A METHOD FOR ASSESSING THE ENVIRONMENTAL BENEFIT OF FUTURE AVIATION TECHNOLOGIES

Peter Hollingsworth , Holger Pfänder , Hernado Jimenez
Aerospace Systems Design Laboratory, Georgia Institute of Technology

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Abstract

The increasing awareness of aviation's environmental impact has stimulated the development of a range of aggressive technology and system level improvement programs. These programs and the goals that are associated with them are described at various levels of abstraction, some at the technology and vehicle level and others at the air transportation system level. The issue is that there is often no clear mapping between the technology level goals and the overall, system level benefit to society. It would, therefore, be valuable to develop a technology and vehicle concept air transportation system environmental analysis capability. This paper describes one such method. It builds up the investigation from a basic vehicle and technology level, incorporates demand operations growth capability along side the environmental analysis and links to a highly capable environmental impact analysis tool. Further, it postulates the value in replacing specific models for each of these components with parametric surrogates to enable rapid investigation of a broad range of vehicles, technologies, and assumptions.

1 Introduction

Air travel and accordingly the commercial aviation fleet is expected to continue to grow over the coming years. In an effort to minimize the environmental impacts of this growth several organizations have proposed a series of environmental goals. The best known of these are the US JPDO [13, 21] and European ACARE [1] impact goals. Along side these impact goals corresponding sets of technology research and development programs have been initiated. Each of these technology development programs, whether at the vehicle or operational level, is designed to reduce the environmental impact that the relevant component of the aviation system has on the local and global environment. Unfortunately, while each of these technologies may be capable of reducing the impact of the individual component on the environment their effect on achieving the overall goals may be considerably damped by other external effects. These effects include assumptions about growth, the status quo technology trends, and market penetration and adoption rates for the technologies that are being considered. This paper describes a process to investigate the impact of several vehicle and engine technologies on a series of global aviation environmental impact goals, e.g. the US Joint Planning and Development Office's (JPDO) goal of a 1% per year improvement in system efficiency and a 4% per year reduction in the number of people exposed to the 65 dB DNL noise contour, to a range of external factors and assumptions [13]. The technologies, which are applicable to a range of vehicle types and posses a variety of anticipated maturity and market introduction dates, represent a range of the programs that are being undertaken by international research organizations.

2 Background

Each different group that has performed aviation environmental analysis has taken a different approach. Some have focused on regulation and policy, while others upon a range of possible operational improvements. Additionally, in each of these cases, the entities have used a relatively fixed range of assumptions that are not, generally, flexible. Two of the historical approaches, ICAO/CAEP and the JPDO, are described in more detail.

2.1 CAEP Process

The Committee on Aviation Environmental Protection of the International Civil Aviation Organization is the primary entity charged with assisting the council with the analysis and formulation of policies related to the adoption of aircraft noise and emissions standards [17]. The committee, acting through its Forecasting and Economic Analysis Support Group (FESG), performs cost-benefit assessments on new stringency levels proposed and reports its results to the council before any new level is officially adopted.

The economic analysis for revised NO_x stringency options reported by the FESG on 2004 is a good representative example illustrating the general methodology used. First, a base case is defined where no additional stringency option is adopted; different stringency options are then evaluated in terms of cost effectiveness ($US/Tonne NO_x). The primary part of the analysis concerns the estimation of aircraft operations in the future with appropriate detail so as to enable the estimation of NO_x emissions in the landing and take-off cycle (LTO). The secondary part concerns the estimation of economic costs incurred to meet different stringency options [16].

