A Comparison of Aircraft Retirement and Fuel Efficiency Policy Instruments:
A Modified Fleet and Operations Module Approach

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Abstract

The EDS Fleet and Operations Module was used to analyze a set of scenarios which spanned a range of retirement and fuel burn efficiency cases. Retirement schedules had little effect over long term time spans; however, they played a key role in stimulating the short term reduction of emissions. Next, the International Air Transport Association's goal of reaching carbon neutral growth by 2020 was analyzed. IATA's goal of a 21% reduction in emissions due to fleet renewal was not supported. An additional 72.5 mega tonnes of CO_2 would need to be offset in order to meet their goal.

I. Introduction

The threat of global warming and the expected rise in jet fuel prices are putting increased pressure on the commercial aviation sector to reduce its green house gas emissions. Technological improvements and strong market forces have driven substantial reductions in fuel usage since the introduction of the first commercial jet aircraft. With the expected growth in the commercial aviation sector and the possible enactment of stringent carbon emission limits, additional measures will be needed to bring fleet wide fuel usage to desired levels.

Aviation's CO_2 emissions are estimated at 2% of the global totals and 3% of potential warming effects [1]. These values are expected to rise as the growth of aviation increases worldwide. Policy makers require tools to forecast the future aviation fleet in operations, emissions, and resulting climate impact to make informed decisions. This is made difficult by the complexity of the global fleet, with millions of individual flights performed by tens of thousands of aircraft. Two common recommendations for effecting change in the aviation sector are mandated phase-outs and fuel efficiency certification standards for new aircraft. Mandated phase-outs alter the economically determined retirement schedules used by airlines to renew their fleets. Fuel efficiency standards dictate what new aircraft are allowed into the fleet. The two methods interact and the best policy is determined by the value policy makers place on short vs. long term emissions reductions.

This paper will utilize a tool developed by the author in the Environmental Design Space (EDS) group at the Georgia Institute of Technology called the EDS Fleet and Operations Module (EFOM). The EFOM is used to compare phase-out and fuel efficiency improvement scenarios spanning a time range of 2006 and 2036. The EFOM is based on a tool accepted for use by the Committee on Aviation Environmental Protection (CAEP) called the Fleet and Operations Module (FOM). Additionally, the EFOM is used to investigate the International Air Transport

Association's goal of reaching carbon neutral growth by 2020. The International Air Transport Association represents 230 international airlines and 93% of the world's scheduled international air traffic. In July of 2009, they announced ambitious goals [2] for emissions reductions. These include a commitment to carbon neutral growth by 2020, a 1.5% annual fuel efficiency improvement, and cutting emissions to 50% of 2005 values by 2050.

II. FOM Methodology

As the EFOM is modeled off of the FOM, a discussion of the FOM's methodology (see Ref [3]) and limitations is important. The FOM incorporates three major aspects: aircraft retirements, aircraft replacement functions, and operations growth.

A. FOM Overview

The FOM is used in conjunction with the Forecasting and Economic Analysis Support Group (FESG) forecast to predict the future path of operations by route ID, stage length, and aircraft seating size. A consensus process, described in [4], is used to arrive at the final forecast. Growth rates for the different route groups are processed through a frequency capacity model which shifts operations to larger aircraft as capacity constraints are approached. The frequency/capacity algorithm is stage length dependent and thus one final output of the FESG forecasting process is a forecast by route group, stage length, and seat class. It is important to note that the FESG forecast is not provided by aircraft type or origin-destination (OD) pair. A replacement schedule is used to assign specific aircraft to forecasted seat class demand.

The first step in the FOM process calculates the number of operations that retired during the prior forecast period. Figure 1 shows the survival curves generated by CAEP which estimate the surviving percent of aircraft as a function of age. The FOM makes an assumption of uniform utilization which allows survival curves (meant for aircraft) to be used for operations. The FOM does not keep track of how many aircraft are in service; only how many operations are performed. One current limitation of the FOM is that it does not retire any aircraft added to the fleet by the forecast. This can have

