23	58.40	17,402.56	7,142,124.61	3,239.61
Boeing 777-200ER/200LR/233LR	179,841.31	3,865,697.04	162.56	4,063.94	31.72	9,452.12	3,879,213.11	1,759.58
Boeing 777-300ER/300LR/333LR	11,773.73	253,076.77	10.64	266.06	2.08	618.81	253,961.63	115.19
Boeing 787-800	46,557.76	1,000,761.18	42.08	1,052.08	8.21	2,446.99	1,004,260.25	455.52
Boeing 787-900	48,551.91	1,043,625.43	43.89	1,097.14	8.56	2,551.80	1,047,274.37	475.04
Airbus A319	1,274,600.85	27,397,602.52	1,152.10	28,802.61	224.80	66,990.65	27,493,395.78	12,470.78
Airbus A321	7,285,530.46	156,602,805.02	6,585.35	164,633.72	1,284.95	382,913.94	157,150,352.68	71,282.14
Airbus A330-200	133,543.48	2,870,523.18	120.71	3,017.73	23.55	7,018.80	2,880,559.71	1,306.60
Airbus A330-300	43,702.43	939,385.71	39.50	987.56	7.71	2,296.92	942,670.18	427.59
Totals	**16,196,157**	**348,137,134**	**14,639.61**	**365,990.32**	**2,856.51**	**851,239.93**	**349,354,364.17**	**158,464.34**

Appendix D. Delta Airlines Data Tables

Table D-1: Delta Airlines Annual Fuel Reduction Data

TASAR Candidate Aircraft Type	Number of Annual Flights		Ratio to Observed Fuel Burn	Fuel Reduction per Flight		Annual Fuel Reduction by Flight Duration		Total Annual Fuel Reduction
	2 - 4 hours	4+ hours		2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
				gal	*gal*	*gal*	*gal*	*gal*
Boeing 737-700/700LR/Max 7	260	269	0.97478	28.54844	55.63054	7,422.59	14,964.62	22,387.21
Boeing 737-800	28,287	13,379	1.06579	31.21382	60.82439	882,945.30	813,769.54	1,696,714.84
Boeing 737-900 ER	46,099	21,220	1.10307	32.30566	62.95199	1,489,258.64	1,335,841.32	2,825,099.96
Boeing 767-300/300ER	1,214	2,865	1.87610	54.94531	107.06845	66,703.61	306,751.11	373,454.72
Boeing 777-200ER/200LR/233LR	293	281	2.76864	81.08528	158.00575	23,757.99	44,399.62	68,157.60
Airbus A319	33,226	2,021	1.03728	30.37888	59.19740	1,009,368.71	119,637.95	1,129,006.66
Airbus A321	32995	3933	1.19846	35.09949	68.39615	1,158,107.67	269,002.07	1,427,109.74
Airbus A330-200	29	494	2.20833	64.67555	126.02914	1,875.59	62,258.40	64,133.99
Airbus A330-300	606	355	2.28399	66.89134	130.34692	40,536.15	46,273.16	86,809.31
Airbus A350-900	12	18	2.33224	68.30431	133.10029	819.65	2,395.81	3,215.46
Totals	**143,021**	**44,835**				**4,680,795.90**	**3,015,293.58**	**7,696,089.49**

Table D-2: Delta Airlines Annual Carbon Dioxide Emissions Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Annual Fuel Reduction by Flight Duration**		**Annual Carbon Dioxide Emissions Reduction by Flight Duration**		**Total Annual Carbon Dioxide Emissions Reduction**
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Boeing 737-700/700LR/Max 7	260	269	7,422.59	14,964.62	159,549.01	321,665.08	481,214.09
Boeing 737-800	28,287	13,379	882,945.30	813,769.54	18,978,948.88	17,492,012.92	36,470,961.81
Boeing 737-900 ER	46,099	21,220	1,489,258.64	1,335,841.32	32,011,681.41	28,713,969.26	60,725,650.67
Boeing 767-300/300ER	1,214	2,865	66,703.61	306,751.11	1,433,797.10	6,593,628.99	8,027,426.09
Boeing 777-200ER/200LR/233LR	293	281	23,757.99	44,399.62	510,679.00	954,371.75	1,465,050.75
Airbus A319	33,226	2,021	1,009,368.71	119,637.95	21,696,425.92	2,571,623.12	24,268,049.03
Airbus A321	32995	3933	1,158,107.67	269,002.07	24,893,576.41	5,782,211.58	30,675,787.99
Airbus A330-200	29	494	1,875.59	62,258.40	40,315.91	1,338,247.02	1,378,562.93
Airbus A330-300	606	355	40,536.15	46,273.16	871,326.44	994,643.60	1,865,970.05
Airbus A350-900	12	18	819.65	2,395.81	17,618.45	51,497.94	69,116.39
Totals	**143,021**	**44,835**	**4,680,795.90**	**3,015,293.58**	**100,613,918.54**	**64,813,871.27**	**165,427,789.81**