For the first part the the U.S. Federal Aviation Administration's (FAA) Emissions Dispersion Modeling System (EDMS) was used for LTO NO_x emission estimates. This tool uses a fleet database which details the engine emissions and fuel flow data for different airframe-engine combinations. Determination of the future fleet for the forecast is based on estimates of the current year fleet expected to remain in service based on retirement rates, and on new generic aircraft delivered to the fleet for its growth and replacement of retired units. Because generic aircraft definition is limited to seat class, airframe and engine information is added to the FESG forecast by considering real production of aircraft models. For this purpose the FESG assumes equal market split for airframe and engine manufacturers, and equal model split within each manufacturer and unit class, both statements consistent with theories of contested markets [16]. With a full definition of the future fleet and a measure of its performance in terms of NO_x emissions, different stringency levels are evaluated and compared side by side after incorporating cost measures for each stringency option.

2.2 JPDO Systems Modeling and Analysis Division

The Joint Planning and Development Office is the executor of the Next Generation Air Transportation Systems (NGATS) Integrated Plan which proposes a transformation of the current system across multiple objectives such as reduced environmental impact, increased capacity, safety and security among others [19].Within the JPDO the Systems Modeling and Analysis Division (SMAD) performs assessment of transformation strategies and reports the key goal tradeoffs to the Office's principals enabling the prioritization of investments [21].

More specifically, SMAD models Operational Improvements (OI), each of which denotes a given measure or concept contributing towards JPDO capabilities and consequently to national goals. Thus, the performance of the system is evaluated under a variety of scenarios of interest to assess the effect of different OI's and the ability to meet goals relative to a baseline year. The integrated modeling and analysis process implemented by SMAD incorporates basic demand modeling tools that are complimented with airport and airspace queuing models to identify feasible demand levels based on capacity limits. It also incorporates system models at the runway, airport and National Airspace System level that feed to economics, security and environmental performance tools [21].

A recent OI assessment involved the evaluation of future fleets which included a baseline forecast fleet, a best in class fleet, and a future technology fleet where aircraft are modeled as best-in-class with technology projections. This analysis assumed 100% replacement rate of new technologies for engines and airframes across all growth scenarios, meaning that the current fleet was replaced in its entirety by best-in-class or next generation units. It was also assumed that the entire fleet is and all operations are equipped and utilize the OIs. The assessment compared all fleets across midterm and end state future scenarios and provided the margins by which each fleet failed or met different noise and emission yearly percentage reduction goals [21].

2.3 Environmental Goals

Each of the different research and policy making organizations have a different set of environmental goals. Figure 1 contains a selection of the goals for three of most pertinent stakeholders in aviation environmental, at least for North America and Europe. It should also be noted that each of these organization has groups within them specifically tasked with aviation environmental modeling, out of which each derive their own respective environmental goals. Unfortunately, they are not easily comparable, because each of them also uses different baselines, metrics, and assumptions. Furthermore, some goals are at the vehicle or flight level, where as others are for the air transportation system. Generally, the environmental goals are limited to fuelburn, noise, and NO_x targets.

2.4 Desire for Parametric Approach

Even using relatively simplified modeling tools, the analysis of the fleet level impact of a single technology is still a computationally significant undertaking. In some highly coupled analysis any simplification of one modeling method/tool could potentially lead to a significant reduction in analysis fidelity. However, each of the modeling steps, from determining demand growth, through operations, to the final environmental outcomes have generally be considered as separate and distinct processes. That means that changes in technology and environmental outputs have, generally, been assumed not to affect the underlying demand. In those cases where technologies have affected demand or operations it has been through a blanket post-process application, e.g. applying capacity constraints by capping operations and producing a direct loss in demand serviced [21]. This reduces the likelihood that critical complexity will be eliminated by introducing a parametric, surrogate-model approach [23].

The primary benefit of moving towards a parametric approach is two-fold. The first is that the computational and storage requirements can be significantly reduced. This means that it becomes practical to move from having to run all of the technology implications on a dedicated server to something that can can be used on a standard laptop computer. Furthermore, because of the significant reduction in cycle time changes in assumptions or technology performance can be propagated in near real time. The second aspect of the movement to a parametric approach is that is allows for much more rapid inclusion of new technologies and future scenarios, at least at the screening level.