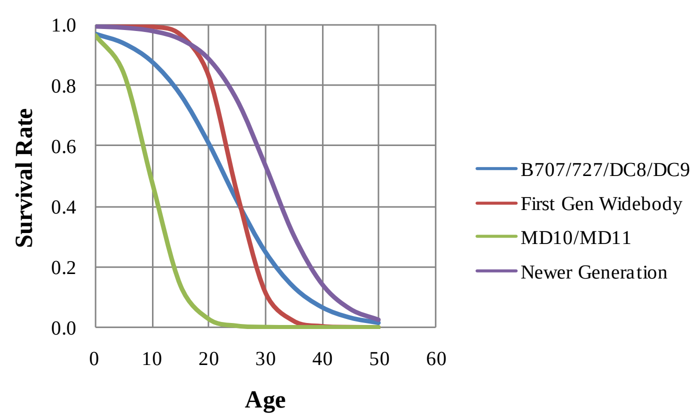


Figure 1: CAEP Survival Curves

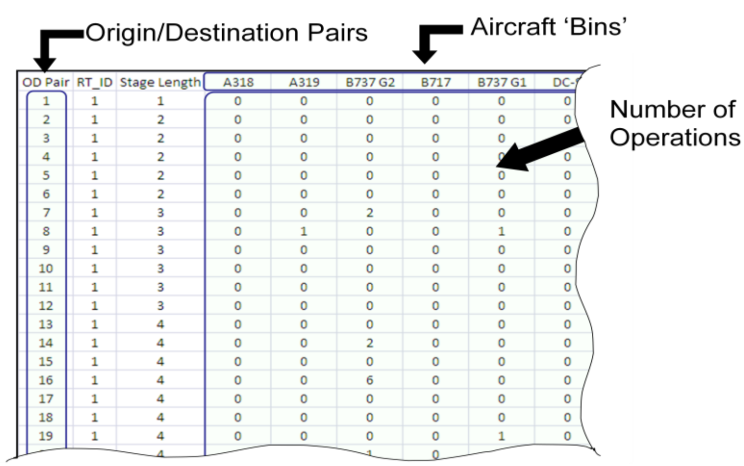
significant implications as will be discussed later. Once operations are retired and new growth is estimated using the forecast, a replacement schedule determines how new operations are distributed to aircraft. A replacement schedule allocates operations to specific aircraft based on the forecast year, aircraft size, and OD pair distance.

The FOM process is often evaluated on a subset of the entire global operations set. This subset consists of a six week period identified by CAEP as being representative of the entire year. This assumption has proven fairly consistent as shown in [5].

The main shortcoming in the FOM methodology is its lack of economic feedback loops. The consensus process used to generate the FESG forecast is fixed. Significant policy exploration is not possible as the forecast will never respond to increases in ticket prices due to carbon trading schemes or fuel taxes. There are other tools available within the FAA/NASA/Transport Canada tool suite to address this limitation, but they have yet to be integrated with the FOM. A more detailed document of the FOM process and an accompanying spreadsheet example are available from the author upon request.

B. EDS Simplifications

The EDS implementation of the FOM takes advantage of several simplifications to reduce the computation time. Consider Figure 2. The array of operations can be reduced by aggregating or trimming the number of OD pairs or aircraft bins. "Aircraft bins" refer to the level of granularity of aircraft information contained in the model. The FOM groups aircraft according to ACCODE (a designation which specifies an airframe), engine code, and engine modification code.



OD Pair	RT_ID	Stage Length	A318	A319	B737 G2	B717	B737 G1	DC-
1	1	1	0	0	0	0	0	0
2	1	2	0	0	0	0	0	0
3	1	2	0	0	0	0	0	
4	1	2	0	0	0	0	0	0
5	1	2	0	0	0	0	0	0
6	1	2	0	0	0	0	0	0
7	1	3	0	0	2	0	0	0
8	1	3	0	1	0	0	1	0
9	1	3	0	0	0	0	0	0
10	1	3	0	0	0	0	0	0
11	1	3	0	0	0	0	0	0
12	1	3	0	0	0	0	0	0
13	1	4	0	0	0	0	0	0
14	1	4	0	0	2	0	0	0
15	1	4	0	0	0	0	0	0
16	1	4	0	0	6	0	0	0
17	1	4	0	0	0	0	0	0
18	1	4	0	0	0	0	0	0
19	1	4	0	0	0	0	1	0

Figure 2: Operational data set snippet

To reduce the number of OD pairs under considerations, the 6 week period is used in lieu of the entire year's operations. OD pairs are also aggregated so that departure and arrival airports are treated the same (ie, LAX to JFK is the same as JFK to LAX). This halves the number of OD pairs.

The number of aircraft bins were reduced by creating "Aircraft Families" (ACFamilies). ACFamilies were created by grouping similar aircraft and ignoring differences in engines. New retirement curves were created for the ACFamilies by using a base year operations weighted average of the original retirement curves for the constituent members. Sample original curves and weighted average curves are shown in Figure 3. The dashed curves represent the outer bounds of the envelope for the solid lined ACFamily.

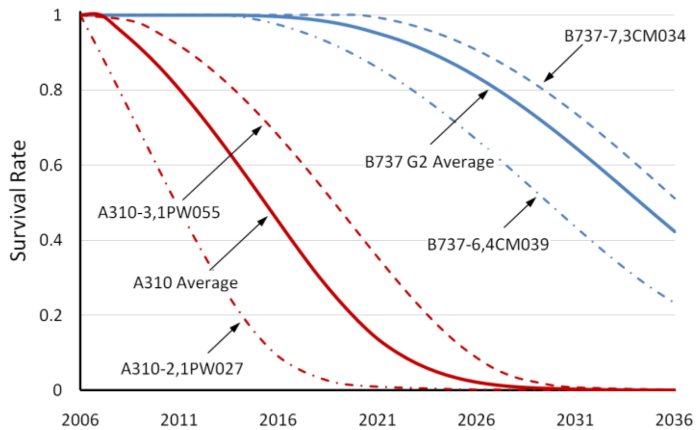


Figure 3: Operations weighted retirement curve examples

The final simplification was to run the forecast with a time step of ten years. The FOM also has this capability, but the validation data provided was run with single year resolution. The EFOM was run with a single year time step and also with a ten year time step in order to evaluate the impact of evaluating fewer out-years.

