USING FAA'S SAGE MODEL TO CONDUCT GLOBAL INVENTORIES AND TO ASSESS ROUTE-SPECIFIC VARIABILITY IN AVIATION FUEL BURN, EMISSIONS AND COSTS

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Abstract

The focus on optimizing aircraft fuel efficiency as well as interest in assessing aviation emissions inventories to measure the efficacy of efforts to limit or reduce aviation emissions worldwide has spurred a number of efforts in the U.S. and Europe to develop robust computer models capable of assessing aircraft emissions at local, regional, and global levels. The present contribution shows both a macro and micro level example of the types of analyses that the Federal Aviation Administration's (FAA) System for assessing Aviation's Global Emissions (SAGE) enables. On the macro level, examples are given of global inventory information computed using SAGE. In addition, a micro-level assessment of fuel burn, emissions and related costs associated with the 2995 nmi (Great Circle), New York (JFK)-to-London (EGLL) origin-destination (O-D) pair is provided.

We highlight this O-D pair since: (1) it is an extremely popular trans-oceanic pair, with a large number of operations; (2) radar-based aircraft position data from FAA's Enhanced Traffic Management System are available for all flights hence enhancing the confidence of the analyses; and (3) a variety of aircraft (B747, B767 and B777), operated by several different international carriers are represented on this O-D pair, which highlights the versatility and robustness of the model. SAGE supports decision making to manage and mitigate aviation fuel consumption and emissions, thereby enabling the sustained growth of this critical mode of transportation.

1 Introduction

Aviation is a critical component of the world's economy, providing for the movement of people and goods throughout the world, and enabling economic growth. Despite significant progress in reducing the environmental effects of aviation [1][2], and despite the relatively small contribution that aviation emissions currently makes to emissions inventories worldwide [3][4], environmental concerns are strong and growing [5][6][7].

Measuring and tracking fuel efficiency from aircraft operations is necessary to assess the benefits from improvements in aircraft/engine technology and operational procedures, and enhancements in the airspace transportation system, thereby weighing their influence on reducing aviation's fuel consumption and emissions contribution. Exploiting growing computing capability is leading to remarkable tools to support decision making in managing and mitigating aircraft fuel consumption and emissions, thereby enabling the sustained growth of this critical mode of transportation.

To support its policy and regulatory activities, the United States [US] Federal Aviation Administration [FAA] Office of Environment and Energy [AEE] has developed SAGE [the System for assessing Aviation's Global

Emissions], with support from the Volpe National Transportation Systems Center [Volpe], the Massachusetts Institute of Technology [MIT] and the Logistics Management Institute [LMI]. SAGE was recently cited by the United Nation's Intergovernmental Panel on Climate Change (IPCC) as a high fidelity (high tier) model for computing emissions inventories. The current version of SAGE, Version 1.5, which was completed in January 2005, is documented extensively in [8] and [9].

The goal of this paper is to convey the types of analyses enabled by SAGE and highlight the application of SAGE capabilities to better inform decision-making by both public and private components of the civil aviation enterprise.

1.1 SAGE Overview

SAGE is a high fidelity computer model used to predict aircraft fuel burn and emissions for all commercial (civil) flights globally in a given year. Although SAGE does not presently consider military aviation, it is capable of supporting such a capability if desired. It provides capabilities to dynamically model aircraft performance, capacity/delay at airports, and forecasts of future scenarios. The model has been developed by the FAA to provide the national and international aviation communities with a tool to evaluate the effects of various policy, technology, and operational scenarios on aircraft fuel burn and emissions. The model has been extensively validated and system-level aggregate fuel burn comparisons with airline-reported values have shown difference of less than 3% [9].

1.2 Scope of SAGE

SAGE is capable of analyses from a single flight segment to airport, regional, and global levels of commercial (civil) flights.

It can generate inventories of fuel burn and emissions of carbon monoxide [CO], hydrocarbons [HC], nitrogen oxides [NOx], carbon dioxide [CO_2], water [H_2O], and sulfur oxides [SOx], calculated as [SO_2]. Other emissions, such as Particulate Matter [PM] and Hazardous Air Pollutants [HAPs] can be computed in principle if adequate aircraft characteristics are available. The three basic inventories generated by SAGE are: (1) four-dimensional [4D] variable world grids currently generated in a standardized 1^o latitude by 1^o longitude by 1 km altitude format; (2) modal results of each individual flight worldwide; and (3) individual chorded (flight segment) results for each flight worldwide. These outputs allow for an extensive set of analyses.

2 Motivation

In its 1999 report focused on aviation, the Intergovernmental Panel on Climate Change [IPCC] noted air transportation accounted for 2 percent of all anthropogenic carbon dioxide emissions in 1992 and 13 percent of the fossil fuel used for transportation. In a 10-year period, passenger traffic on scheduled airlines grew by 60 percent; and air travel was expected to increase by 5 percent per year for the next 10 to 15 years [5]. The IPCC estimated that in 1992, aircraft were responsible for 3.5 percent of all anthropogenic radiative forcing of the climate and (at the time of the report) expected to grow as much as 12 percent by 2050 [5].