3 Approach

Any modeling of aviation environmental impacts, wether or not it includes health and welfare effects, and the technologies that are designed to minimize these impacts must include an understanding of the future changes in the aviation market, the future change in fleet, and the technologies themselves. Even in a parametric implementation these basic functions must be captured.

3.1 Future Operations

Any estimate of future operations usually involves three basic components. The change in passenger and cargo demand, the associated change in the fleet, and finally the change in the way the fleet is used to satisfy the chang-

	ACARE			JPDO/FAA			NASA SFW Vehicles			
	Metric	Baseline	Goal by 2020	Metric	Baseline	Goal by 2025	Metric	Baseline	Goal by 2015	Goal by 2020
Fuel Consumption/ CO2		2000	-50%	Tg/Billion km	2002-2012	1%/year	Aircraft Fuelburn	737/CFM56 777/GE90	-33%	-40%
Noise		2000	-50%	# people exposed to 65DNL	2002-2007 2008-2012	1%/year 4%/year	cumulative dB	Stage 3	-42dB	-52db
NOx		2000	-80%	part of Fuel			LTO NOx	CAEP/2	-70%	-80%

Fig. 1 Comparison of Goals [1, 13, 22]

ing demand for passenger and cargo transport. While different modeling groups and techniques approach each of the sections differently, often using simplifying assumptions, these three basic functions are the underpinning of the development of future operations upon which the new environmental technologies can be investigated.

3.1.1 Passenger Growth

Passengers, and traders in the case of cargo, are the ultimate customers in the air transportation system. Thus the demand for air travel is originated in these stakeholders and effectively drives the provision of service at all levels within the system. Ultimately, passenger demand provides a measure of how many people will travel between origin and a destination pairs within a geographic and temporal scope of interest. More detailed demand data can offer valuable insight on passenger preferences such as airline, airport in a catchment area, time of day for travel, or route between the origin and destination. Traveling public demand is usually described as a function of social, demographic, geographic, and economic variables that are known to correlate well with passenger choices [18]. It follows that forecasting techniques for passenger demand will often attempt to estimate the evolution of these driving factors first, and have demand levels follow. For instance gravity models incorporate historical data on economic and social descriptors to estimate the geographic distribution of demand in the future. Some economic and social factors at the national level may at times serve as scaling parameters that can be generally applied to all segments of the market. Examples include the overall economic health of the nation or the public's perception towards air travel safety/security. Ultimately, regardless of the specifics of the method adopted, passenger demand growth attempts to quantify and characterize the volume of potential person-trips expected to exist some time in the future. [5]

3.1.2 Fleet Growth

Fleet growth defines the evolution of the mix of aircraft in service over time, and is particularly important for system performance assessments such as the present one because it captures the age and technology of aircraft as drivers of system performance. Aircraft manufacturers use passenger growth projections and work closely with airlines to understand the future travelers' needs, and to define a fleet composition to meet those needs. This offers guidance to the manufacturers in terms of what aircraft models should continue to be produced, and at what rate, as well as what new models should be introduced in the future. These findings are reported and published by the manufacturers as market outlooks for time horizons spanning a couple of decades into the future. [3, 2] The general approach taken

