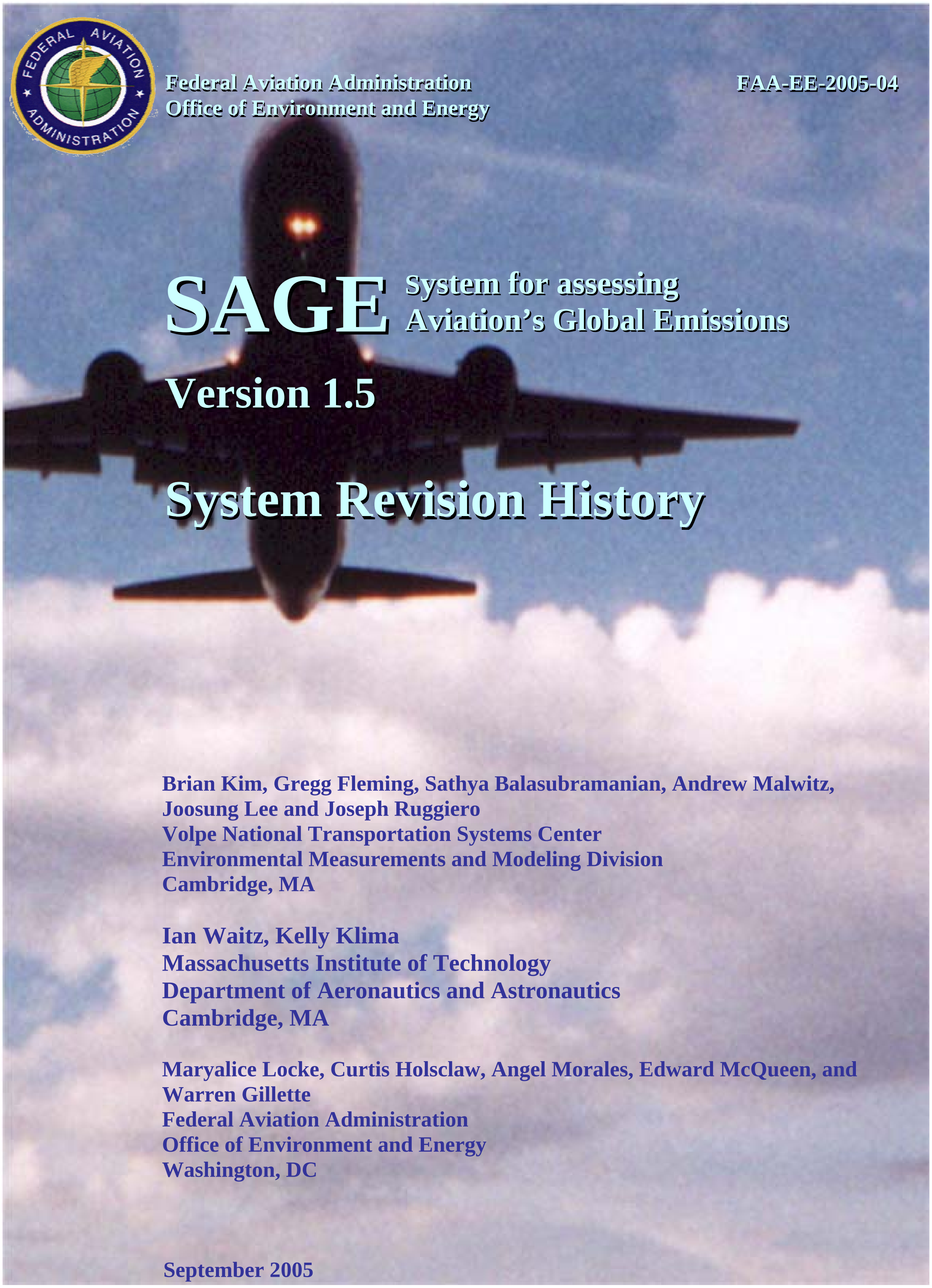

Federal Aviation Administration
Office of Environment and Energy

FAA-EE-2005-04

SAGE System for assessing Aviation's Global Emissions

Version 1.5

System Revision History

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September 2005

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13. ABSTRACT (Maximum 200 words)

The United States (US) Federal Aviation Administration (FAA) Office of Environment and Energy (AEE) has developed the System for assessing Aviation's Global Emissions (SAGE) with support from the Volpe National Transportation Systems Center (Volpe), the Massachusetts Institute of Technology (MIT) and the Logistics Management Institute (LMI). Currently at Version 1.5, 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. This means that the model is capable of analyzing scenarios from a single flight to airport, country, regional, and global levels. SAGE is able to dynamically model aircraft performance, fuel burn and emissions, capacity and delay at airports, and forecasts of future scenarios. FAA's purpose in developing SAGE is to provide the international aviation community with a tool to evaluate the effects of various policy, technology, and operational scenarios on aircraft fuel use and emissions. FAA is committed to the continued development and support of SAGE. Although the results from the model have been made available to the international aviation community, SAGE is currently an FAA government research tool and has not been released to the general public.