The Committee on Aviation Environmental Protection [CAEP] of the International Civil Aviation Organization [ICAO], an organization of the United Nations [UN], addresses aviation emissions and has a goal to "limit or reduce" these emissions. In addition, the UN Framework Convention on Climate Change [UNFCCC] promoted a series of multilateral agreements that target values of emissions reductions for the primary industrialized nations [5].

Modeling aviation fuel use and emissions on a global level helps track inventories and assess the efficacy of options to reduce fuel consumption and emissions. In response to the needs of international bodies, studies have been conducted resulting in global inventories of emissions by various organizations including the National Aeronautics and Space Administration [NASA]/Boeing [5][10][11], Abatement of Nuisance Caused by Air Transport [ANCAT]/European Commission [EC] 2 group [12], Deutsche Forschungsanstalt fur Luft- and Raumfahrt [DLR] [13], and the Dutch Directorate-General of Civil Aviation's Aviation Emissions and Evaluation of Reduction Options Modeling System [AERO-MS] [14]. These inventories represent significant accomplishments since they are the first set of "good-quality" global emissions estimates. However, the data and tools used to develop these inventories were generally unsuitable for long-term regulatory and policy applications as they fell short of one or more of the following criteria: (1) non-proprietary data and methods that would provide the international aviation community with a clear understanding of how the model works (i.e., no "black boxes"); (2) a commitment by the developers to continue updating the data and methods used by the model, vital to develop yearly inventories and track temporal trends; and (3) a dynamic and robust modeling environment that could be used to assess various scenarios. The development of SAGE was partly stimulated by concern about the rapid growth in aviation and accompanying growth in emissions and driven by the concerns about some of the limitations of existing models.

SAGE advances emissions inventory modeling capabilities and addresses some of the deficiencies noted in previous models. More recently, SAGE has been used to track progress on FAA's goal to improve aviation fuel efficiency per revenue plane-mile by 1% per year through FY 2009, as measured by a three-year moving average, from the three-year average for calendar years 2000-2002.

SAGE, currently at Version 1.5, incorporates lessons learned from the past studies in modeling commercial flights on a global basis. Table 1 summarizes data and methods used in previous efforts and describes the improvements incorporated into SAGE.

3 Model Description

The fundamental "unit of work" in SAGE is a single flight. All data including those related to flight schedules, trajectories, performance, and emissions are represented at a level of detail sufficient to support the modeling of a single flight. This allows high-fidelity modeling of global inventories of fuel burn and emissions where all commercial flights worldwide for each day of the year are accounted for. Each flight is modeled from gate-to-gate as indicated in Figure 1.

The current worldwide coverage in SAGE includes approximately 30 million commercial flights per year and accounts for over 400 different aircraft types. The intention is to preserve as much specificity for each flight as possible; therefore, for each aircraft type, specific aircraft data was used whenever possible. If exact data did not exist for a certain aircraft type, an aircraft with similar attributes (i.e., number of engines, weight class, etc.) was used. The current input databases allow SAGE to be used to model flights for all years from 2000 to 2005.

To accomplish the detailed flight-by-flight modeling, SAGE includes various aircraft fleet, operations, and performance data as well as the modules to process the information and perform computations. The basic computational modules and outputs are shown in Figure 2.

A detailed description of the computational modules as well as the corresponding databases is provided in [15].

The basic outputs from SAGE are noted in Section 1.1. The model is also capable of computing particulate matter (PM) emissions with suitable input, and this capability is still undergoing development.

Table 1 Comparison of Selected Data and Methods in Previous Studies to those in SAGE Version 1.5

Capability	**Previous Models**	**SAGE Version 1.5**
Goals	Goal of the study was to develop a static inventory of fuel burn and emissions.	Goal in developing SAGE was to develop a model that could be used to generate inventories of fuel burn and emissions. This allows SAGE to be used for various other studies using dynamic modeling components (e.g., as opposed to static lookup tables).
Flight Coverage	A portion (e.g., a day, week, month, etc.) of the world flight schedules and flight plans were used as a representation of all worldwide movements.	All commercial flights worldwide are modeled such that there are no assumptions associated with modeling a smaller set of flights and extrapolating to account for all flights.
En-route Flight Data	Schedule data were used as the basis for modeling global flights with model trajectories.	SAGE uses a mix of radar data and schedule information. The radar data takes precedence over schedule information as it provides both actual flight plans and actual trajectories. Radar data is available for North America and parts of western Europe and South America.
En-route Flight Modeling	Great Circle paths were used to model trajectories between Origin and Destination (OD).	Flight trajectories are dispersed around the Great Circle using trajectory distributions developed from analyzing radar trajectories
Unscheduled and Cancelled Flights Coverage	Unscheduled and cancelled flights were not accounted for.	An airport-based factor has been introduced to empirically account for the effects of unscheduled and cancelled flights
Delay Modeling	Airport delays were not modeled.	Airport delay-modeling capabilities are included in SAGE, thereby providing a dynamic capability to assess capacity/delay issues.