Table D-3: Delta Airlines Annual Methane Emissions Reduction Data

TASAR Candidate Aircraft Type	Number of Annual Flights		Annual Fuel Reduction by Flight Duration		Annual Methane Emissions Reduction by Flight Duration		Total Annual Methane Emissions Reduction
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Boeing 737-700/700LR/Max 7	260	269	7,422.59	14,964.62	6.71	13.53	20.24
Boeing 737-800	28,287	13,379	882,945.30	813,769.54	798.09	735.56	1,533.65
Boeing 737-900 ER	46,099	21,220	1,489,258.64	1,335,841.32	1,346.13	1,207.46	2,553.59
Boeing 767-300/300ER	1,214	2,865	66,703.61	306,751.11	60.29	277.27	337.56
Boeing 777-200ER/200LR/233LR	293	281	23,757.99	44,399.62	21.47	40.13	61.61
Airbus A319	33,226	2,021	1,009,368.71	119,637.95	912.36	108.14	1,020.50
Airbus A321	32995	3933	1,158,107.67	269,002.07	1,046.81	243.15	1,289.96
Airbus A330-200	29	494	1,875.59	62,258.40	1.70	56.28	57.97
Airbus A330-300	606	355	40,536.15	46,273.16	36.64	41.83	78.47
Airbus A350-900	12	18	819.65	2,395.81	0.74	2.17	2.91
Totals	**143,021**	**44,835**	**4,680,795.90**	**3,015,293.58**	**4,230.94**	**2,725.51**	**6,956.45**

Table D-4: Delta Airlines Annual Nitrous Oxide Emissions Reduction Data

TASAR Candidate Aircraft Type	Number of Annual Flights		Annual Fuel Reduction by Flight Duration		Annual Nitrous Oxide Emissions Reduction by Flight Duration		Total Annual Nitrous Oxide Emissions Reduction
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Boeing 737-700/700LR/Max 7	260	269	7,422.59	14,964.62	1.31	2.64	3.95
Boeing 737-800	28,287	13,379	882,945.30	813,769.54	155.72	143.52	299.25
Boeing 737-900 ER	46,099	21,220	1,489,258.64	1,335,841.32	262.66	235.60	498.26
Boeing 767-300/300ER	1,214	2,865	66,703.61	306,751.11	11.76	54.10	65.87
Boeing 777-200ER/200LR/233LR	293	281	23,757.99	44,399.62	4.19	7.83	12.02
Airbus A319	33,226	2,021	1,009,368.71	119,637.95	178.02	21.10	199.12
Airbus A321	32995	3933	1,158,107.67	269,002.07	204.25	47.44	251.70
Airbus A330-200	29	494	1,875.59	62,258.40	0.33	10.98	11.31
Airbus A330-300	606	355	40,536.15	46,273.16	7.15	8.16	15.31
Airbus A350-900	12	18	819.65	2,395.81	0.14	0.42	0.57
Totals	**143,021**	**44,835**	**4,680,795.90**	**3,015,293.58**	**825.55**	**531.81**	**1,357.36**

Table D-5: Delta Airlines Annual Carbon Dioxide Equivalent Emissions Reduction Data

TASAR Candidate Aircraft Type	Annual Fuel Reduction	Annual Carbon Dioxide Emissions Reduction	Annual Methane Emissions Reduction	Annual CO$_2$ Equivalent Methane Emission Reduction	Total Annual Nitrous Oxide Emissions Reduction	Annual CO$_2$ Equivalent Nitrous Oxide Emission Reduction	Annual Reduction in Carbon Dioxide Equivalent Reduction	
	gal	lbs	lbs	lbs	lbs	lbs	lbs	Mt C0$_2$e
Boeing 737-700/700LR/Max 7	22,387.21	481,214.09	20.24	505.89	3.95	1,176.63	482,896.61	219.04
Boeing 737-800	1,696,714.84	36,470,961.81	1,533.65	38,341.27	299.25	89,176.18	36,598,479.25	16,600.78
Boeing 737-900 ER	2,825,099.96	60,725,650.67	2,553.59	63,839.79	498.26	148,482.00	60,937,972.46	27,640.98
Boeing 767-300/300ER	373,454.72	8,027,426.09	337.56	8,439.09	65.87	19,628.09	8,055,493.26	3,653.91
Boeing 777-200ER/200LR/233LR	68,157.60	1,465,050.75	61.61	1,540.18	12.02	3,582.24	1,470,173.17	666.86
Airbus A319	1,129,006.66	24,268,049.03	1,020.50	25,512.56	199.12	59,338.49	24,352,900.09	11,046.28
Airbus A321	1,427,109.74	30,675,787.99	1,289.96	32,248.91	251.70	75,006.23	30,783,043.13	13,962.94
Airbus A330-200	64,133.99	1,378,562.93	57.97	1,449.26	11.31	3,370.76	1,383,382.95	627.49
Airbus A330-300	86,809.31	1,865,970.05	78.47	1,961.66	15.31	4,562.54	1,872,494.24	849.35
Airbus A350-900	3,215.46	69,116.39	2.91	72.66	0.57	169.00	69,358.05	31.46
Totals	**7,696,089.49**	**165,427,789.81**	**6,956.45**	**173,911.27**	**1,357.36**	**404,492.15**	**166,006,193.23**	**75,299.08**