As part of SAGE development, this report has been assembled to document the revision history of the model. This includes changes to the methods as part of model improvement and updates to the component databases.

14. SUBJECT TERMS
SAGE, aircraft, fuel burn, emissions, emissions inventory, aircraft performance, global flights, computer model, emissions model, world fleet, forecasting, capacity and delay, aircraft movements

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LIST OF ACRONYMS

4D	Four-Dimensional
ACI	Airport Council International
AEE	Office of Environment and Energy
AIR	Aerospace Information Report
APO	Office of Aviation Policy and Plans
ARTCC	Air Route Traffic Control Center
ARTS	Automatic Radar Tracking System
ASQP	Airline Service Quality Performance
ATC	Air Traffic Control
ATCSCC	Air Traffic Control System Command Center
ATM	Air Traffic Management
BACK	BACK Aviation Solutions
BADA	Base of Aircraft Data
BFFM2	Boeing Fuel Flow Method 2
BTS	Bureau of Transportation Statistics
CAEP	Committee on Aviation Environmental Protection
CAS	Calibrated Air Speed
CDA	Continuous Descent Approach
CNS	Communication, Navigation, and Surveillance
CRS	Computer Reservation System
EDMS	Emissions and Dispersion Modeling System
EI	Emissions Index
ETMS	Enhanced Traffic Management System
Eurocontrol	European Organization for the Safety of Air Navigation
FAA	Federal Aviation Administration
FBE	Fuel Burn and Emissions (module)
FESG	Forecasting and Economics Sub Group
GC	Great Circle
GDP	Gross Domestic Product
GIS	Geographic Information System
GMT	Greenwich Mean Time
GSE	Ground Service Equipment
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
INM	Integrated Noise Model
IPCC	Intergovernmental Panel on Climate Change
ISA	International Standard Atmosphere
LMI	Logistics Management Institute
LMINET	Logistics Management Institute network queuing model of the US
LTO	Landing and Takeoff
MAGENTA	Model for Assessment of Global Exposure due to Noise from Transport Aircraft
MSL	Mean Sea Level
MTF	Mixed Turbofan
MMU	Manchester Metropolitan University
NASA	National Aeronautics and Space Administration
NPD	Noise versus Power versus Distance

NPIAS	National Plan of Integrated Airport System
OAG	Official Airline Guide
OD	Origin-Destination
PM	Particulate Matter
ROC	Rate of Climb
RVSM	Reduced Vertical Separation Minimum
SAE	Society of Automotive Engineers
TAF	Terminal Area Forecast
TAS	True Air Speed
TEM	Total Energy Model
TERP	Terminal and En Route Procedure
TF	Turbofan
TIM	Time In Mode
TMU	Traffic Management Unit
TOGW	Takeoff Gross Weight
TRACON	Terminal Radar Approach Control
TSFC	Thrust Specific Fuel Consumption
OD	Origin-Destination
UID	Unique Identification Number
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USDOT	United States Department of Transportation
USEPA	United States Environmental Protection Agency
WG3	Working Group 3
WWLMINET	Worldwide version of the LMINET

1 INTRODUCTION

The United States (US) Federal Aviation Administration (FAA) Office of Environment and Energy (AEE) has developed the System for assessing Aviation's Global Emissions (SAGE) with support from the Volpe National Transportation Systems Center (Volpe), the Massachusetts Institute of Technology (MIT) and the Logistics Management Institute (LMI). Currently at Version 1.5, 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. This means that the model is capable of analyzing scenarios from a single flight to airport, country, regional, and global levels. SAGE is able to dynamically model aircraft performance, fuel burn and emissions, capacity and delay at airports, and forecasts of future scenarios. FAA's purpose in developing SAGE is to provide the international aviation community with a tool to evaluate the effects of various policy, technology, and operational scenarios on aircraft fuel use and emissions. FAA is committed to the continued development and support of SAGE. Although the results from the model have been made available to the international aviation community, SAGE is currently an FAA government research tool and has not been released to the general public.