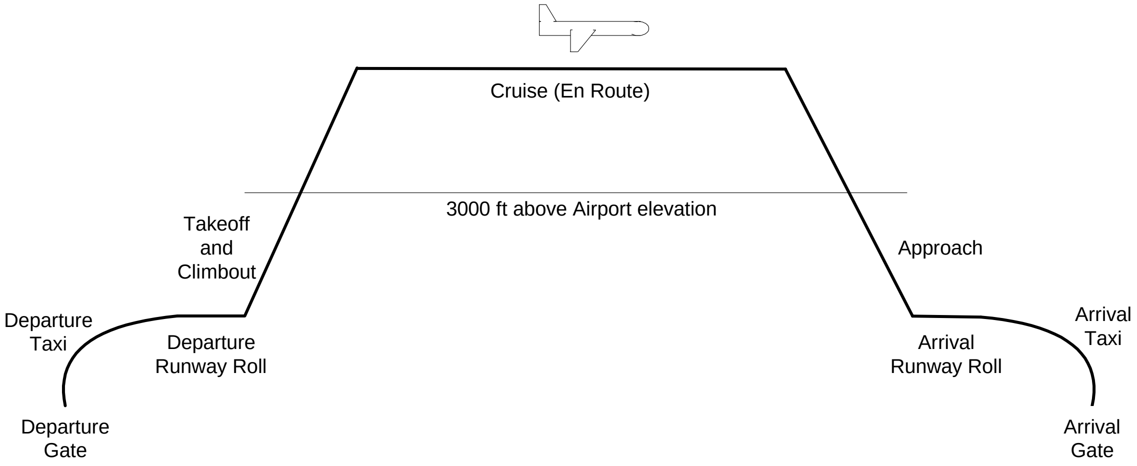


Fig. 1. Full Gate-to-Gate Flight Modeling in SAGE

Inventories, as noted above, are generated at three levels: airport, regional, and global. These inventories are generated for each year and stored in a relational database. Further details on these raw inventories can be found in [15].

Since the raw inventories have been stored in a relational database, they can be easily queried to generate various derivative inventories. These processed inventories are the results of further categorizations, aggregations, and computations using the raw data. Further details of these processed inventories can be found in [15].

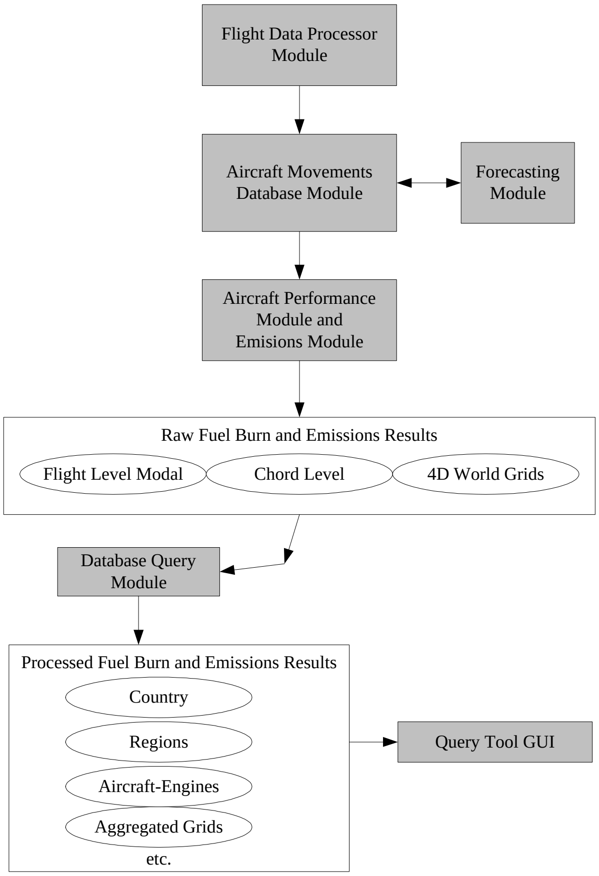


Fig. 2. Overview of the Main Modules and Databases in SAGE

4 Analyses

Section 4 presents results of analyses using SAGE outputs to assess fuel burn and efficiency of aircraft both on a global, macro level as well as a local, micro level. The macro-level quantifies any trends in global aircraft operations; and the micro-level analysis determines if these trends are noticeable on a flight-by-flight basis, and also if other factors have an impact on overall fuel burn and emissions. These analyses are conducted by querying the data produced by SAGE for the years 2000-2005. No new data was generated, but rather, the data that already exist has been analyzed for selected parameters, as the intent was to demonstrate SAGE's flexibilities and capabilities. The SAGE data can be used for any number of assessments not performed below. However, for the purposes of this section, only global data and a specific O-D pair were considered.

4.1 Macro-Level

This section presents trends in fuel burn and emissions over the years SAGE currently models (2000-2005). The goal is to assess how fuel burn and emissions change over time, and if any noticeable trends can be observed. A second goal is to assess if efficiency, particularly specific fuel consumption [SFC], increase over time [16]. Efficiency metrics are calculated to confirm or reject this idea using the SAGE data.

4.1.1 Global Total Fuel Burn and Emissions

Global fuel burn and emissions totals are shown in Table 2.