C. Fuel Burn Calculations

Fuel burn data were not provided with the FOM gold standard data set. Fuel burn data from the "AEDT ULS 2006" database (generated for the ultra low sulfur study) were used. The AEDT ULS dataset did not have fuel burn data for every OD pair aircraft combination included in the FOM gold standard data. For these cases, similar aircraft were used to create linear fuel burn approximations as a function of great circle distance. AEDT fuel burn calculations always assume a 65% load factor and thus the total mission fuel burn is primarily a function of the aircraft, engine, and great circle distance. The resulting fuel burn calculations from AEDT are surprisingly linear, as can be seen in Figure 4.

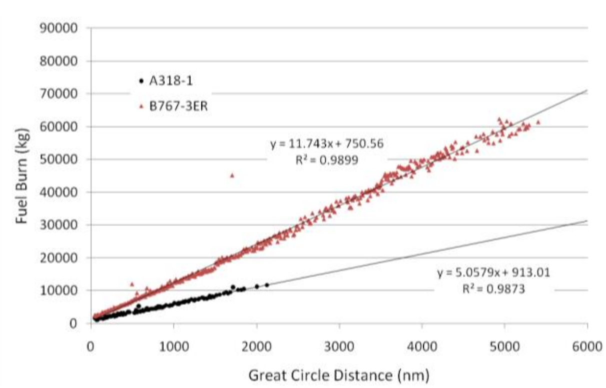


Figure 4: Representative AEDT fuel burn values

The FOM fuel burn calculations were performed by ACCODE, engine code, and engine modification (when available, when not available, the linear approximations were used). New fuel burn numbers had to be calculated for the EFOM aircraft families. For each aircraft family, the AEDT ULS data for each member of the family were grouped by great circle distance and an operations weighted average fuel burn per operation was calculated. The operation set used to compute the average came from the FOM validation set and thus the fuel burn values for the aircraft families were weight in favor of those aircraft in the families that had the most operations in the base year data set.

D. EFOM Fidelity

The EFOM was tested using the same inputs as the original FOM and produced the same output. The EFOM simplifications were then made and the results re-run and compared to the FOM output. Due to the aggregation of aircraft into larger families, the most accurate results will pertain to the highest levels of aggregation, with the error increasing as more granularity is exposed. This should be expected as the retirement curves and fuel burn relationships were weighted towards the original datum set of operations. Thus, an individual aircraft / OD pair might have very large fuel burn and operation count errors as it may not have contributed much to the aircraft family weighted averages.

The difference in worldwide fuel burn between the EFOM and the FOM in 2036 is only 0.14%. The largest regional error increases to 0.95%. Aggregating the results by route name and stage length exposes more granularity; and, thus a larger maximum percent error equal to 6.24%. Other dimensions along which to examine the fidelity of the EFOM are by aircraft family and OD pair. An extensive analysis has been conducted and results are presented in [6].

It is unrealistic to predict exactly which airframes and engines will be used to fill future operational needs, especially when forecasting out thirty years as they have yet to be developed. In this fidelity study, all new operations are filled by generic vehicles, one per seat class. Thus, as long as the number of new operations is calculated correctly, the FOM and EFOM will have the same fuel burn estimates. This helps explain why the total fuel burn estimates between the FOM and EFOM are so close in 2036. Operations are shifting away from the original fleet (with its aggregate retirement curves and fuel burn approximations) to the new generic fleet (with its precise fuel burn equations and absence of retirement curves). As long as operations within the aircraft families are retired appropriately, and the aggregate retirement curves are designed to do just that, the new fleet fuel burn will match very closely between the FOM and EFOM, and this new fleet dominates as the forecast progresses.

III. Experimental Setup

The EFOM was used to analyze a set of scenarios that span a range of retirement and fuel burn improvement cases. Changing how aircraft are retired serves as a proxy for enforcing a phase-out based on some future policy. An actual phase-out would affect aircraft families differently depending on how the certification standard were structured, but a uniform change in retirement schedules approximates a wide number of possible situations. Modifying how quickly aircraft improve their fuel efficiency serves as an approximation to accelerating research and development efforts. Each scenario was run from 2006-2036 with a time step of five years.

A. Retirement Schedule Modifications

Several different methods of modifying the retirement schedules for the aircraft families were investigated. Retirement schedules can be translated, scaled, or linearly adjusted.

Translating retirement curves down has the advantage of reducing the survival rate to zero earlier – it forces aircraft completely out of the fleet at an early date. However, the slope of the survival curve does not change. On new aircraft, the net effect is to force a great deal of operations out of the fleet initially, and then do nothing. The scaling method uses exponential decay and has the benefit of keeping the retirement rate the same for the base year, but new vehicles are impacted more than old ones – an unlikely situation. Also, the year at which vehicles are completely forced out of the fleet is not altered with exponential decay. The linearly adjusted method reduces the final survival rate by a specified amount, and then linearly adjusts the survival rates back to the base year, where the adjustment is zero (see Figure 5). This combines the benefits of the other methods while avoiding their more obvious pitfalls.