As part of SAGE development, this report has been assembled to document the revision history of the model. This includes changes to the methods as part of model improvement and updates to the component databases. Since the purpose of this document is to mainly report the revisions to the model, technical details, outputs, and validation assessments are not discussed. Such discussions can be found in FAA[a, b, c] 2005.

1.1 Background

The development of SAGE was in part stimulated by the rapid growth in aviation and the need for better emissions modeling capabilities on a global level. According to the "Special Report on Aviation and the Global Atmosphere" by the Intergovernmental Panel on Climate Change (IPCC), 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 for the next 10 to 15 years [IPCC 1999]. With this forecast, aircraft remain an important source of greenhouse gases in coming decades [IPCC 1999]. It was also 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, were) expected to grow to as much as 12 percent by 2050 [IPCC 1999].

The Committee on Aviation Environmental Protection (CAEP) of the International Civil Aviation Organization (ICAO), an organization of the United Nations (UN), has formed several working groups to address aviation environmental emissions. In addition, the UN Framework Convention on Climate Change (UNFCCC) has promoted a series of multilateral agreements that target values of emissions reductions for the primary industrialized nations [IPCC 1999]. However, prior to SAGE, there was no comprehensive, up-to-date, non-proprietary model to estimate aviation emissions at national or international levels that could be used for evaluating policy, technology and operational alternatives.

Although the degree of projected growth of the air transportation industry may be debated, the unique characteristics of the industry, the influence that they may have upon the environment, and the influence that policies may have upon the industry dictates a clear need for a computer model that analysts can use to predict and evaluate the effects of different policy, technology, and operational scenarios.

Past studies on aircraft emissions have resulted in global inventories of emissions by various organizations including the National Aeronautics and Space Administration (NASA)/Boeing [Baughcum 1996[a,b] and Sutkus 2001], Abatement of Nuisance Caused by Nuisances Caused by Air Transport (ANCAT)/European Commission (EC) 2 group [Gardner 1998], and Deutsche Forschungsanstalt fur Luft- and Raumfahrt (DLR) [Schmitt 1997]. These inventories represent significant accomplishments since they are the first set of "good-quality" global emissions estimates. In this light, SAGE represents the lessons learned from these past studies. Using the best publicly available data and methods, SAGE improves upon these past studies in producing the highest quality emissions inventories to date.

1.2 Objective and Scope

The objective for SAGE is to be an internationally accepted computer model that is based on the best publicly available data and methodologies, and that can be used to estimate the effects on global aircraft fuel burn and emissions from various policy, technology, and operational scenarios. With regard to scope, the model is capable of analyses from a single flight to airport, regional, and global levels of commercial (civil) flights on a worldwide basis.

1.3 Modeling Capabilities

SAGE can generate inventories of fuel burn and emissions of carbon monoxide (CO), unburned hydrocarbons (HC), nitrogen oxides (NOx), carbon dioxide (CO_2), water (H_2O), and sulfur oxides (SOx calculated as sulfur dioxide, SO_2). 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 and the dynamic modeling environment allow for a comprehensive set of analyses that can be conducted using SAGE.

With the computation 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 and delays, etc. This results in the ability to use SAGE for applications such as 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).

1.4 Document Outline

The remainder of this document is organized as follows. Section 2 presents the milestones and revisions prior to the release of Version 1.0 at the end of 2002. Section 3 describes the modifications and corrections to Version 1.0. The version number was kept at 1.0 to allow proper first release of the model. Section 4 presents the updates for Version 1.1. And Section 5 provides details in updating SAGE to Version 1.5 (the latest version).