Appendix E. Frontier Airlines Data Tables

Table E-1: Frontier Airlines Annual Fuel Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Ratio to Observed Fuel Burn**	**Fuel Reduction per Flight**		**Annual Fuel Reduction by Flight Duration**		**Total Annual Fuel Reduction**
	2 - 4 hours	4+ hours		2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
				gal	*gal*	*gal*	*gal*	*gal*
Airbus A319	9,687	461	0.98575	28.86957	56.25631	279,659.54	25,934.16	305,593.69
Airbus A320	21,394	1,987	0.85197	24.95179	48.62197	533,818.54	96,611.85	630,430.39
Airbus A321	14,686	839	1.14145	33.42961	65.14217	490,947.32	54,654.28	545,601.61
Totals	**45,767**	**3,287**				**1,304,425.40**	**177,200.29**	**1,481,625.69**

Table E-2: Frontier Airlines Annual Carbon Dioxide Emissions Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Annual Fuel Reduction by Flight Duration**		**Annual Carbon Dioxide Emissions Reduction by Flight Duration**		**Total Annual Carbon Dioxide Emissions Reduction**
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Airbus A319	9,687	461	279,659.54	25,934.16	6,011,294.32	557,455.86	6,568,750.19
Airbus A320	21,394	1,987	533,818.54	96,611.85	11,474,453.52	2,076,676.06	13,551,129.58
Airbus A321	14,686	839	490,947.32	54,654.28	10,552,934.78	1,174,796.28	11,727,731.06
Totals	**45,767**	**3,287**	**1,304,425.40**	**177,200.29**	**28,038,682.62**	**3,808,928.20**	**31,847,610.82**

Table E-3: Frontier Airlines Annual Methane Emissions Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Annual Fuel Reduction by Flight Duration**		**Annual Methane Emissions Reduction by Flight Duration**		**Total Annual Methane Emissions Reduction**
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Airbus A319	9,687	461	279,659.54	25,934.16	252.78	23.44	276.22
Airbus A320	21,394	1,987	533,818.54	96,611.85	482.52	87.33	569.84
Airbus A321	14,686	839	490,947.32	54,654.28	443.76	49.40	493.17
Totals	**45,767**	**3,287**	**1,304,425.40**	**177,200.29**	**1,179.06**	**160.17**	**1,339.23**

Table E-4: Frontier Airlines Annual Nitrous Oxide Emissions Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Annual Fuel Reduction by Flight Duration**		**Annual Nitrous Oxide Emissions Reduction by Flight Duration**		**Total Annual Nitrous Oxide Emissions Reduction**
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Airbus A319	9,687	461	279,659.54	25,934.16	49.32	4.57	53.90
Airbus A320	21,394	1,987	533,818.54	96,611.85	94.15	17.04	111.19
Airbus A321	14,686	839	490,947.32	54,654.28	86.59	9.64	96.23
Totals	**45,767**	**3,287**	**1,304,425.40**	**177,200.29**	**230.06**	**31.25**	**261.31**

Table E-5: Frontier Airlines Annual Carbon Dioxide Equivalent Emissions Reduction Data

TASAR Candidate Aircraft Type	**Annual Fuel Reduction**	**Annual Carbon Dioxide Emissions Reduction**	**Annual Methane Emissions Reduction**	**Annual CO_2 Equivalent Methane Emission Reduction**	**Total Annual Nitrous Oxide Emissions Reduction**	**Annual CO_2 Equivalent Nitrous Oxide Emission Reduction**	**Annual Reduction in Carbon Dioxide Equivalent Reduction**	
	gal	lbs	lbs	lbs	lbs	lbs	lbs	Mt C0$_2$e
Airbus A319	305,593.69	6,568,750.19	276.22	6,905.61	53.90	16,061.44	6,591,717.23	2,989.95
Airbus A320	630,430.39	13,551,129.58	569.84	14,246.06	111.19	33,134.25	13,598,509.89	6,168.18
Airbus A321	545,601.61	11,727,731.06	493.17	12,329.15	96.23	28,675.81	11,768,736.01	5,338.20
Totals	**1,481,625.69**	**31,847,610.82**	**1,339.23**	**33,480.82**	**261.31**	**77,871.49**	**31,958,963.13**	**14,496.33**