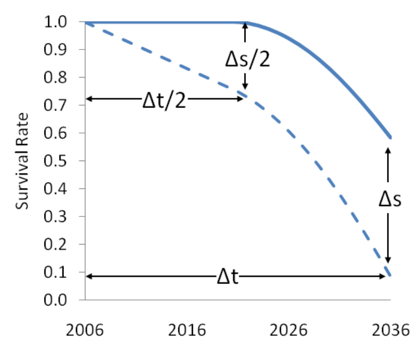


Figure 5: Linearly adjusted survival curve

B. New Aircraft

For all the scenarios, new aircraft are introduced at the end of every ten years, starting in 2006 and ending in 2036. The ten year gap is meant to resemble a product development schedule were fuel burn improvements resemble step functions instead of smooth curves. A new vehicle is introduced for every seat class. They are used to fulfill operations starting the next year. The aircraft introduced in 2006 (and used to fill operations from 2007 to 2016) are the same for every scenario as it is assumed that no policy would have impacts before 2016. These aircraft are modeled after the 'best in class' vehicles in the original fleet and have fuel burn characteristics comparable to the lowest fuel burn aircraft in 2006. Vehicles for seat classes 50-100, 150-210, 210-300, and 300-400 (roughly corresponding to regional jets, single aisle, small twin aisle, and large twin aisle configurations) were generated using the EDS software and a process developed in [7]. The fuel burn characteristics for the remaining seat classes were generated using extrapolation of the EDS vehicles and checked using the AEDT fuel burn data. Fuel burn relationships are provided for the EDS vehicles in Figure 6. The steps in the graph are due to the EDS vehicles attempting to match AEDT outputs, which assume a constant takeoff weight for each stage length.

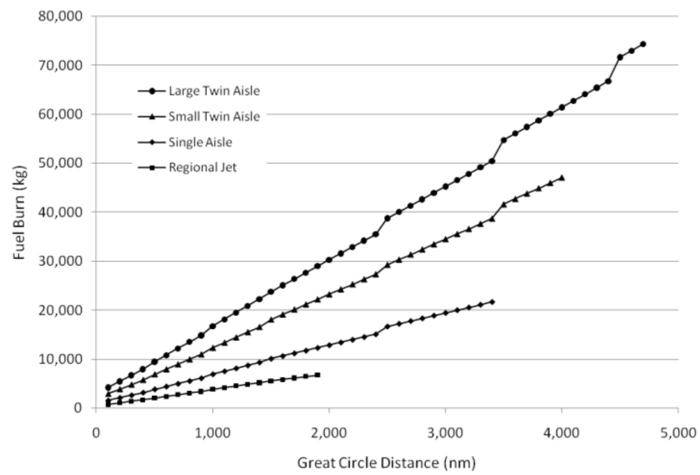


Figure 6: Fuel burn vs. great circle distance for the EDS supplied

C. Fuel Burn Improvement Modeling

Fuel burn improvements are represented by yearly percentage improvements in the fuel burn equations for the datum year new vehicles. This method essentially post processes the fuel burn data and does not take into account which technologies would actually make the improvement possible or any interdependencies with other emissions or noise. Emissions in this paper are limited to carbon dioxide (via the fuel burn).

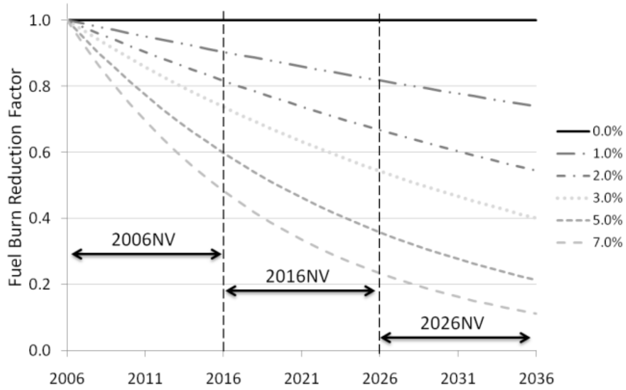


Figure 7: Fuel burn reduction schedule for different technology advancement scenarios

Fuel burn improvement estimates vary considerably over the next 30 years. Reference [8] estimates energy usage per seat kilometer to improve at a rate of 1.0-2.0% per year for the next 25 years. More ambitious goals were set by the Advisory Council for Aeronautics Research in Europe (ACARE) in their strategic research agenda (Ref. [9]). A 50% reduction in CO_2 emissions by 2020 was called for which is equivalent to a 5.0% annual improvement. ACARE acknowledges that this goal is only achievable with novel concepts like blended wing bodies or high aspect ratio wings. A study conducted by The Centre for Air Transport and the Environment at Manchester Metropolitan University and Cranfield University [10] assumed fuel efficiency improvements of 1.3% annually through 2030 and 0.8% annually until 2050. The International Air Transport Association (IATA) states in [2] a goal of 1.5% improvement through 2020.

Six different fuel burn advancement scenarios were explored in total. These varied from unreasonably pessimistic – a fixed technology fleet (FTF) with no efficiency improvements, to overly optimistic – a 7.0% yearly efficiency improvement. These trends are illustrated in Figure 7 where the vertical lines denote the introduction years of new technology infused aircraft (20##NV).