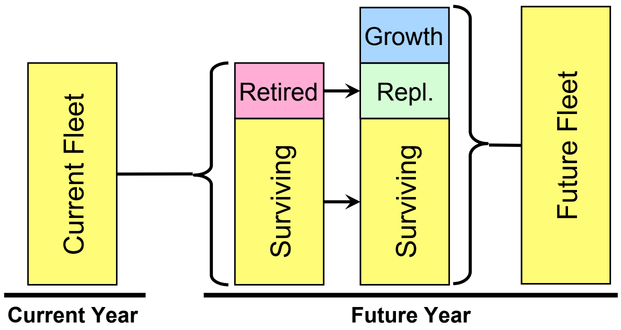


Fig. 2 Fleet Evolution with Retired, Replacement and Growth aircraft

in fleet projections involves a number of basic steps. First, it is necessary to have some measure of the current fleet age on an individual aircraft basis. Retirement functions for specific aircraft models of families describe how units are retired over time based on their age, and are used to calculate how many aircraft of the current fleet will be retired and how many will survive some time in the future. In the next step passenger demand estimates are incorporated with airline operation assumptions, e.g. load factor and utilization, to define the number of aircraft necessary to meet demand in the future. This number will determine how many new aircraft must be added to the surviving fleet to replace retired units and to address any demand growth that may additionally occur. This concept is graphically illustrated in Figure 2.

In general aircraft replacement occurs on a seat-class basis, meaning that when an aircraft of a given seat-class is retired it is replaced with available models of the same seat-class. Many assumptions can be implemented in fleet growth to handle how models within a seat-class are used for replacements. Moreover, new models such as the A-380 or the Boeing 787 are introduced into the fleet mix after being assigned to a seat class and incorporating assumptions/estimates about their market penetration rates relative to other pre-existing models in their same seat-class, and retirement curves. In brief the fleet growth analysis provides a complete description of the fleet mix at any moment in time within the scope of interest.

3.1.3 Operations Growth

An aircraft operation is any instance of an aircraft, modeled as an airframe-engine combination, performing a flight between an origin and a destination according to prescribed procedures. The collection of all operations taking place within a scope of interest, geographic and temporal, constitutes the bulk of information describing the demand and unconstrained supply of the system. It also constitutes the key inputs that are fed to the modeling and simulation environment so that system performance, in this case expressed as fuel burn, emissions and noise, can be quantified for the prescribed demand and fleet/technology characterization. Thus obtaining a complete and adequate operational data set reflecting demand data of interest is absolutely critical for this research.

Operations growth estimation is usually performed from the perspective of the airlines. Airlines are the first tier of service providers that passengers interact with, and represent one of the key interfaces between supply and demand within the system. Because airlines operate in a competitive environment and act as profit maximizers they attempt to capture the right size and segment of the market so as to achieve this profit objective. To do so airlines make decisions in terms of what routes to compete in, what flight frequency to use over a given day or week, and what aircraft to use for each of those flights. Benefits such as the potential for market capture and profit are weighted against various types of costs in these decisions [5, 18]. It is therefore the task of the analyst to emulate the key aspects of this decision-making rationale, and to incorporate it with a variety of market assumptions, passenger demand growth estimates, and the fleet evolution, in order to produce an operations set.

One assumption involves projected load factor values, often generated for general route groups, which adjust the number of passengers allocated in each operation. Another assumption is that of projected aircraft utilization which drives the number of flights per unit time that a given aircraft performs. Utilization and aircraft count estimates can be reconciled with frequency-capacity split relationships, which define how airlines allocate more flights and bigger aircraft to a route with increasing passenger demand. Other considerations can be incorporated into the analysis, potentially providing a higher degree of operational data resolution but requiring more detailed information as an input which may not always be available. Clearly there is no unique process for producing an operational data set, but rather it changes on a case-by-case basis and depends on available data, data fidelity required, and desired outputs.

3.2 Technology Modeling

The modeling of technology and vehicle concepts focuses on creating as accurate as possible representations of each vehicle or technology in the metrics of interest, which here are mainly environmental. The information needed to model vehicles, at a minimum, consists among other things of specific fuel consumption, weights, drag polar, and thrust. This type of information is generally not available or at least only in limited form. The process then uses a set of weights and mission range along with specific fuel consumption improvement estimates to estimate the lift to drag ratio. This along with some geometry information can be used to finally estimate the drag polar. This information is the converted into the Base of Aircraft Data (BADA) [8] and SAE 1845 [25] coefficients which is what is used by the environmental and airspace tools to calculate system level metrics.