Appendix F. JetBlue Airways Data Tables

Table F-1: JetBlue Airways Annual Fuel Reduction Data

TASAR Candidate Aircraft Type	Number of Annual Flights		Ratio to Observed Fuel Burn	Fuel Reduction per Flight		Annual Fuel Reduction by Flight Duration		Total Annual Fuel Reduction
	2 - 4 hours	4+ hours		2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
				gal	*gal*	*gal*	*gal*	*gal*
Airbus A321	14,029	29,710	1.10526	32.37	63.08	454,117.14	1,874,022.05	2,328,139.18
Totals	**14,029**	**29,710**				**454,117.14**	**1,874,022.05**	**2,328,139.18**

Table F-2: JetBlue Airways Annual Carbon Dioxide Emissions Reduction Data

TASAR Candidate Aircraft Type	Number of Annual Flights		Annual Fuel Reduction by Flight Duration		Annual Carbon Dioxide Emissions Reduction by Flight Duration		Total Annual Carbon Dioxide Emissions Reduction
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Airbus A321	14,029	29,710	454,117.14	1,874,022.05	9,761,268.25	40,282,188.26	50,043,456.51
Totals	**14,029**	**29,710**	**454,117.14**	**1,874,022.05**	**9,761,268.25**	**40,282,188.26**	**50,043,456.51**

Table F-3: JetBlue Airways Annual Methane Emissions Reduction Data

TASAR Candidate Aircraft Type	Number of Annual Flights		Annual Fuel Reduction by Flight Duration		Annual Methane Emissions Reduction by Flight Duration		Total Annual Methane Emissions Reduction
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Airbus A321	14,029	29,710	454,117.14	1,874,022.05	410.47	1,693.92	2,104.39
Totals	**14,029**	**29,710**	**454,117.14**	**1,874,022.05**	**410.47**	**1,693.92**	**2,104.39**

Table F-4: JetBlue Airways Annual Nitrous Oxide Emissions Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Annual Fuel Reduction by Flight Duration**		**Annual Nitrous Oxide Emissions Reduction by Flight Duration**		**Total Annual Nitrous Oxide Emissions Reduction**
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Airbus A321	14,029	29,710	454,117.14	1,874,022.05	80.09	330.52	410.61
Totals	**14,029**	**29,710**	**454,117.14**	**1,874,022.05**	**80.09**	**330.52**	**410.61**

Table F-5: JetBlue Airways Annual Carbon Dioxide Equivalent Emissions Reduction Data

TASAR Candidate Aircraft Type	**Annual Fuel Reduction**	**Annual Carbon Dioxide Emissions Reduction**	**Annual Methane Emissions Reduction**	**Annual CO_2 Equivalent Methane Emission Reduction**	**Total Annual Nitrous Oxide Emissions Reduction**	**Annual CO_2 Equivalent Nitrous Oxide Emission Reduction**	**Annual Reduction in Carbon Dioxide Equivalent Reduction**	
	gal	lbs	lbs	lbs	lbs	lbs	lbs	Mt C0$_2$e
Airbus A321	2,328,139.18	50,043,456.51	2,104.39	52,609.79	410.61	122,362.67	50,218,428.97	22,778.68
Totals	**2,328,139.18**	**50,043,456.51**	**2,104.39**	**52,609.79**	**410.61**	**122,362.67**	**50,218,428.97**	**22,778.68**

Appendix G. Southwest Airlines Data Tables

Table G-1: Southwest Airlines Annual Fuel Reduction Data

TASAR Candidate Aircraft Type	Number of Annual Flights		Ratio to Observed Fuel Burn	Fuel Reduction per Flight		Annual Fuel Reduction by Flight Duration		Total Annual Fuel Reduction
	2 - 4 hours	4+ hours		2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
				gal	*gal*	*gal*	*gal*	*gal*
Boeing 737-700/700LR/Max 7	226,849	12,876	0.95504	27.97041	54.50416	6,345,059.02	701,795.59	7,046,854.61
Boeing 737-800	146,653	22,769	0.97478	28.54844	55.63054	4,186,714.58	1,266,651.76	5,453,366.34
Boeing 737-Max 8	14,510	2,278	0.84539	24.75911	48.24651	359,254.68	109,905.55	469,160.22
Totals	**388,012**	**37,923**				**10,891,028.28**	**2,078,352.90**	**12,969,381.17**

Table G-2: Southwest Airlines Annual Carbon Dioxide Emissions Reduction Data

TASAR Candidate Aircraft Type	Number of Annual Flights		Annual Fuel Reduction by Flight Duration		Annual Carbon Dioxide Emissions Reduction by Flight Duration		Total Annual Carbon Dioxide Emissions Reduction
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Boeing 737-700/700LR/Max 7	226,849	12,876	6,345,059.02	701,795.59	136,387,329.18	15,085,127.80	151,472,456.98
Boeing 737-800	146,653	22,769	4,186,714.58	1,266,651.76	89,993,618.24	27,226,736.54	117,220,354.78
Boeing 737-Max 8	14,510	2,278	359,254.68	109,905.55	7,722,195.48	2,362,424.67	10,084,620.15
Totals	**388,012**	**37,923**	**10,891,028.28**	**2,078,352.90**	**234,103,142.90**	**44,674,289.01**	**278,777,431.91**