D. Scenario Matrix

The prior stated fuel burn efficiency and retirement alternatives were used in the scenario selection process. Each scenario is coded by several identifying abbreviations listed in Table 1.

Table 1: Abbreviations used in the scenario names

Abbrev.	Description
RAU	Retirements as Usual, retirement schedules are unaffected
EF	Accelerated retirement refers to the Entire Fleet
OoP	Accelerated retirement refers only to the Out of Production fleet
AR	Aggressive Retirement schedule, linear adjustment of 75%
MR	Moderate Retirement schedule, linear adjustment of 50%
FTF	Fixed Technology Fleet (no technology improvement over time)
MTI	Moderate Technology Infusion, 1% annual efficiency improvement

Abbrev.	Description
ATI	Aggressive Technology Infusion, 2% annual efficiency improvement
3FB, 5FB, 7FB	3%, 5%, and 7% annual efficiency improvements respectively.
AllRetire	Limiting case of all base year operations retiring immediately after 2006
NoRetire	Limiting case of no aircraft ever retiring from the fleet

For instance, a scenario entitled “OoP,AR,MTI” has an aggressive retirement schedule (AR) applied only to the out of production aircraft (OoP) with new vehicles having moderate technology infusion (MTI=1% annual efficiency improvement). MTI should be considered a ‘Business as Usual’ case for technology improvement, not the FTF case. A full factorial design was not performed for the 3FB, 5FB, and 7FB fuel efficiency scenarios as these were deemed sufficiently unrealistic as to not warrant a full treatment.

IV. Experimental Results

A. Datum Scenario Results

Results for the year 2006 were constant across all scenarios and will be presented first. Subsequent charts will be normalized to the “RAU,MTI” scenario as this is the closest thing to ‘Business as Usual’ in this analysis. Figure 8 displays the BAU fuel burn and operations by route group for the 2006 datum year.

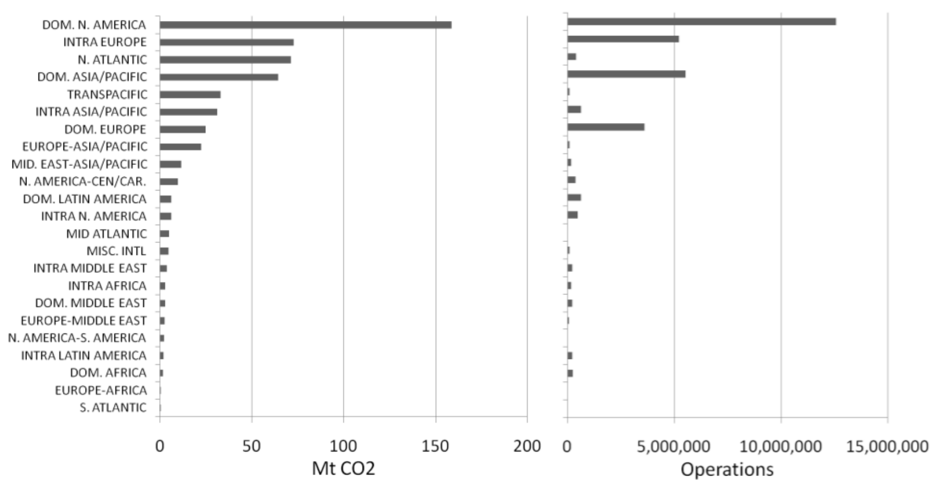


Figure 8: CO_2 in millions of metric tonnes (left), and operations (right), for each route group for 2006.

The total fuel burn from the EFOM compares reasonably to other global fuel burn studies. In summary, the EFOM is within 3.2% of the AEDT ULS study and about 10% to several other global inventories. More details can be found in reference [6].

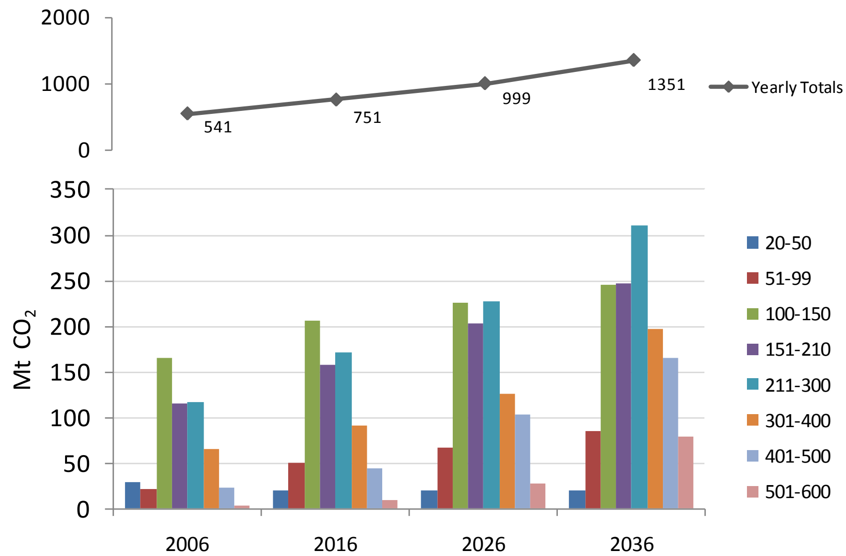


Figure 9: CO_2 for the BAU case with totals emissions and emissions by seat class

Figure 9 shows the annual BAU emissions by seat class with total annual emissions displayed above. Results from this point forward will be comparisons between different policy scenarios and are normalized to the BAU base year data.