A number of models of this type were created and include committed industry vehicles as well as number of further out vehicles representative of variations in technology packages thought to be available for vehicles coming into the market at certain future dates. It should be noted that these represent particular size class vehicles thought to be the most likely ones to receive completely new vehicles. The technologies and concepts that can be investigated in this manner include, but are not limited to, the introduction of Blended-wing Body (BWB) aircraft, Ultra-high bypass ratio engines (UHB), Hybrid-laminar Flow control aircraft (HLFC), and Cruise Efficient STOL (CESTOL) aircraft.

3.3 Impact Modeling

The modeling of aviation environmental impacts, i.e. fuelburn, emissions, and noise can be performed using a variety of tools. However, there are only a few which allow the modeling of all three simultaneously, this includes the FAA's *Aviation Environmental Design Tool* (AEDT) [24, 14, 15]. AEDT is intended to be the successor to the FAA's legacy environmental analysis tools and is intended to provide the capability of full *gate-to-gate* modeling of environmental impacts. The original legacy environment included four tools:

- Global:
  - System for Assessing Aviation's Global Emissions (SAGE) [20].
  - Model for Assessing Global Exposure to the Noise of Transport Aircraft (MAGENTA) [10].
- Local:
  - Emissions and Dispersion Modeling System (EDMS) [11, 12].
  - Integrated Noise Model (INM) [9].

The AEDT model set models fuelburn, emissions, and noise independently. The specific approaches are described in the following subsections.

3.3.1 Fuelburn

The modeling of the fuelburn performance is performed using the Aviation Environmental Design Tool (AEDT) Aircraft Performance Module (APM) [24]. Operations can flown using either a dispersed great circle track methodology with a randomized cruise altitude or existing radar information. The AEDT/APM handles cruise climb allowing the vehicles to climb to their designated cruise altitude as they burn fuel if they are unable to reach that altitude at the prescribed take-off weight. The great circle tracks can be saved so that any new vehicles or reruns would fly the same ground track. This minimizes the sources of differences between the existing and future fleet to those that are obtained from the variation of the performance and emissions coefficients.

3.3.2 Emissions

The modeling of aircraft emissions is performed on a flight-segment basis using the Boeing Fuel Flow Method 2 (BFFM2) [6]. This is implemented in the the AEDT Aircraft Emissions Module (AEM) [24]. The AEM uses a series of log-log relationships on Emissions Indicies and fuel-flow that are described in BFFM2. The typical source for the baseline emissions information is the ICAO Emissions Databank [4].

3.3.3 Noise

The modeling of aircraft noise is performed using the methods described in SAE AIR1845 and ECAC Doc 29 [25, 7]. This is implemented in the the AEDT Aircraft Acoustics Module (AAM) [24]. The AAM uses segment level performance plus the NPD curves associated with INM to calculate a range of noise metrics for single flights at multiple observer positions. In this work the metric of interest is Sound Exposure Level (SEL) on the flight-level and Day-Night Noise Level (DNL) for all operaitons.

3.3.4 Impact Analysis

While the development of a capability to model fuelburn, emissions, and noise is beneficial; ideally the method would incorporate the capability of modeling downstream environmental impacts. In order to do this, a link between the AEDT outputs and the Aviation Environmental Portfolio Management Tool's (APMT) Benefits Valuation Block (BVB) has been established [26, 27]. This enables an investigation of climate, local-air-quality, and noise exposure impacts, including health and welfare and, ultimately, monetization.

4 Implementation

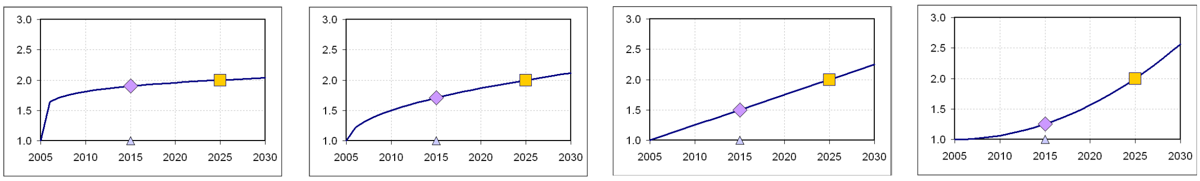
The development of a capability, fully parametric or otherwise, for the identification of technology gaps and the evaluation of the effect of specific technologies requires three major components: The parametric demand, the demand to operations transformation, and the modeling of existing and future advanced technology vehicles.