2 MILESTONES AND REVISIONS PRIOR TO RELEASE OF VERSION 1.0

2.1 ETMS Processing

- April 2001 – ASQP year 2000 data tapes were delivered, read into the Volpe Center Data Processing mainframe, and transferred via the Volpe Local Area Network. An MS-SQL database table was designed and the year 2000 data loaded.
- June 2001 - Permission was obtained to use archived ETMS flight position data. SAGE developers were granted security clearance to enter the Volpe ETMS Hub Site.
- June 2001 - An Oracle database was implemented using one of the ETMS Hub Site’s Unix/Oracle Servers. Software was developed and procedures were established to transfer the 365 daily archived data tapes into the database.
- June 2001 - Three days of archived ETMS data (October 3,4,5) were read into the Oracle database for use during development and testing
- July 2001 – Design of a data compression algorithm to reduce the volume of ETMS position data was begun.
- September 2001 - Three days of compressed ETMS data was transferred to CD for initial SAGE testing.
- September 2001 - The year 2001 ETMS archive was read, compressed and loaded into the ETMS Hub Site’s Unix/Oracle Server.
- August 2001 - ETMS data compression algorithm was implemented in C code.
- August 2001 – The Back Aviation Fleet database for years up to and including the year 2000 was procured and delivered. Software was developed to extract those aircraft that were active and in service during 2000. An MS-SQL database table was designed and the year 2000 data loaded.
- September 2001 - The ETMS database design was finalized. MS-SQL database tables were implemented
- September 2001 - MS-SQL database tables were built and Airport Taxi Times data (based on analysis of ASQP data) were loaded and tested.
- September 2001 - Database tables were implemented for an Airports Position Information database. Various data sources were merged and loaded
- October 2001 – MS-SQL script was developed to perform the preprocessing.
- November 2001 - Database input/output code was developed and tested.

- November 2001 - ETMS cleaning software was developed and tested using the 3 days of ETMS data.

- December 2001 - Aircraft/Engine distribution database tables were implemented based on analysis of the Back Aviation Fleet database,

- December 2001 - Preprocessing tested using the 3 days test data.

- February 2002 – A dedicated local area network connection was installed to connect the high security Volpe ETMS Hub Site with the Environmental Measurement and Modeling SAGE development area.

- March 2002 – the year 2000 data was transferred to the Sage Database Server via the dedicated network connection.

- October 2002 – Airport Position Information database was updated to include data acquired from the Eurocontrol Experimental Centre.

- October 2002 – The whole month of October 2000 was preprocessed.

- November 2002 – The year 2001 data was read, compressed and loaded into the ETMS Hub Site's Unix/Oracle Server.

- November 2002 – The year 2000 was preprocessed.

2.3 OAG Processing

- June 2002 – The OAG database design was finalized. MS-SQL database tables were built and tested.

- July 2001 – MS-SQL script was developed to perform preprocessing.

- August 2002 – Software was developed to generate altitude and track dispersion data from clean ETMS flight position data. OAG altitude and track dispersion tables were implemented based on the ETMS data analysis.

- September 2002 –Database design was modified to optimize to minimize size. MS-SQL database tables were re-built and tested. One month (October 2000) of data was pre-processed and loaded into the OAG SQL database.

- October 2002 - Database input/output code was developed and tested.

- November 2002 – As a result of analyzing the one-month Fuel Burn results:
  - Preprocessing longitude assignment problem corrected.
  - The altitude assignment algorithm was modified to correct problem with short flights.
  - The aircraft/engine assignment tables were modified

2.4 Fuel Burn

- December 2002 – Grid Cell algorithm design complete. The algorithm maps a flight chord's initial and final position and altitude into a three-dimensional grid representation.

- January 2002 – Implementation of Grid Cell algorithm as a stand-alone C++ object completed.
    - A container object (Flight Cells) was implemented to accept a list of flight chords and output a list of grid cells traversed by the flight.
    - Code tested with ETMS flight chords.

- February 2002 - Development of Fuel Burn Version 0.1 begun.
    - MS-SQL Database tables were implemented to hold the BADA Aircraft Performance and ICAO Engine Exhaust Emissions. Code for Fuel Burn to access this data was developed and tested.
    - Initial design complete. The Fuel Burn is designed as a component process with parallel process capability.

- March 2002 - Fuel Burn Version 0.1 component shell implemented and tested.
    - All database input and output functions implemented and tested.
    - Implementation of ETMS database position completed and tested.
    - Implementation of Fuel Burn output completed.

- April 2002 - Implementation of core Version 0.1 Fuel Burn functions begun
    - Implementation according to fuel burn documentation: "SAGE Fuel Burn and Emissions Module, Version 0.1."
    - Iterative process of comparing SAGE output with spreadsheet implementation (one ETMS flight) is begun.

- May 2002 – Fuel Burn Version 0.1 completed.
    - Iterative process of comparing the spreadsheet implementation to the SAGE C++ implementation is completed. The results match to within rounding error.

- June 2002 - SAGE Fuel Burn was computed for ETMS flights and compared with fuel burn data from a major US airline.

- July 2002 – Development of Fuel Burn Version 0.2 begun.
    - The Fuel Burn component re-designed based on Version 0.1 experiences.
    - The Version 0.2 Fuel Burn shell component was implemented and tested.
    - The grid cell generation object (Flight Cells object) was added to the Fuel Burn Component.