Table G-3: Southwest Airlines Annual Methane Emissions Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Annual Fuel Reduction by Flight Duration**		**Annual Methane Emissions Reduction by Flight Duration**		**Total Annual Methane Emissions Reduction**
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Boeing 737-700/700LR/Max 7	226,849	12,876	6,345,059.02	701,795.59	5,735.26	634.35	6,369.61
Boeing 737-800	146,653	22,769	4,186,714.58	1,266,651.76	3,784.35	1,144.92	4,929.27
Boeing 737-Max 8	14,510	2,278	359,254.68	109,905.55	324.73	99.34	424.07
Totals	**388,012**	**37,923**	**10,891,028.28**	**2,078,352.90**	**9,844.34**	**1,878.61**	**11,722.95**

Table G-4: Southwest Airlines Annual Nitrous Oxide Emissions Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Annual Fuel Reduction by Flight Duration**		**Annual Nitrous Oxide Emissions Reduction by Flight Duration**		**Total Annual Nitrous Oxide Emissions Reduction**
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Boeing 737-700/700LR/Max 7	226,849	12,876	6,345,059.02	701,795.59	1,119.08	123.78	1,242.85
Boeing 737-800	146,653	22,769	4,186,714.58	1,266,651.76	738.41	223.40	961.81
Boeing 737-Max 8	14,510	2,278	359,254.68	109,905.55	63.36	19.38	82.75
Totals	**388,012**	**37,923**	**10,891,028.28**	**2,078,352.90**	**1,920.85**	**366.56**	**2,287.40**

Table G-5: Southwest Airlines Annual Carbon Dioxide Equivalent Emissions Reduction Data

TASAR Candidate Aircraft Type	**Annual Fuel Reduction**	**Annual Carbon Dioxide Emissions Reduction**	**Annual Methane Emissions Reduction**	**Annual CO_2 Equivalent Methane Emission Reduction**	**Total Annual Nitrous Oxide Emissions Reduction**	**Annual CO_2 Equivalent Nitrous Oxide Emission Reduction**	**Annual Reduction in Carbon Dioxide Equivalent Reduction**	
	gal	lbs	lbs	lbs	lbs	lbs	lbs	Mt $C0_2e$
Boeing 737-700/700LR/Max 7	7,046,854.61	151,472,456.98	6,369.61	159,240.28	1,242.85	370,369.58	152,002,066.83	68,946.92
Boeing 737-800	5,453,366.34	117,220,354.78	4,929.27	123,231.66	961.81	286,618.80	117,630,205.23	53,356.12
Boeing 737-Max 8	469,160.22	10,084,620.15	424.07	10,601.78	82.75	24,658.19	10,119,880.12	4,590.30
Totals	**12,969,381.17**	**278,777,431.91**	**11,722.95**	**293,073.71**	**2,287.40**	**681,646.56**	**279,752,152.18**	**126,893.34**

Appendix H. Spirit Airlines Data Tables

Table H-1: Spirit Airlines Annual Fuel Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Ratio to Observed Fuel Burn**	**Fuel Reduction per Flight**		**Annual Fuel Reduction by Flight Duration**		**Total Annual Fuel Reduction**
	2 - 4 hours	4+ hours		2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
				gal	*gal*	*gal*	*gal*	*gal*
Airbus A319	21,025	3,805	1.01754	29.80	58.07	626,562.82	220,960.25	847,523.07
Airbus A321	28,737	817	1.01864	29.83	58.13	857,309.79	47,495.15	904,804.94
Totals	**49,762**	**4,622**				**1,483,872.61**	**268,455.40**	**1,752,328.02**

Table H-2: Spirit Airlines Annual Carbon Dioxide Emissions Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Annual Fuel Reduction by Flight Duration**		**Annual Carbon Dioxide Emissions Reduction by Flight Duration**		**Total Annual Carbon Dioxide Emissions Reduction**
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Airbus A319	21,025	3,805	626,562.82	220,960.25	13,467,996.08	4,749,550.48	18,217,546.57
Airbus A321	28,737	817	857,309.79	47,495.15	18,427,912.55	1,020,910.43	19,448,822.98
Totals	**49,762**	**4,622**	**1,483,872.61**	**268,455.40**	**31,895,908.63**	**5,770,460.92**	**37,666,369.55**

Table H-3: Spirit Airlines Annual Methane Emissions Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Annual Fuel Reduction by Flight Duration**		**Annual Methane Emissions Reduction by Flight Duration**		**Total Annual Methane Emissions Reduction**
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Airbus A319	21,025	3,805	626,562.82	220,960.25	566.35	199.72	766.07
Airbus A321	28,737	817	857,309.79	47,495.15	774.92	42.93	817.85
Totals	**49,762**	**4,622**	**1,483,872.61**	**268,455.40**	**1,341.26**	**242.66**	**1583.92**