B. Scenario Comparison

Please refer to the scenario legend in Table 1 for clarification on the scenario names. The charts in Figure 10 are ordered by total emissions – note that the ordering *does* change between 2021 and 2036. Each scenario is subdivided into operations filled by out of production aircraft, in production aircraft, and the new vehicles (NV) for 2006, 2016, and 2026. The scenarios where all aircraft are retired immediately (‘AllRetire’) still include some original fleet aircraft due to chapter 2 noise considerations. The scenarios where no aircraft are ever retired (‘NoRetire’) have slightly less than the baseline number of in and out of production vehicles as the forecast will occasionally call for a reduction in the number of operations and this eliminates some of them from the fleet.

The stepped nature of the 2036 data is a result of a phenomenon dubbed ‘saturation.’ Due to the limitations of the FOM, new vehicles are never retired from the fleet. As vehicles retire, the new vehicle is ‘locked in’ in the sense that it will never leave the fleet.

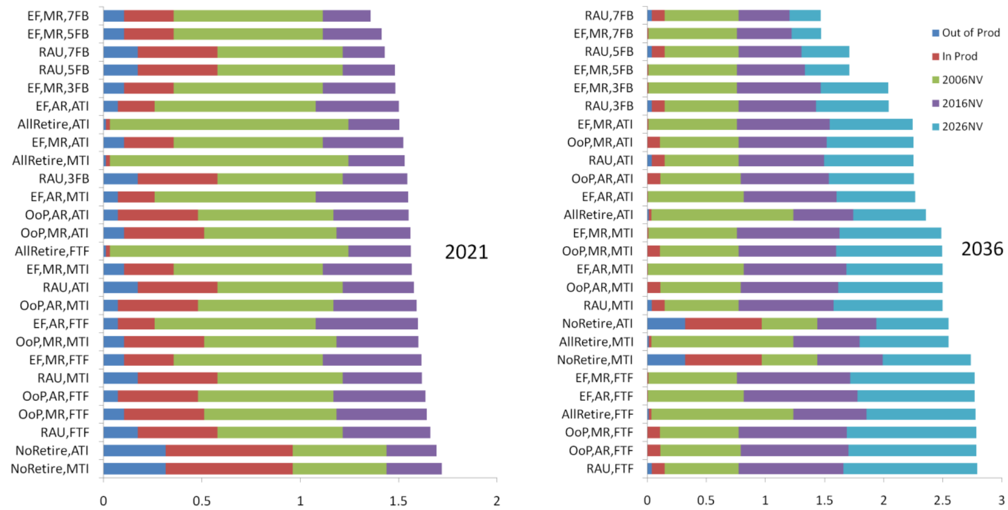


Figure 10: Emissions for all the scenarios for years 2021 and 2036

Once the fleet has been saturated with new vehicles and the original fleet is retired, retirement schedules cease to effect the fleet dynamics. This can lead to some unintuitive results. Comparing retirements as usual and aggressive retirement schedules as in Figure 11 results in the retirement schedule having little to no impact in the final year's emission value. The accelerated retirement schedules initially give the scenario a lower annual emission total but it locks in less technologically advanced aircraft. The slower retirement schedule replaces more operations with more efficient aircraft later in the forecast.

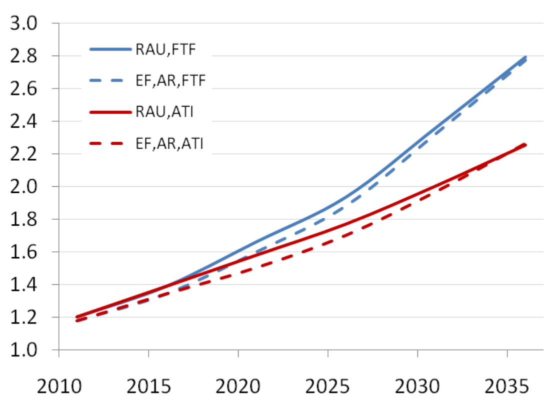


Figure 11: Emissions comparison between retirements

In the end, the rate of technological advancement dominates the annual emission rate. Of course, if new aircraft were allowed to leave the fleet then accelerated retirement schedules would continue to have a moderating impact on emissions. The extent of the effect needs to be further investigated. The best CAEP survival curve (see Figure 1) has only 10% of the fleet retiring after 20 years, so the impact may be small. If so, then policies makers need to be acutely aware of the dangers of accelerating fleet turnover before suitably advanced aircraft are ready to enter the fleet.

Carbon emissions summed over all years are displayed in Figure 12 below. The results are more intuitive then the final year alone. The technology adoption rate is the primary driver and within technology brackets accelerating the retirements curves creates a net benefit. It is interesting to note that the worst case is not retiring anything and only modestly accelerating the technology infusion rate. This performs slightly worse than a fixed technology fleet with a regular retirement schedule.