These results and all that follow do not include piston-powered aircraft as they are excluded due to the uncertainties associated with their emissions data. Piston-powered flights account for approximately 2% of propeller (piston plus

Table 2. Yearly Global Total Fuel Burn and Emissions

Year	Flights (millions)	Distance (nm)	Fuel Burn (Tg)	NOx (Tg)	CO (Tg)	HC (Tg)	CO_2 (Tg)
2000	29.7	1.80E+10	181	2.51	0.541	0.0757	572
2001	27.7	1.72E+10	170	2.35	0.464	0.063	536
2002	28.5	1.76E+10	171	2.41	0.48	0.0639	539
2003	28.8	1.86E+10	176	2.49	0.486	0.0617	557
2004	30.4	2.00E+10	188	2.69	0.511	0.0625	594
2005	32.4	2.20E+10	203	2.90	0.554	0.0652	641

turboprops) and approximately 0.05% of total (propeller plus jet) fuel burn, hence their emissions are expected to be small.

In general, as more fuel is burned, more emissions are likely to be generated. As expected, emissions of CO_2, H_2O, and SOx follow the same yearly trend as fuel burn since they are modeled strictly based on fuel composition assuming complete combustion. NOx also follows fuel burn changes closely but is much less linear. CO and HC follow fuel burn the least due to stronger non-linear effects.

These nonlinear effects are evident in plots of emissions indices [EI] versus fuel flow plots (which use Log-Log scales). CO and HC exhibit a greater degree of non-linearity. Select corresponding fuel burn and emissions metrics are provided in Table 3.

Fuel efficiency (i.e., fuel burn per unit distance) is used as a metric for measuring changes (presumably improvements) in annual fuel burn efficiency for the global fleet. Data indicates that there may be a global 1-2% annual improvement in efficiency over the 6 years considered.
This trend is consistent with the findings in [16] that show historical decreases in [SFC], energy intensity defined as energy (or fuel) used per revenue passenger kilometer, and energy used per available seat kilometer. Although some trends may appear to be present with regard to the EIs for NOx, CO, and HC, consideration of non-linear effects would make any conclusions difficult.

4.1.2 Global Gridded Results

Examples of processed, gridded fuel burn and emissions inventories are shown in Figures 3 and 4. Figure 3 shows where most of the fuel is consumed: North America, Western Europe, and Eastern Asia. Figure 4 shows a distribution of total fuel burn and emissions by 1 km altitude bins for year 2000. The altitude bins with the highest fuel burn and emissions are between 9 and 12 km (or approximately 29,500 ft and 39,400 ft). This corresponds to the frequent use of these altitudes for the cruise flight segment. The relatively high levels of HC and CO in the 0 to 1 km band are due to the higher emissions characteristics for those pollutants at lower aircraft power settings (e.g., during taxiing, idle, and approach conditions).

4.2 Micro-Level

In addition to global inventory development process, SAGE also allows for user-specified micro-level analyses. Figure 5 presents a screen dump of SAGE's querying tool. The tool provides the user with the flexibility to conduct very complex queries ranging from single flights (micro-level) to much larger levels including country, regional, and global levels.

The micro-level analyses use the data in SAGE on a single origin-destination [O-D] pair. The goal is to observe what specific conditions can impact a flight's overall fuel burn and emissions. While the macro-level analysis allows observing overall annual trends in fuel burn and emissions, the micro-level analysis allows focus on individual flights, and, for instance, determining why a particular flight route may have less fuel burn for some months.

Table 3. Yearly Global Total Fuel Burn and Emissions Efficiency

Year	Fuel Burn per Distance (Tg/Billion km)	EI NOx (g/kg)	EI CO (g/kg)	EI HC (g/kg)	EI CO_2 (g/kg)	EI H_2O (g/kg)	EI SOx (g/kg)
2000	5.43	13.8	2.98	0.417	3155	1237	0.8
2001	5.33	13.8	2.73	0.371	3155	1237	0.8
2002	5.23	14.1	2.81	0.374	3155	1237	0.8
2003	5.12	14.1	2.76	0.350	3155	1237	0.8
2004	5.08	14.3	2.71	0.332	3155	1237	0.8
2005	4.99	14.3	2.72	0.320	3155	1237	0.8