Table H-4: Spirit Airlines Annual Nitrous Oxide Emissions Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Annual Fuel Reduction by Flight Duration**		**Annual Nitrous Oxide Emissions Reduction by Flight Duration**		**Total Annual Nitrous Oxide Emissions Reduction**
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Airbus A319	21,025	3,805	626,562.82	220,960.25	110.51	38.97	149.48
Airbus A321	28,737	817	857,309.79	47,495.15	151.20	8.38	159.58
Totals	**49,762**	**4,622**	**1,483,872.61**	**268,455.40**	**261.71**	**47.35**	**309.06**

Table H-5: Spirit Airlines Annual Carbon Dioxide Equivalent Emissions Reduction Data

TASAR Candidate Aircraft Type	**Annual Fuel Reduction**	**Annual Carbon Dioxide Emissions Reduction**	**Annual Methane Emissions Reduction**	**Annual CO$_2$ Equivalent Methane Emission Reduction**	**Total Annual Nitrous Oxide Emissions Reduction**	**Annual CO$_2$ Equivalent Nitrous Oxide Emission Reduction**	**Annual Reduction in Carbon Dioxide Equivalent Reduction**	
	gal	lbs	lbs	lbs	lbs	lbs	lbs	Mt C0$_2$e
Airbus A319	847,523.07	18,217,546.57	766.07	19,151.78	149.48	44,544.24	18,281,242.58	8,292.23
Airbus A321	904,804.94	19,448,822.98	817.85	20,446.20	159.58	47,554.87	19,516,824.05	8,852.68
Totals	**1,752,328.02**	**37,666,369.55**	**1583.92**	**39,597.98**	**309.06**	**92,099.10**	**37,798,066.63**	**17,144.90**

Appendix I. Sun Country Airlines Data Tables

Table I-1: Sun Country Airlines Annual Fuel Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Ratio to Observed Fuel Burn**	**Fuel Reduction per Flight**		**Annual Fuel Reduction by Flight Duration**		**Total Annual Fuel Reduction**
	2 - 4 hours	4+ hours		2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
				gal	*gal*	*gal*	*gal*	*gal*
Boeing 737-700/700LR/Max 7	3,622	84	0.81689	23.92417	46.61952	86,653.35	3,916.04	90,569.39
Boeing 737-800	13,155	122	0.93421	27.36026	53.31521	359,924.23	6,504.46	366,428.69
Totals	**16,777**	**206**				**446,577.58**	**10,420.49**	**456,998.08**

Table I-2: Sun Country Airlines Annual Carbon Dioxide Emissions Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Annual Fuel Reduction by Flight Duration**		**Annual Carbon Dioxide Emissions Reduction by Flight Duration**		**Total Annual Carbon Dioxide Emissions Reduction**
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Boeing 737-700/700LR/Max 7	3,622	84	86,653.35	3,916.04	1,862,617.67	84,175.45	1,946,793.12
Boeing 737-800	13,155	122	359,924.23	6,504.46	7,736,587.61	139,813.56	7,876,401.17
Totals	**16,777**	**206**	**446,577.58**	**10,420.49**	**9,599,205.28**	**223,989.01**	**9,823,194.29**

Table I-3: Sun Country Airlines Annual Methane Emissions Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Annual Fuel Reduction by Flight Duration**		**Annual Methane Emissions Reduction by Flight Duration**		**Total Annual Methane Emissions Reduction**
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Boeing 737-700/700LR/Max 7	3,622	84	86,653.35	3,916.04	78.33	3.54	81.87
Boeing 737-800	13,155	122	359,924.23	6,504.46	325.33	5.88	331.21
Totals	**16,777**	**206**	**446,577.58**	**10,420.49**	**403.66**	**9.42**	**413.08**

Table I-4: Sun Country Airlines Annual Nitrous Oxide Emissions Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Annual Fuel Reduction by Flight Duration**		**Annual Nitrous Oxide Emissions Reduction by Flight Duration**		**Total Annual Nitrous Oxide Emissions Reduction**
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Boeing 737-700/700LR/Max 7	3,622	84	86,653.35	3,916.04	15.28	0.69	15.97
Boeing 737-800	13,155	122	359,924.23	6,504.46	63.48	1.15	64.63
Totals	**16,777**	**206**	**446,577.58**	**10,420.49**	**78.76**	**1.84**	**80.60**

Table I-5: Sun Country Airlines Annual Carbon Dioxide Equivalent Emissions Reduction Data

TASAR Candidate Aircraft Type	**Annual Fuel Reduction**	**Annual Carbon Dioxide Emissions Reduction**	**Annual Methane Emissions Reduction**	**Annual CO$_2$ Equivalent Methane Emission Reduction**	**Total Annual Nitrous Oxide Emissions Reduction**	**Annual CO$_2$ Equivalent Nitrous Oxide Emission Reduction**	**Annual Reduction in Carbon Dioxide Equivalent Reduction**	
	gal	lbs	lbs	lbs	lbs	lbs	lbs	Mt C0$_2$e
Boeing 737-700/700LR/Max 7	90,569.39	1,946,793.12	81.87	2,046.63	15.97	4,760.16	1,953,599.91	886.14
Boeing 737-800	366,428.69	7,876,401.17	331.21	8,280.32	64.63	19,258.81	7,903,940.30	3,585.16
Totals	**456,998.08**	**9,823,194.29**	**413.08**	**10,326.95**	**80.60**	**24,018.97**	**9,857,540.21**	**4,471.30**