- August 2002 - Implementation of core Version 0.2 Fuel Burn functions begun
    - Implementation according to fuel burn documentation: "SAGE Fuel Burn and Emissions Module, Version 0.2."
    - Iterative process of comparing SAGE output with 3 spreadsheet implementations (3 ETMS flights) is begun.

- August 2002 - The SAGE Database Server was procured and delivered to the Volpe Center.
    - Hardware setup and all necessary software installed.
    - Year 2000 ETMS data was transferred to system

- September 2002 – Fuel Burn Version 0.2 completed.
  - Iterative process of comparing three spreadsheet implementations to the SAGE C++ implementation is completed. The results match to within rounding error.

- October 2002 – SAGE Fuel Burn was computed for all sample flights from a major US airline using ETMS October 2000 data.

- October 2002 – Fuel Burn Version 0.2 modified to process OAG flights
  - "ComputeBADAEngineThrust" sub function was modified to correct takeoff to cruise join-chord problem.
  - "ComputeLatLongs" sub function was modified to correct OAG latitude/longitude assignments to takeoff and landing chords.
  - Debugging/testing performed by comparing to spreadsheet implementations.

- November 2002 – SAGE Fuel Burn was computed for all sample flights from a major US airline using OAG October 2000 data.

- November 2002 – Developed two new main functions to allow analysis of CNS/ATM Initiatives using data as necessary from FAA/ASD's parametric model.
  - The "ProcessCNSATMFlights" main function was developed to implement the CNS/ATM Base vs. Optimal Delay comparison. Flight track and aircraft/engine data are prepared and the Fuel Burn core computation sub functions are called to compute fuel burn and emissions.
  - The "ProcessCNSATMTracks" main function was developed to implement the CNS/ATM Base vs. Optimal Track comparison. Flight track and aircraft/engine data are prepared and the Fuel Burn core computation sub functions are called to compute fuel burn and emissions.

- October 2002 – SAGE fuel burn and emissions computed for Year 2000, OAG plus ETMS flights.

2.5 Capacity/Delay and Forecasting

- February 2002 - Developed code (Schedule6.sas) to read 2000 OAG schedule and generate a forecasted schedule.

- March 2002 – Changes made to the Schedule6.sas script as follows:
  - FESG growth rate and seat category distribution are separated to give the user flexibility to modify the input data set. The FESG2.sas script was developed.
  - Seat category is generated randomly according to the seat distribution in FESG.
  - Cargo growth is considered.
  - Commuter flight growth is assumed to be the same of seat 51-99 for the same region and range.
  - Indivisual flight is considered instead of hourly total to use the base OAG times (exact) for the forecast flight.
  - New logic added to compute the terminal growth beyond 2015 in TAF.
  - New naming convention to better identify variables and data sets.
  - Bounds are added in the Fratar algorithm to prevent extreme values from iteration and incomplete connection network.
  - Renamed to Schedule9.sas.

- March 2002 - Developed code (FESG2.sas) to process traffic growth rates and seat distribution based on FESG forecasts.

- March 2002 - The Schedule9.sas script was modified to add flight number.

- September 2002 – The Schedule9.sas script was modified to add carrier code. Renamed to Schedule10.sas.

- September 2002 – The Schedule10.sas script was modified to produce integer flights (i.e., not fractional). Renamed to Schedule11.sas.

- October 2002 – The Schedule11.sas script was modified:
    - Combine "DemandProcess2.sas" to add the "ticket" column in the forecast.
    - Drop the data field of "flt_base" and "flt_target_int" since flights are listed individually.
    - Output the baseline year information separately.
    - Rename to Schedule12.sas.

- October 2002 – Developed code and executable for WWLMINET.

- November 2002 – Developed code for aircraft retirements/replacements

- December 2002 – The Schedule12.sas script was modified to be able to produce a forecasted schedule beyond 2020. Renamed to Schedule13.sas.

3 MODIFICATIONS AND CORRECTIONS TO VERSION 1.0

These modifications and corrections were made to Version 1.0 during 2003. Because the model had not been widely exercised, the version number was kept at 1.0 after these changes in order to allow a proper first release of the model. After these changes were implemented, inventories for 2000-2002 were redeveloped (rerun). It should be reiterated that the model is an FAA government research tool and has not been released to the public.