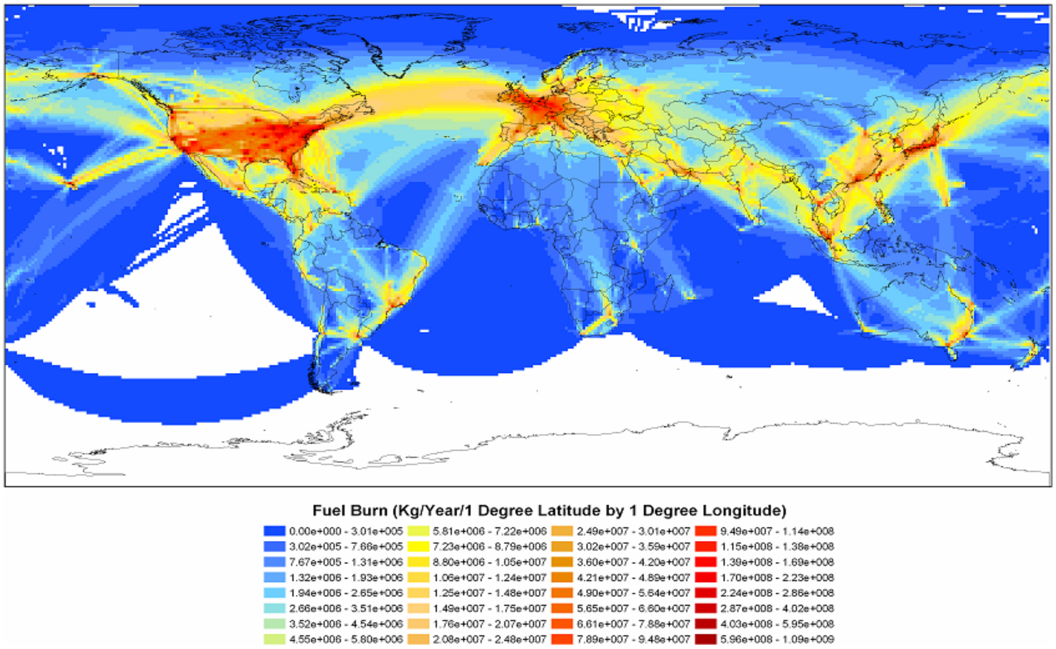


Fig. 3. Gridded Plot of Global Fuel Burn for 2000 with all Altitudes Aggregated

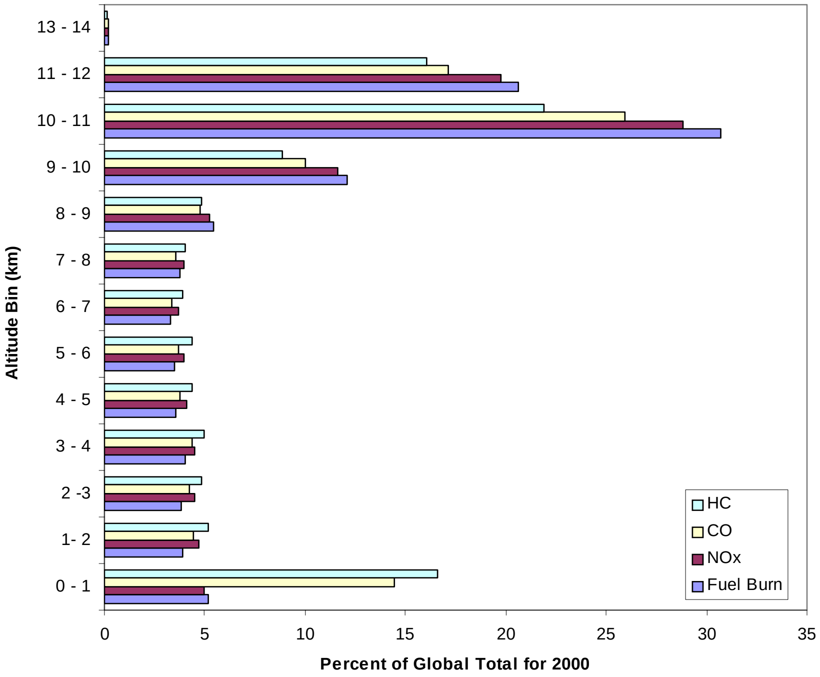
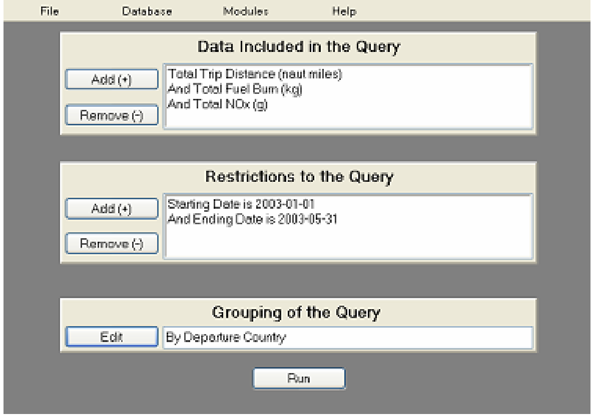


Fig. 4. Altitude Distribution of Fuel Burn and Emissions for Year 2000

Below we present a demonstration query-assessment involving a multi-year (2000 through 2004) examination of fuel burn and emissions for the New York (JFK)-to-London (EGLL) O-D pair. This particular O-D pair was selected for analysis based on the rationale outlined above.

Since the same aircraft types and airlines operate on this O-D pair consistently from 2000 to 2004, temporal comparisons and trend assessments are possible.