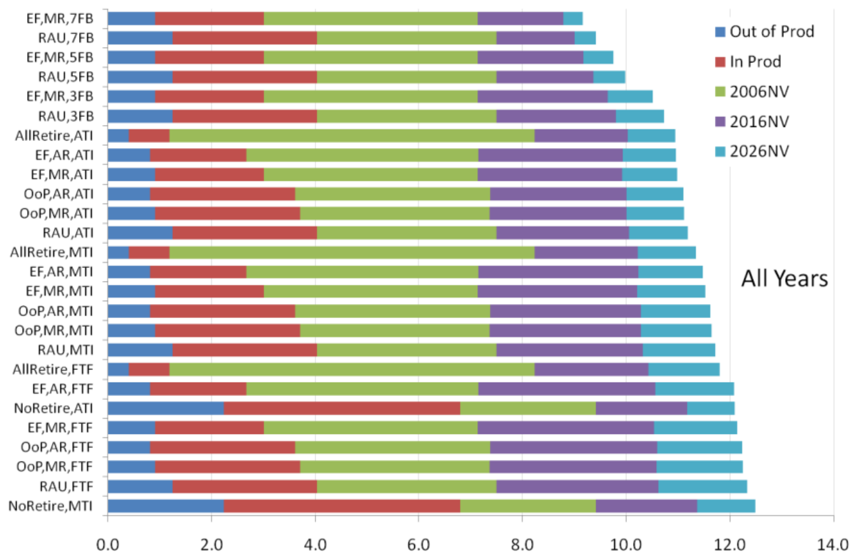


Figure 12: Carbon emissions for all scenarios summed over every forecasted year

C. Carbon Neutral Growth

An often stated goal in aviation is to achieve carbon neutral growth. The technological improvement rate to make that a reality can be estimated using the EFOM. All the technology infusion scenarios for retirements as usual are plotted in Figure 13 below. The results show that to achieve carbon neutral growth by 2036, aviation must achieve the impossibly high fuel burn improvement rate of 7% per year (starting in 2006). This would imply the introduction of vehicles which burn 75% less fuel than modern day aircraft by 2026.

This gives weight to the argument for bio-fuels as they can reduce the life cycle emissions of vehicles of all types. Other alternatives to aircraft efficiency improvements must be explored if carbon neutral growth is to remain more than a lofty aspiration.

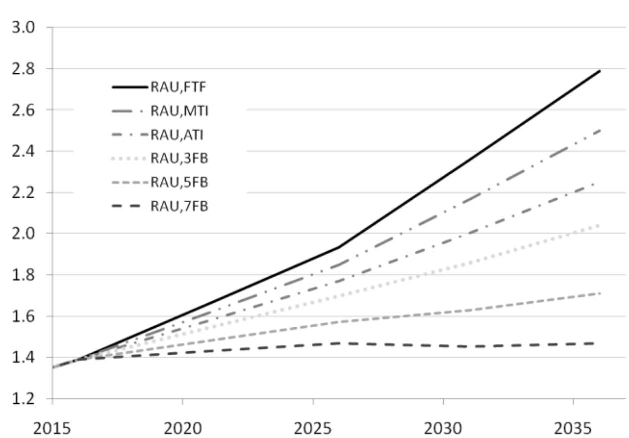


Figure 13: Annual carbon emission for RAU technology infusion schedules

It is important to note that this analysis was done without incorporating any economic feedback loops. Forcing early retirement of aircraft will surely raise ticket prices for passengers and thus dampen future demand – actually causing further carbon emissions reductions but at potentially high cost. Similarly, accelerating the rate of technological innovation may come at a steep (non-linear) price. These results must remain notional - though that does not diminish their importance in guiding the development of more sophisticated tools and potential FOM improvements.

D. IATA Carbon Neutral Growth Analysis

In July of 2009, the International Air Transport Association announced ambitious goals [2] for emissions reductions. These include a commitment to carbon neutral growth by 2020, a 1.5% annual fuel efficiency improvement, and cutting emissions to 50% of 2005 values by 2050. The meaning of “1.5% per year improvement in fuel efficiency” most likely refers to a fleet wide efficiency metric like liters of fuel per revenue-ton-kilometer (alluded to, but not explicitly stated in [11]). IATA expects a 21% reduction in CO_2 emissions via the fuel efficiency improvements of new aircraft, and the rest of the reductions to come from a mixture of operational and infrastructure improvements (3% and 4%), engine retrofits (1%), biofuels (5%), and carbon offset mechanisms (~90 million tonnes of CO_2). The EFOM can be used to explore these goals.

Ref. [2] also states that “5,500 aircraft will be replaced by 2020, or 27% of the total fleet.” This provides a convenient check on the retirement assumptions behind their model and the EFOM. Using the retirements as usual scenario, the EFOM predicts a reduction in the original 2009 fleet of 28.2%. The next claim to be examined is the 21% reduction in CO_2 due to “fleet renewal.”