4.1 Parametric Growth Function

The desire to dynamically explore a wide variety of growth scenarios in a flexible manner provided the motivation to develop and implement a parametric operations growth function that could be easily manipulated to generate a spectrum of growth profiles. In the formulation of such a capability researchers sought to keep the mathematical complexity at a relatively low level without losing data resolution and traceability between passenger demand and operations. It was therefore decided to consider a parametric function for passenger growth, and then to process passenger demand into an operations set.

First, a baseline year is defined and used to normalize all demand values of the projected future, thus transforming growth figures from absolute values, e.g. million enplanements per year, to relative growth factors, e.g. $1.5X$. The use of growth factors allows for more intuitive understanding of growth scenario implications contrasts with the manipulation of absolute figures, particularly very large values, that do not allow the analyst to get a "good feel" of the expected system performance.

In the context of futures assessments, the profile of growth over time is just as critical as the initial and end state values because it determines the impact of technologies and concepts that are introduced into the system in the future. This



(a) $\gamma = 0.15$; 1.9X@2025 (b) $\gamma = 0.5$; 1.5X@2025 (c) $\gamma = 1.0$; 1.5X@2025 (d) $\gamma = 2.0$; 1.25X@2025

Fig. 3 Two-compontent Parametric Growth Function

is especially true for technologies that cannot be retro-fitted into the existing fleet. In order to manipulate the growth profile a shape parameter, γ, is defined in the parametric formula whose baseline year and final year with their respective growth factors bracket the function. The resulting parametric growth function allows the user to dial in a baseline and end year for the temporal scope, a growth factor for the end year, and a value for γ to tailor the growth profile. The resulting curve can then be queried to determine the resulting growth factors in any of the evaluation years between the baseline and the end year. The parametric growth function is graphically depicted in Figure 3, parts a) through d). In all cases 2005 is used as the baseline year, 2025 as the end year, and 2015 as the evaluation year for illustrative purposes. Values of γ less than 1.0 result in a front-loading (concave down) of the growth profile, with lower and smoother curvature accompanying greater values of γ as shown in Figure 3(a) and 3(b). When γ is 1.0 the curvature is zero and the profile is reduced to a linear relationship, as seen in Figure 3(c). For γ greater than 1.0 the profile is concave up and back-loaded, as seen in Figure 3(d).

4.2 Operations from Parametric Passenger Demand

The ultimate goal of the demand growth function is not just to easily create passenger demand data profiles but to actually generate the adequate operational sets needed for environmental analyses. To do so, it is necessary to incorporate the passenger demand data with projections about how airlines will utilize their aircraft.

The first task is to determine how the demand growth profile is applied. In reality, variability in the demand between origin and destination pairs is expected to occur, reflecting the geographic non-uniformity of passenger demand evolution. As a result airlines modify, to some extent, their operations to better compete across various routes. Additionally airlines may implement changes to their network based on a variety of reasons such as cost reductions, market penetration or business model re-structuring [18]. In this research, however, the demand profile is applied equally to all city-pairs, implying that no major change is made in the network topology of airlines, and that the geographic distribution of demand remains mostly constant.

The next step is to determine how the future demand is allocated to flights. The simplest method is to maintain the same aircraft size distribution on all of the routes, but it neglects the fact that airlines will adjust schedule and aircraft size in an attempt to maximize profits. Instead, what is often done is to determine a relationship between revenue traffic, route length, number of flights, and size of aircraft. One example of an aircraft size vs. flight frequency model is that used by Airbus and described briefly in [2]. These models can be applied directly to the passenger growth model, or replaced by parametric surrogates that can represent a wide variety of frequency-capacity trade-offs in a straightforward and rapid manner.