Total Trip Distence (naut miles)
And Total Fuel Burn (kg)
And Total NOx (g)

Starting Date is 2003-01-01
And Ending Date is 2003-05-31

By Departure Country

Fig. 5. SAGE Querying Tool

This flight assessment is based on the following model conditions and assumptions: (1) SAGE models fuel burn based on the aircraft airframe using a specific "default" engine for each aircraft; and (2) the specificity of engines for each flight modeled in SAGE is based on one of three methods, the most common of which is the assignment of engines through the use of airline fleet distributions. Engines are also assigned through exact tail number matchings and through the use of aircraft-specific default engines (i.e., most popular engines for an aircraft). The assigned engines are only used for emissions calculations and post-processing of the results into equipment categories. Therefore, both the aircraft and engine modeled for a flight may have actually been used on that flight, but the modeled fuel burn is not directly specific to the engine type. However, the effects of the actual engine that was used on a flight may have some indirect effects since the incorporation of radar data, including trajectories and speed, affect aircraft performance modeling.

4.2.1 Temporal Trends Assessment

Figures 6-10 present average, monthly, per-trip fuel burn for the Boeing 747 with three engine types, the 777, and the 767. Although engines are not specific to the fuel burn results, they are noted here for completeness. The plots show that the month-to-month variability is relatively small for each aircraft-engine combination. Also, there is a wide range of fuel burn standard deviations as indicated by the error bars. This appears to illustrate the variability of operational factors (e.g., trajectories, speeds, etc.) and winds along this O-D pair.

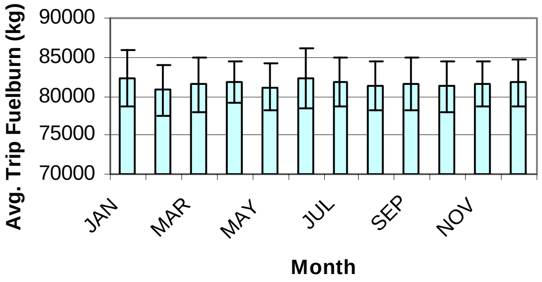


Fig. 6. B747 (Engine 1) Average Fuel Burn for 2004

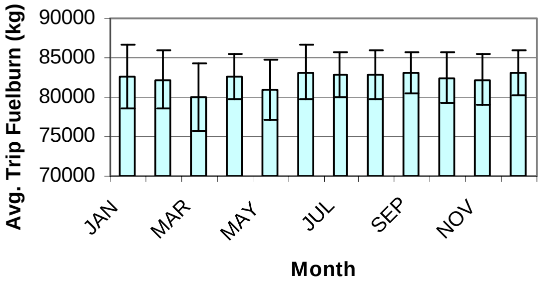


Fig. 7. B747 (Engine 2) Average Fuel Burn for 2004

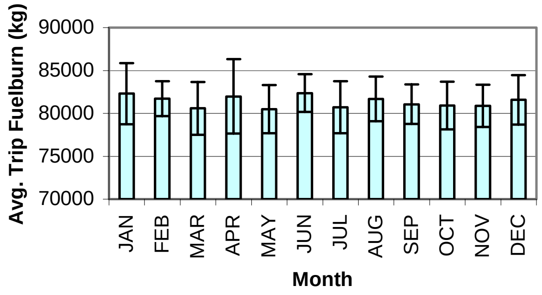


Fig. 8. 747 (Engine 3) Average Fuel Burn for 2004

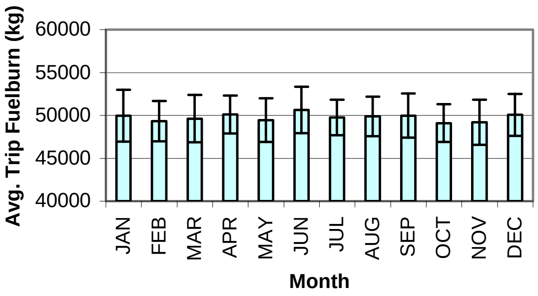


Figure 9: B777 Average Fuel Burn for 2004

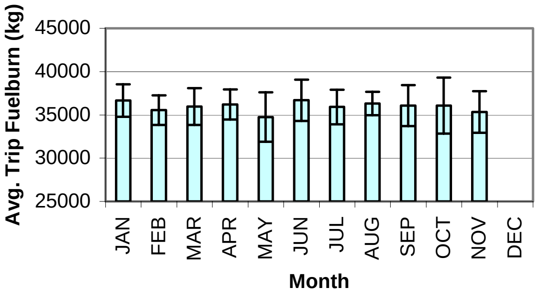


Figure 10: B767 Average Fuel Burn for 2004

There were no observed temporal trends for these aircraft for 2004. For instance, over the time period observed, fuel burn and emissions will not be noticeably different for a flight in January versus July. However, the same data was observed for 2003 and an anomaly was seen. Figure 11 shows the month-by-month analysis for the B747 and Engine 1.

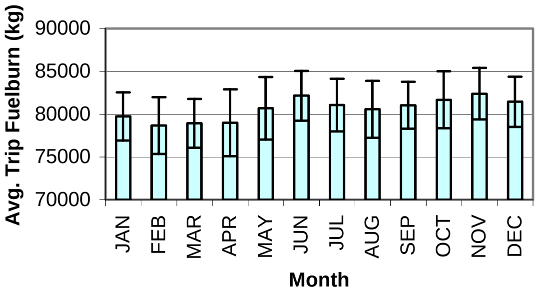


Fig. 11. B747 (Engine 1) Average Fuel Burn for 2003

As shown, the average fuel burn is less during the months January, February, March, and April when compared to the rest of the year. Using a t-test, it was found that these four months were statistically different (lower) at a 5% confidence level; when the same test was conducted on the same aircraft in 2004, only the month of February was statistically different (lower) to the same 5% confidence level. Therefore, some factor existed in the January-April timeframe of 2003 that led to a reduction in fuel burn (although not presented, this behavior was also observed for the other aircraft types).