- Changed the implementation of BM2 to strictly follow Boeing's documentation rather than the NASA write-up that was made available. The primary differences were: (1) the NASA write-up specified non-log curve fits while Boeing specified log-log plots; (2) NASA specified the use of percent thrust settings while Boeing specified the use of fuel flows directly; and (3) NASA specified point-to-point interpolations for all pollutants while Boeing specified log-log transformed linear curve fit for NOx and a log-log transformed bilinear curve fit for CO and HC. The use of log-log plots solved a minor problem where it was possible to produce negative emissions due to the slope of the EI versus fuel flow (or percent thrust) plots.

- Since log-log plots for CO and HC become asymptotic near zero, a limit on emissions corresponding to the 7% idle condition (i.e., the emissions indices cannot fall below this point) was implemented to prevent unreasonably high emissions from occurring.

- Corrected the times ("epochs") associated with the delay data generated from WWLMINET. The data corresponded (by default) to GMT minus 5 hours. Therefore, 5 hours was added to these times in order to model them based on GMT directly.

- Fixed a bug in the burn/emissions gridding code that resulted in "streaks" of fuel burn/emissions over the +90 to +180 degree longitude segment.

- Improved aircraft matches between OAG, ETMS, BADA, and INM. These were generally minor improvements to more closely match aircraft types.

- Improved engine matches between BACK, ICAO, and EDMS. These were generally minor improvements to more closely match engine types.

- The airline-aircraft-engine distributions for each year (2000 to 2002) were made more consistent by automating the process of matching BACK equipment to OAG equipment. This automation prevents discrepancies due to judgment calls when manually developing the distributions.

- The use of a single, conservative, default engine (JT8D-17R) for those cases when an airline-aircraft-engine distribution could not be used (due to non-matches between an airline or aircraft category) was replaced with aircraft-specific default engines.

- In modeling turboprops, maximum power values had been derived from various sources (Janes Aircraft, internet, etc.). These values were replaced by the power ratings from the INM database.

- Exact engine assignments through the use of the ASQP and BACK databases were previously conducted using, in part, the departure date. This was changed to include the departure time as well in order to improve the accuracy of the assignments.

- An investigation of the inventory results and the underlying emissions indices showed that the emissions data corresponding to piston-driven aircraft may not be trustworthy. In general, these emissions indices (as well as those from other turboprop aircraft) are all suspect, especially since they have not been verified through a certification process. Due to their high EI values, the piston engines produced emissions that were magnitudes higher than those from jet engines. Because the accuracy of these EI data were suspect and they could cause havoc in analyzing emissions trends, it was decided by FAA/AEE that results from piston aircraft were to be left out of any inventory-derived results. Any aircraft that could potentially use either a turboprop or piston engine were also conservatively excluded.

4 LIST OF CHANGES FROM VERSION 1.0 TO VERSION 1.1

The following list of changes were implemented during 2003 in upgrading SAGE from Version 1.0 to 1.1. After implementation, these changes were only used to generate the 2003 inventories. Inventories for 2000-2002 were not rerun.

- BADA 3.5 has been incorporated (older version was 3.2). Some name changes of aircraft types have been changed, but these make no difference since we were able to identify the name changes.

- Updated ICAO databank Issue 10 (release date: May 19, 2003) from Issue 7 (release date: November 14, 2000).

- Improved the ETMS-BADA-INM aircraft matches. This results in a larger number of ETMS flights modeled for the 2003 inventories.

- Found matches for all BACK engines to ICAO/EDMS. This reduces the number of default engines that we need to use. The only remaining reason is now because we cannot find a match between an OAG aircraft (from schedule) to BACK aircraft (in the distributions).

- Used updated forecasting module with new forecast data from FESG and TAF in order to obtain 2003 schedules for determining delays. The base year used in the forecasting module is now 2002.

- Matched OAG flights to ASQP (similar to the ETMS-ASQP matching) in order to get precise engine assignments for some OAG flights as well.

- We now have the ability to report fuel burn/emissions by countries (similar to regions). Each airport was allocated to a country.

- Added a criteria in the fuel burn code where any flights that have a single chord with a distance greater than the Great Circle distance is removed (filtered out).

A comparison analysis was conducted to ascertain the effects of these different changes using a week's (middle of May) worth of flights. The analysis showed that the update of BADA (from Version 3.2 to 3.5) and improvements to the ETMS aircraft mathings were the most significant changes resulting in a fuel burn decrease of 1.6% and an increase of 0.25%, respectively, when these changes were modeled separately. These small changes helped justify not having to rerun 2000-2002.