The final step incorporates the retirement of existing aircraft and the addition of new aircraft to replace them and cover operations resulting from demand growth. There are multiple methods of determining aircraft retirement, the sim-

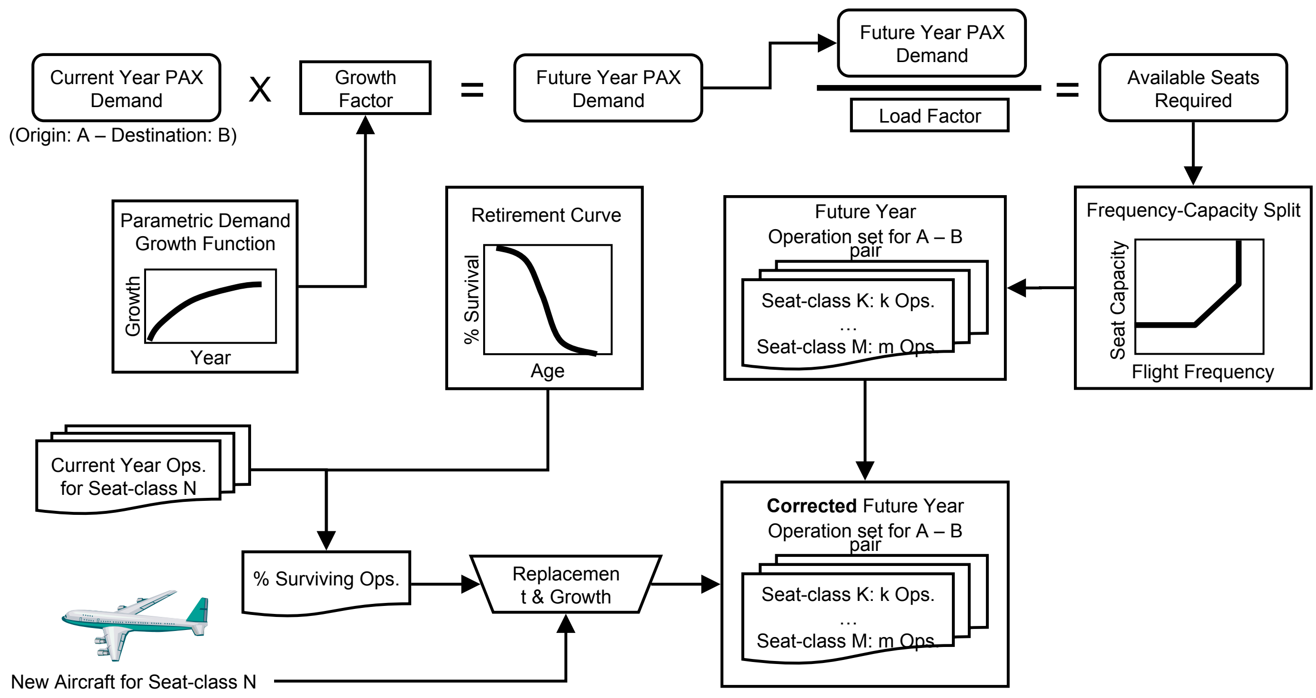


Fig. 4 General Process for the Generation of Operations Data from Parametric Growth Function

plest of these is an age-based approach such as that used by ICAO/CAEP [16]; other approaches use economic models to determine the point at which an aircraft or class of aircraft are retired [27]. The method described in this paper uses age based curves; however, work is underway to develop a more dynamic approach. The entire process from growth to operations is graphically represented in Figure 4.

4.3 Parametric Vehicle and Technology Modeling

While the process described in Section 3.2 can be used to create single models of vehicles and their associated technologies, the desire of this capability is to create a method of analyzing a series of arbitrary concepts and technologies that can be applied to those concepts. Furthermore, because the existing fleet is large and relatively diverse it is also important to develop parametric models to represent these aircraft and engine combinations.