Appendix J. United Airlines Data Tables

Table J-1: United Airlines Annual Fuel Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Ratio to Observed Fuel Burn**	**Fuel Reduction per Flight**		**Annual Fuel Reduction by Flight Duration**		**Total Annual Fuel Reduction**
	2 - 4 hours	4+ hours		2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
				gal	*gal*	*gal*	*gal*	*gal*
Boeing 737-700/700LR/Max 7	13,094	3,087	0.80263	23.51	45.81	307,796.77	141,403.20	449,199.97
Boeing 737-800	56,135	14,306	0.89364	26.17	51.00	1,469,169.75	729,604.23	2,198,773.98
Boeing 737-900 ER	74,043	22,540	0.93202	27.30	53.19	2,021,080.33	1,198,903.84	3,219,984.16
Boeing 737-Max 9	4,158	657	0.79496	23.28	45.37	96,806.19	29,806.77	126,612.96
Boeing 767-300/300ER	1,743	36	1.75439	51.38	100.12	89,556.69	3,604.41	93,161.09
Boeing 777-200ER/200LR/233LR	1,898	3,502	2.43531	71.32	138.98	135,370.93	486,716.66	622,087.59
Boeing 777-300ER/300LR/333LR	62	107	2.79386	81.82	159.45	5,073.08	17,060.62	22,133.70
Boeing 787-800	612	165	1.71930	50.35	98.12	30,816.13	16,189.80	47,005.93
Boeing 787-900	780	28	1.91667	56.13	109.38	43,784.12	3,062.75	46,846.87
Airbus A319	24,245	5,066	0.81469	23.86	46.49	578,484.39	235,540.46	814,024.85
Totals	**176,770**	**49,494**				**4,777,938.38**	**2,861,892.71**	**7,639,831.09**

Table J-2: United Airlines Annual Carbon Dioxide Emissions Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Annual Fuel Reduction by Flight Duration**		**Annual Carbon Dioxide Emissions Reduction by Flight Duration**		**Total Annual Carbon Dioxide Emissions Reduction**
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Boeing 737-700/700LR/Max 7	13,094	3,087	307,796.77	141,403.20	6,616,105.45	3,039,468.04	9,655,573.49
Boeing 737-800	56,135	14,306	1,469,169.75	729,604.23	31,579,869.89	15,682,875.70	47,262,745.59
Boeing 737-900 ER	74,043	22,540	2,021,080.33	1,198,903.84	43,443,212.56	25,770,491.90	69,213,704.46
Boeing 737-Max 9	4,158	657	96,806.19	29,806.77	2,080,853.44	640,697.82	2,721,551.26
Boeing 767-300/300ER	1,743	36	89,556.69	3,604.41	1,925,024.98	77,476.92	2,002,501.91
Boeing 777-200ER/200LR/233LR	1,898	3,502	135,370.93	486,716.66	2,909,804.21	10,461,996.52	13,371,800.73
Boeing 777-300ER/300LR/333LR	62	107	5,073.08	17,060.62	109,046.09	366,718.71	475,764.81
Boeing 787-800	612	165	30,816.13	16,189.80	662,394.14	348,000.50	1,010,394.64
Boeing 787-900	780	28	43,784.12	3,062.75	941,141.73	65,833.86	1,006,975.59
Airbus A319	24,245	5,066	578,484.39	235,540.46	12,434,547.99	5,062,952.70	17,497,500.69
Totals	**176,770**	**49,494**	**4,777,938.38**	**2,861,892.71**	**102,702,000.48**	**61,516,512.68**	**164,218,513.17**

Table J-3: United Airlines Annual Methane Emissions Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Annual Fuel Reduction by Flight Duration**		**Annual Methane Emissions Reduction by Flight Duration**		**Total Annual Methane Emissions Reduction**
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Boeing 737-700/700LR/Max 7	13,094	3,087	307,796.77	141,403.20	278.22	127.81	406.03
Boeing 737-800	56,135	14,306	1,469,169.75	729,604.23	1,327.97	659.49	1987.46
Boeing 737-900 ER	74,043	22,540	2,021,080.33	1,198,903.84	1,826.84	1,083.68	2,910.53
Boeing 737-Max 9	4,158	657	96,806.19	29,806.77	87.50	26.94	114.44
Boeing 767-300/300ER	1,743	36	89,556.69	3,604.41	80.95	3.26	84.21
Boeing 777-200ER/200LR/233LR	1,898	3,502	135,370.93	486,716.66	122.36	439.94	562.30
Boeing 777-300ER/300LR/333LR	62	107	5,073.08	17,060.62	4.59	15.42	20.01
Boeing 787-800	612	165	30,816.13	16,189.80	27.85	14.63	42.49
Boeing 787-900	780	28	43,784.12	3,062.75	39.58	2.77	42.34
Airbus A319	24,245	5,066	578,484.39	235,540.46	522.89	212.90	735.79
Totals	**176,770**	**49,494**	**4,777,938.38**	**2,861,892.71**	**4,318.75**	**2,586.85**	**6,905.60**