The EFOM was reconfigured to examine the IATA fuel efficiency goals. IATA states that next generation vehicles like the Boeing 787 are 20% more fuel efficient than current aircraft. This was interpreted to mean the best available current aircraft. The Boeing 787 is not scheduled for delivery until the end of 2010 with production reaching ten airplanes per month by late 2013 [12]. Erring on the side of optimism, all new aircraft regardless of size were made 20% more efficient at the end of 2012 – not just aircraft resembling the 787. A new set of aircraft were then introduced at the end of 2015 with efficiency improvements that varied between 1% and 3% annually depending on the scenario. Table 1 can still be used to interpret the scenario names.

The efficiency scenarios are illustrated in Figure 14 and the scenario results in Figure 15. As opposed to the long term forecast, the retirement schedule modifications played a key role in estimating the percent reduction in emissions over the static fleet case. This is expected as the prior analysis showed that the retirement schedules have the most impact during interim years.

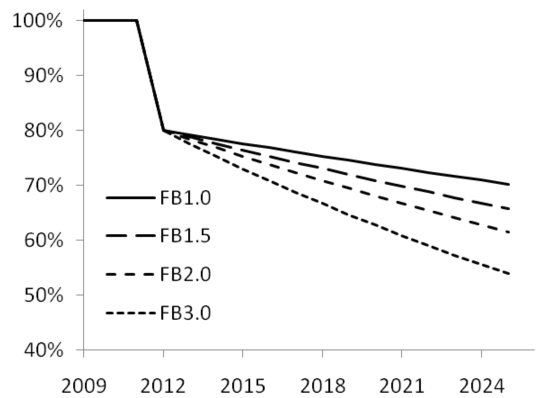


Figure 14: IATA analysis fuel efficiency scenarios

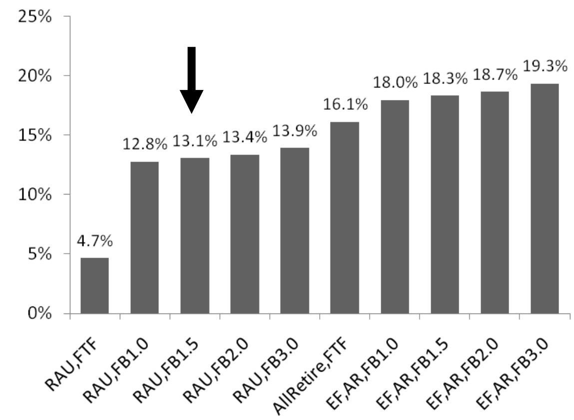


Figure 15: Scenarios by percent improvement over NoRetire,FTF

The IATA stated goal of 21% emissions reduction due to fleet turnover effects is not attained by even the most ambitious policy scenario – though the aggressive retirement schedule with an annual 3% fuel efficiency improvement comes close. The scenario most closely resembling that put forth by IATA is the RAU,FB1.5 case. This exhibits only a 13.4% reduction in CO_2 emissions. This is especially meaningful as conditions were setup to be over-optimistic. It is highly unlikely that an entire fleets worth of new, more fuel efficient aircraft would become available only three years after the introduction of the Boeing 787, and that all sizes of new aircraft would become 20% more fuel efficient by the end of 2012. The model also assumed complete market take-over by the new aircraft, rather than a more realistic phase-in over four or five years. To make the RAU,FB1.5 scenario a 21% improvement over the baseline would require an additional reduction of 72.5 mega tonnes of CO_2.

V. Conclusion

This paper has reviewed the Georgia Institute of Technology's new EFOM forecasting tool. It was found to provide reasonably accuracy and fast execution time relative to comparable tools. It was used to analyze a set of policy scenarios involving potential fuel efficiency trends and vehicle retirement rates. Retirement schedules were found to have little impact on long term emissions – though this may be an artifact of the CAEP approved retirement algorithm. For short term studies however, the assumption is reasonably accurate. In the long term it is clear that technology improvements drive emissions reductions by setting lower bounds – the retirement schedules determine how quickly those lower bounds are attained.

The EFOM was used to analyze IATA's goal of carbon neutral growth by 2020 and concluded that no realistic scenario existed which did not depend to a large degree on carbon offset purchases or a readjustment of the 'no growth from this point forward' mark.

Further work should be done to quantify the impact of never retiring new aircraft. For long time horizon studies (over 20 years) the impact of an enhanced retirement method may be substantial. Technology improvements were essentially post-processed for this analysis. The EDS team should investigate linking physics based aircraft technology tools into the model to establish technology road maps for different levels of fuel efficiency improvement. Finally, economic analyses should be conducted to quantify the impact of adjusting retirement schedules and accelerating technology adoption.

Acknowledgements

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Student Biography

Steven Isley obtained a Bachelors degree in Aerospace and Aeronautical Engineering from the University of Washington. He then went on to become the Operations Manager of the University of Washington Aeronautical Laboratory where he oversaw extensive wind tunnel testing for numerous aerospace, automotive, and sports companies. He completed his Masters degree in Aerospace Engineering at the Georgia Institute of Technology in the spring of 2010. While there, he performed analysis on potential CO_2 certification standards for aircraft and developed the EDS Fleet and Operations Module analysis tool. He is now pursuing a Ph.D. in policy analysis at the Pardee RAND Graduate School where he hopes to work in transportation policy and economics.

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