To develop parametric models of fuel-burn and emissions, it is necessary to determine upon which factors the outputs are dependent. The result of this is that the existing fleet fuel-burn can be approximated using two primary factors: *Aircraft* and *Flight Distance*. This is the result of the fact that the fuel-burn methods in the BADA database do not, currently, differentiate between the multiple engine options on most modern aircraft. The effect of flight distance involves multiple factors. The first is that the required weight increases as the flight range increases. This increase in weight leads to greater fuel-burn, especially for extremely long range flights. The second factor is that on shorter flights a higher percentage of the total flight length is spent in high thrust regimes, especially take-off and climb.

For emissions the primary factors are: *Engine* and *Fuel-burn*. An issue with generating emissions surrogate models arises from the fact that actual emissions are a function of the flight-segment level fuel-flow. This means that the relationship between fuel-burn and emissions cannot be performed at the full flight or LTO level, but must be related with the fuel-burn rate. This meant that the specific relationship that worked best was not with the total fuel-burn but with a

Table 1 Correlation Factors Between the AEDT results and Surrogate Models for the Existing Fleet

Factor	Correlations
Fuel-burn Rate (kg/nm)	0.98766
NO_x (g/nm)	0.97739
LTO Fuelburn (kg/cycle)	0.99294
LTO NO_x (g/cycle)	0.97022

Table 2 Baseline Aircraft

Seat Class	Aircraft
50	ERJ145
99	CRJ-900
150	A319-100 & B737-700
210	A320-200 & B737-800
300	A330-200 & B777-200ER
400	B777-300ER
500	B747-400ER
600	B747-400ER

fuel-burn/distance (kg/nm or kg/km). The resulting correlations between the AEDT calculated and the surrogate predictions are given in Table .

To develop advanced technology surrogates using the method described above, a representative aircraft-engine combination is selected in each of the seat classes. These aircraft represent a selection of the "best in class" from the existing aircraft. The engine was chosen based upon the engine ID that is most common in the database. The baseline replacement aircraft are given in Table 2. The baseline replacements are used to fulfill all vacant operations until the year of introduction of the advanced technology aircraft. Starting with the year of introduction the existing aircraft are substituted out of the replacement options using a linear function of 25% per year. Additionally, the baseline replacement aircraft were used as the basis for developing the advanced technology aircraft.

In order to determine the relationship between future emissions goals and the technology capability that needs to be developed in order to achieve them a design of experiments was created to manipulate the BADA [8] and SAE/AIR-1845 [25] coefficients to produce a range of potential technology developments that represent improvements in both the terminal and enroute aerodynamics, engine efficiency, weight, and emissions performance. The development of equations that relate the environmental performance of future vehicles to the BADA and SAE coefficients can then be used to create transformations between these coefficients and typical technology level metrics such as terminal area SFC, L/D (cruise and terminal area), Mission Weights, Landing Weights, Payload, Thrust performance, etc. This enables the modeling of a broad range of future technologies without having to develop specific AEDT models for each. It also increases flexibility with respect to changing technologies, concepts, and assumptions.

5 Future Work

The development of the process described within this paper enables the rapid evaluation of an range of technologies and future vehicle concepts. Each of the portions of the process described herein requires a significant amount of effort to produce results for a range of assumptions. As such the process is designed to allow for the replacement of specific assumptions and models with broader parametric implementations. The development and implementation of a first level of these parametric meta-models has also been described. However, while this process is a necessary component of any investigation of any technology and concept portfolio there are many additional steps that need to be undertaken to return usable results. These include the development of technology mappings and the creation of a portfolio analysis capability that makes use of the parametric results. These processes are underway and will be described in the future. Finally, the method described herein has not explicitly considered the effect of airport or airspace capacity. This capability is also be incorporated for future versions.

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