Table J-4: United Airlines Annual Nitrous Oxide Emissions Reduction Data

TASAR Candidate Aircraft Type	**Number of Annual Flights**		**Annual Fuel Reduction by Flight Duration**		**Annual Nitrous Oxide Emissions Reduction by Flight Duration**		**Total Annual Nitrous Oxide Emissions Reduction**
	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	2 - 4 hours	4+ hours	
			gal	*gal*	*lbs*	*lbs*	*lbs*
Boeing 737-700/700LR/Max 7	13,094	3,087	307,796.77	141,403.20	54.29	24.94	79.23
Boeing 737-800	56,135	14,306	1,469,169.75	729,604.23	259.12	128.68	387.80
Boeing 737-900 ER	74,043	22,540	2,021,080.33	1,198,903.84	356.46	211.45	567.91
Boeing 737-Max 9	4,158	657	96,806.19	29,806.77	17.07	5.26	22.33
Boeing 767-300/300ER	1,743	36	89,556.69	3,604.41	15.80	0.64	16.43
Boeing 777-200ER/200LR/233LR	1,898	3,502	135,370.93	486,716.66	23.88	85.84	109.72
Boeing 777-300ER/300LR/333LR	62	107	5,073.08	17,060.62	0.89	3.01	3.90
Boeing 787-800	612	165	30,816.13	16,189.80	5.44	2.86	8.29
Boeing 787-900	780	28	43,784.12	3,062.75	7.72	0.54	8.26
Airbus A319	24,245	5,066	578,484.39	235,540.46	102.03	41.54	143.57
Totals	**176,770**	**49,494**	**4,777,938.38**	**2,861,892.71**	**842.68**	**504.75**	**1,347.43**

Table J-5: United Airlines Annual Carbon Dioxide Equivalent Emissions Reduction Data

TASAR Candidate Aircraft Type	Annual Fuel Reduction	Annual Carbon Dioxide Emissions Reduction	Annual Methane Emissions Reduction	Annual CO_2 Equivalent Methane Emission Reduction	Total Annual Nitrous Oxide Emissions Reduction	Annual CO_2 Equivalent Nitrous Oxide Emission Reduction	Annual Reduction in Carbon Dioxide Equivalent Reduction	
	gal	lbs	lbs	lbs	lbs	lbs	lbs	Mt $C0_2e$
Boeing 737-700/700LR/Max 7	449,199.97	9,655,573.49	406.03	10,150.73	79.23	23,609.12	9,689,333.33	4,395.00
Boeing 737-800	2,198,773.98	47,262,745.59	1987.46	49,686.48	387.80	115,563.47	47,427,995.54	21,512.96
Boeing 737-900 ER	3,219,984.16	69,213,704.46	2,910.53	72,763.13	567.91	169,236.38	69,455,703.96	31,504.55
Boeing 737-Max 9	126,612.96	2,721,551.26	114.44	2,861.12	22.33	6,654.54	2,731,066.92	1,238.79
Boeing 767-300/300ER	93,161.09	2,002,501.91	84.21	2,105.19	16.43	4,896.37	2,009,503.47	911.49
Boeing 777-200ER/200LR/233LR	622,087.59	13,371,800.73	562.30	14,057.53	109.72	32,695.77	13,418,554.03	6,086.55
Boeing 777-300ER/300LR/333LR	22,133.70	475,764.81	20.01	500.16	3.90	1,163.31	477,428.28	216.56
Boeing 787-800	47,005.93	1,010,394.64	42.49	1,062.21	8.29	2,470.54	1,013,927.40	459.91
Boeing 787-900	46,846.87	1,006,975.59	42.34	1,058.62	8.26	2,462.18	1,010,496.39	458.35
Airbus A319	814,024.85	17,497,500.69	735.79	18,394.81	143.57	42,783.63	17,558,679.13	7,964.48
Totals	**7,639,831.09**	**164,218,513.17**	**6,905.60**	**172,639.98**	**1,347.43**	**401,535.32**	**164,792,688.46**	**74,748.65**

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14. ABSTRACT

Reduction of greenhouse gas emissions has been a focus area of the scientific community for the past several years. Specifically, the aviation industry has set goals to reduce greenhouse gas emissions. A potential solution for reducing aviation emissions is the Traffic Aware Strategic Aircrew Requests (TASAR) concept. This report discusses analyses that provide an estimate of the potential environmental benefits that result from the application of the TASAR concept. Analyses determined that there are impactful potential environmental benefits to be realized using the TASAR concept.

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