Two possible variables were considered for the observed reduction in fuel burn from January to April 2003 that would have impacted SAGE fuel burn results: more efficient cruise times, balancing the penalties of decreased efficiency when cruising faster with the increased benefits of less time aloft (at cruise altitudes); or a reduced overall trip distance.

Figure 12 presents monthly, per trip average distance and Figure 13 presents monthly, per trip average time aloft. As these figures show, for the months January to April, trip distance is noticeably less, yet time aloft does not seem to correlate with fuel burn.

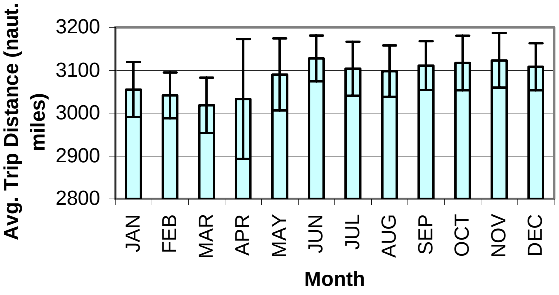


Fig. 12. B747 (Engine 1) Average Time Trip Distance for 2003

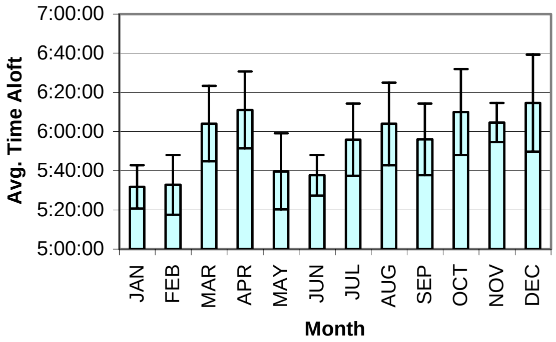


Fig. 13. B747 (Engine 1) Average Time Aloft for 2003

Table 3 shows the correlation of fuel burn with time aloft and trip distance. This reinforces what is observed in Figures 12 and 13 – that trip distance is a greater impact on fuel burn than time aloft.

Table 3. B747 (Engine 1) Correlation to Fuel Burn for 2003

Variable	**Correlation**
Trip Distance	0.77
Time Aloft	-0.04

Furthermore, Table 4 shows the correlation of fuel burn with time aloft and trip distance for 2004, demonstrating this behavior extends beyond 2003.

Table 4. B747 (Engine 1) Correlation to Fuel Burn for 2004

Variable	**Correlation**
Trip Distance	0.79
Time Aloft	-0.08

We observed that temporal differences may occur in total fuel burn for a given year, for instance, a noticeable reduction between January-April 2003. However, any observed trends can be related to a distinct aspect of the time period; in this analysis it was an overall reduction in trip distance. This does not necessarily reject the previous claim of the macro-analysis, that fuel burn efficiencies generally improve over time, but rather, large trends are not necessarily noticeable on a small scale, and outside factors have a greater impact on fuel burn and emissions than a general improvement in efficiency.

4.2.2 Carrier Assessment

In addition to assessing aggregated aircraft totals, the data was further separated by carrier. Figure 14 presents average per flight fuel burn for one carrier operating B777 aircraft from JFK to EGLL route for 2004. Figure 15 is a similar presentation, but for a separate carrier. As the figures show, the month-to-month trends in the data are very similar. In fact, the average per flight annual fuel burn for the first carrier is 49,566 kg, while it is 49,360 kg for second; and a t-test comparing the two demonstrated no statistical difference at a 5% confidence level. This implies that operational factors (including trajectories) are not significantly different, at least between these two carriers for this O-D pair.

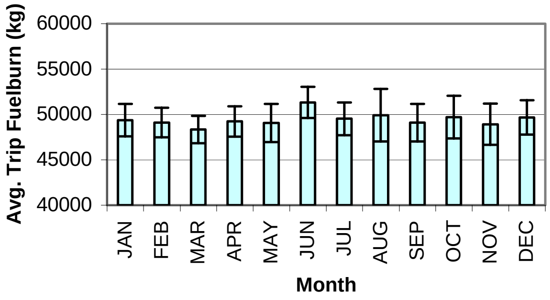


Fig. 14. B777 Average Fuel Burn for Carrier 1 2004

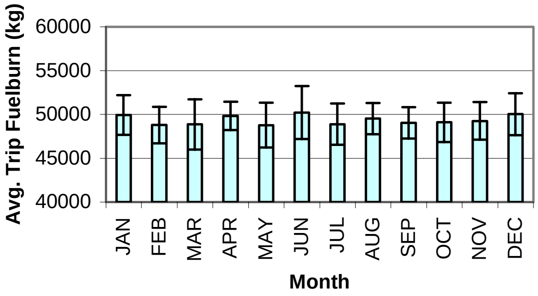


Fig. 15. B777 Average Fuel Burn for Carrier 2 2004

Seating capacity is used as the normalizing variable to assess fuel efficiency by carrier. Table 5 presents the number of total seats per aircraft-engine-carrier combination obtained from the BACK world fleet database.