5 LIST OF CHANGES FROM VERSION 1.1 TO VERSION 1.5

The following list of changes were implemented during the 4th quarter of 2004 and the 1st quarter of 2005 in upgrading SAGE from Version 1.1 to 1.5. All of the prior inventories (2000-2003) were rerun using Version 1.5, and the 2004 inventories were also developed using this latest version. Since 2000-2002 had not been updated with the Version 1.1 changes, these inventories effectively experienced an upgrade directly from Version 1.0 to Version 1.5 (i.e., skipping Version 1.1).

- The latest BADA (version 3.6) has been implemented.

- The latest ICAO Databank (Issue #13) has been implemented.

- The latest emissions indices (EI) data from EDMS (Version 4.2) has been implemented.

- Instead of airline-aircraft-engine distributions for just the top 50 (with a 51st category for all else), distributions for all airlines within BACK have been created. In addition, an aggregated distribution (of all airlines together) has also been created to be used for assigning default engines when an OAG/ETMS aircraft cannot be matched to a BACK aircraft or when a similar match cannot be made for an airline. This change allows all flights to be assigned an engine from a distribution (even if it is a default distribution) instead of single default engines.

- A method to account for unscheduled flights has been developed. The method uses a regressed equation to relate airport operations to both unscheduled and cancelled flights. This general equation provides factors that allow scaling of the scheduled (i.e., OAG) flights either up or down depending on the factor. The equation provides airport-specific factors. Cargo airports are handled separately using pre-developed factors (i.e., not from the general equation).

- Airports data from various sources were aggregated. These sources include: SAGE (includes FAA and LMI), INM 6.2, EDMS 4.2, BTS, Eurocontrol, MMU, and a commercial internet source. The Jeppesen database was used for spot-checking and verifications as necessary. Note, the Jeppesen database is in a binary format and therefore, could not be used as one of the aforementioned sources in the aggregation. The Jeppesen database can only be accessed through their supplied graphical user interface which only allows a few airports to be accessed at a time.

- Airport altitude data is now uniformly based on digital elevation data as mapped out in a GIS system. Therefore, all airports now have an elevation, including those that were previously assigned a default value of sea level due to a lack of data.

- All taxi time modeling for ETMS flights were changed to use average airport taxi times rather than flight-specific taxi times. This was done to prevent the use of erroneous taxi+delay times from the ASQP database. Because of this, modeled ground delays from WWLMINET are also applied similar to all ETMS flights. Airborne arrival delays are still assumed to be inherent within the ETMS trajectory data.

- For consistency in modeling taxi times in SAGE, all airport taxi data are from the ASQP database. That is, taxi data is either an airport-specific average or an average of all airports covered in ASQP. The 2000 taxi data from Eurocontrol for European airports are no longer used in order to prevent inconsistencies in analyzing yearly trend effects.

- Increased the amount of significant digits (after the decimal point from 2 to 6) in the latitude and longitude fields in the chorded flight results. This significant digits change has no impact in the internal calculations since the resolution of the numbers were preserved internally; just the outputs had a shortened set of digits.

- Corrected a bug in the code that was calculating the speed of sound incorrectly based on sea-level conditions rather than at-altitude conditions.

- Created new trajectory (lat/lon/alt) distributions (for use with OAG schedules) based on analyzing four months' worth of ETMS radar trajectories (two months from 2000 and two months from 2003). The months were May and October in each of the years. The previous distribution had been based on one month's worth (October 2000) of ETMS data.

- Based on an initial statistical analysis of inventory results for 2000-2003, it was determined that the single best week for representing an entire year's worth of results was May 29 to June 4. Therefore, this week rather than the previous "middle of May" was used to model delays. This week will also be used for any forecasting work.

- An inconsistency between the use of IATA and ICAO airport codes was rectified by using one common approach (i.e., preference is to use the IATA code where available and then the ICAO code). Previously, it was a mixture where the IATA codes were used for trajectory modeling while the ICAOs code was used for stage length determinations.

- ETMS-BADA-INM matching table was improved with the identification of several more aircraft types in ETMS. This matching table was aggregated with the OAG aircraft matching table to form one SAGE matching table.

- Corrected the engine assignments for the MD90 (the previous assignment for defaults was JT8D-219). This was changed such that any default assignments are conducted through the default distribution which will assign the V2525-D5 or V2528-D5 engine.

- Transonic drag rise effects have been implemented. This effect adds onto the drag forces calculated by BADA, and therefore, is an improvement to the use of BADA within SAGE. Currently, the transonic drag rise method only affects ETMS flights because of the availability of speed data within ETMS; it has no effects on OAG flights. It is expected that this method will help to further improve SAGE results once wind data is implemented.