Table 5. Seat Count Assumptions for Configuration/Carrier 2004

Aircraft	Engine	Carrier	Seats per Aircraft
B744	1	1	361
B744	2	1	419
B744	3	1	414
B744	3	2	427
B744	3	3	407
B772	1	1	250
B763	1	1	217

Table 6 presents a fuel efficiency comparison for 2004, which represents an aggregation of the data in Table 5 to essentially remove the carrier specificities. Similar results exist for 2000 through 2003. As indicated, the 767 is the most efficient aircraft-engine combination operating on this O-D pair. This is just one measure of efficiency and could potentially serve as a first order surrogate for an economic assessment if other factors (e.g., ticket prices, load factors, etc.) were assumed equal. The B747 Engine 1 is the least efficient aircraft, but as shown in Table 5, this is driven primarily by the low number of seats in a particular configuration of this aircraft. Presumably, that factor is somewhat offset by increased ticket prices (i.e., selling for passenger comfort).

Table 6. Efficiency for Equipment in 2004

Equipment	Total Fuel Burn (kg)	Total Seats	Efficiency (kg/seat)
B744 Engine 1	146601000	649571	225.69
B744 Engine 2	43462000	221033	196.63
B744 Engine 3	42545000	215910	197.05
B772	106580000	535548	199.01
B763	11466000	69215	165.66

5 Conclusions

SAGE is a versatile tool developed by FAA to provide a modeling capability to estimate aircraft fuel burn and emissions on a global scale based upon non-proprietary databases and methodologies. As such, SAGE, now at Version 1.5, uses the best publicly available data and methods in order to provide the U.S. and the international aviation community with a high-fidelity tool that can be used to analyze various policy, technology, and operational scenarios for their influence on aircraft fuel burn and emissions. The primary elements within SAGE include aircraft movements data, aircraft performance (including fuel flow), emissions, capacity and delay, and forecasting. All of these components reside within a dynamic modeling environment allowing access to all of the input parameters that can be queried and modified to evaluate these various scenarios. SAGE input databases currently allow for the development and analysis of fuel burn and emissions inventories for years 2000 to 2005. FAA intends to continue development and assessment of SAGE and its underlying databases and methodologies, and will produce inventories on an annual basis.

The outputs from the model provide a comprehensive set of information that can be used to estimate and analyze spatial and temporal distributions of aircraft-generated fuel burn and emissions. Aggregated yearly inventories show that from 2000 to 2005, global fuel burn has increased from 181 Tg to 220 Tg and NOx has increased from 2.51 Tg to 2.90 Tg. However, these increases also reflect recovery from the effects of September 11, 2001 as the totals for each of the years from 2001 to 2002 are lower than those for 2000. Derivative metrics such as fuel burn per distance were also shown to have changed from 5.43 Tg/Billion km in 2000 to 4.99 Tg/Billion km in 2005. This decrease is indicative of more efficient operations of the world's fleet as well as the use of more efficient aircraft types.

Also, the SAGE model may be used to observe variations on a micro level. This paper provided an example of the micro-level assessments that can be conducted from just the historical inventory data. Based on query results corresponding to flights for a single O-D pair, the assessments included comparisons of fuel burn by equipment for different months and years. Comparisons were also performed by carrier, using different metrics including a measure of fuel efficiency. Tests were conducted to see if variations in the average fuel burn were statistically significant and also to determine correlations between variables. The tests helped to identify trip distance as a significant variable causing variations in month-to-month fuel burn values. Also, fuel burn from two different airlines using the same aircraft type was found not to be statistically different implying similar operational factors between the two carriers. Furthermore, the efficiency metric (fuel burn per seat) showed that a first order surrogate assessment of economics could be achieved if assumptions of various factors (i.e. weight of fuel and associated fuel costs, average number of seats per aircraft) were made. A more rigorous economic analysis could be conducted using these types of data by adding additional information (e.g., ticket prices, load factors, etc.). Such micro-level assessments typify the robustness of the pre-computed SAGE inventory data.

Although the static inventories could themselves provide a wide-range of assessment possibilities, the computational modules provide a wealth of further capabilities. With the modules and the supporting data integrated in a dynamic modeling environment, SAGE provides the capability to model changes to various parameters including those associated with flight schedules, trajectories, aircraft performance, airport capacities/delays, etc. This results in the ability to use SAGE for applications such as global quantification of the effects of Communication, Navigation, and Surveillance [CNS]/Air Traffic Management [ATM] initiatives, determining the benefits of Reduced Vertical Separation Minimum [RVSM], investigation of trajectory optimizations, and computing potential emissions benefits from the use of a Continuous Descent Approach [CDA]. The FAA is pursuing such modeling to identify promising approaches to enhancing aviation fuel efficiency and reducing emissions.

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