- The taxi time algorithm was changed such that instead of using a 50 percentile value, a 15 percentile value is now being used to better represent just the effects of taxi times without any influence from delays. The 15 percentile was thought to be somewhat arbitrary but it appears to provide a good compromise between too low (e.g., 5 or 10 percentiles) and too high (e.g., 20 percentile). There is also precedence in the use of the 15 percentile it some academic studies.

- ETMS flights including those with bad trajectory data are now preserved. These ETMS flights are flown just like OAG flights but with ETMS schedules.

- Added takeoff and approach ground roll chords to explicitly model runway roll movements. Previously, the effects of these movements had been aggregated into the first (takeoff) and last (approach) chords.

- Scaling factors have been developed to fill drag coefficient data when it is not available in BADA (i.e., indicated as zeros). Previously, cruise coefficients were used by default as prescribed in the BADA user's guide. These scaling factors are an improvement to the use of BADA within SAGE. The factors were developed by determining average ratios of coefficients for each mode to the cruise coefficient. The factors are also separated into jets and propeller-driven aircraft categories. The factors are only applied to OAG flights and therefore, their effects are proportional to the number of OAG versus ETMS flights in a given region (e.g., the more ETMS flights there are, the less of an effect by these factors).

- Additional methods have been developed to salvage as much ETMS flights as possible. If an ETMS flight's radar data is not viable but the schedule/flight-plan is, then it is flown similar to an OAG flight by using constructed trajectories. In the ETMS, if either the departure time, aircraft, or airport are not reported, then a search is made to try to identify a matching OAG flight in order to salvage the flight.

- A smoothing algorithm was implemented to smooth out any erratic ETMS speed data. The algorithm was developed from analyzing CFDR data from a non-US airline. Except for the first and last chords, each chord's speed (Mach) value is checked to see if the difference between the current and previous chords is less than 0.2 or if the current chord is less than 0.65 times or greater than 1.1 times the average (nominal) BADA mach number. If any of these conditions are met, then the following chords' speeds are checked until the a suitable speed is found, in which case, the suitable speed is assigned to the current chord.

- Flight chords are now generated dynamically in the fuel burn module rather than using pre-generated trajectory tables. All of the OAG-based trajectories are generated dynamically while just the takeoff and approach chords are generated for ETMS flights (i.e., when radar data is viable).

- Make a temperature units correction in the INM thrust equation. The units were changed from Kelvin to Celsius.

- The takeoff weights for all flights were systematically increased by two stage lengths to account for the effects of fuel tankering. This follows precedent set in some previous INM studies that also used this method.

- The fuel burn module C/C++ code was translated to work under Microsoft's .NET platform.

- Added 2 x INM Rated Output limit for thrust on cruise chords including joining chords.

- The approach distance for comparing against ground projected distance was corrected. Previously, a 3 degree glide slope was used throughout, now 3 degrees is used for jets but 5 degrees is used for turboprops. This degree information is used to calculate approach distance when comparing the takeoff and approach ground projected distance against the total ground distance (used for stage weight determination).

- Included a matching table to help improve matching of OAG and ETMS flights. The table helps to better match the flight ID and carrier for each flight, thereby dealing with the issue of airline-code shares between the databases (i.e., not code-shares within each database which isn't an issue).

- Modified a filter to better catch bad ETMS lat/lon/alt data. The filter criteria was changed from any chord distance greater than 10 times the great circle OD distance to any chord distance greater than one great circle OD distance. This provides a tighter filter to catch more erroneous data.

- Added a filter/condition to the joining chord (i.e., between takeoff/climbout/approach and cruise modes) to prevent very low rates of climb. This basically involved adding the joining chord to the existing filtering condition that prevents rate of climbs from becoming lower than 2 m/s.

- Removed duplicate ETMS flights that were listed due to a recursive reporting system within ETMS. Multiple records of the same flight could have been listed by the system in an effort to preserve better data.

- To more accurately categorize aircraft types as turboprop or piston, the classification was changed from being aircraft-airframe dependent to engine-dependent. While most aircraft are consistent in terms of either being a turboprop or piston, a few could be either depending on the engine that was used. Previously, these aircraft were designated into a “dual” category where they were treated like pistons and not included in the inventories in order to be conservative. But with the classifications now dependent on engine types, the dual category is no longer necessary as both the piston and turboprop versions of the same aircraft type can now exist in the inventories, with the removal of just the pistons from the final inventories.

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