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Probabilistic assessment of fleet-level noise impacts of projected technology improvements

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A R T I C L E I N F O

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Abbreviations:
DNL
Day-Night Average Level
LSA
Large Single-Aisle
LTA
Large Twin-Aisle
RJ
Regional Jet
$r_{x,y}$
Correlation between variables x, y
$rx_{,z}$
Correlation between variable x and response z
$r_{y,z}$
Correlation between variable y and response z
$R_{x,y,z}$
Multiple correlation between variables x,y and response z
SSA
Small Single-Aisle
STA
Small Twin-Aisle
VLA
Very Large Aircraft

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A B S T R A C T

Demand projections for civil aviation have forecast increases in operations in future decades. Increases in demand are beneficial to the growth and advancement of the aviation industry, but also come with the threat of significant increase in environmental impacts. In response, the industry is focusing on programs to develop technologies for reductions in fuel burn, NO_x emissions, and noise. While aircraft-level impacts are an obvious metric of success, it is difficult to make informed robust technology investment decisions with respect to noise without understanding the fleet-level impacts. Fleet-level predictions of noise for technology explorations are especially complicated because it is computationally expensive, highly combinatorial, and airport-specific. Recently, rapid automated airport noise models have been developed, which can be simulated using Design of Experiments (DOE). The results of these simulations are used to generate surrogate models for airport noise contour area, which can be summed to yield a fleet-level impact. These models make use of simplifying assumptions to provide estimates of airport-level noise that are substantially cheaper to compute. They can be used to perform parametric trade-off analyses in conjunction with the equivalency assumption. Equivalency asserts that environmental impacts of a technology infused aircraft can be represented by scaled operations of the baseline aircraft in the same class. This simple assumption allows for the modeling of technology and market penetration factors under the same units: operations. This research uses surrogate models in conjunction with the equivalency assumption to examine two potential technology scenarios in a target forecast year, simulating technology and market performance factors to identify vehicle classes that could have the greatest impact in reducing contour area. Results show that technology and market performance of future notional Small Single Aisle and Large Single Aisle vehicle aircraft have the highest positive correlations with potential reductions in contour area.

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1. Introduction

Several government and private entities, such as the Federal Aviation Administration (FAA), Boeing, and Airbus, predict that United States aviation demand is expected to increase significantly in future decades (FAA, 2014b), (Boeing, 2013), (Airbus, 2015). To upgrade the current National Airspace System (NAS) to handle larger capacity, the NextGen initiative has been charged with updating systems and practices to reflect state-of-the-art technology, while preparing for future technological improvements (Office of NextGen (2013)). NextGen goals include ensuring that increases in aviation operations do not negatively impact the environment, such as increases in fuel burn, NO_x emissions, and community noise exposure.

To address these issues, several technology programs have been established, such as the FAA Continuous Lower Emissions, Energy, and Noise (CLEEN) (FAA, 2014a), National Aeronautics and Space Administration (NASA) Environmentally Responsible Aviation (ERA) (Aeronautics Science and Technology Subcommittee, 2010), and NASA Fixed Wing (FW) programs (Del Rosario, 2014). These programs target various generations of future aircraft to bring promising technologies to a level of maturity suitable for industry adoption while reducing the financial risk to airframers through cost-share agreements and development of higher Technology Readiness Level (TRL) technologies (Springer, 2013). Program targets are set based on vehicle-level improvements relative to a reference aircraft, and may vary between different aircraft types. The NASA goals are summarized in Table 1 (Guynn et al., 2013).

While state-of-the-art physics-based aircraft-level technology modeling has advanced substantially in recent decades, these analyses do not provide a fleet-level perspective on technology impacts. Without investigating the interaction between technology infused aircraft, existing aircraft, and evolving operations, the true environmental impact is difficult to quantify (Tetzloff and Crossley, 2014).

Airport community noise is especially challenging to evaluate in this context because of its spatial and temporal characteristics that fundamentally distinguish it from fuel burn and NO_x emissions (Heleno et al., 2014). Fuel burn and NO_x emissions can be summed directly to the fleet-level as they are single-point values for each flight. Noise has a spatio-temporal component that requires advanced mathematical techniques to analyze, first at the aircraft-level, then considered at the individual airport-level, and finally integrated to the fleet-level. As a result, detailed aircraft and airport noise models are typically computationally expensive and require unique detailed airport information that is not always practical for technology evaluation scenarios at a fidelity-level appropriate for screening.

As summarized in Fig. 1, source noise prediction is provided through fundamental aeroacoustic models addressing specific noise generating components. These noise sources are not constant; they are a function of the aircraft performance through a Landing and Takeoff (LTO) cycle. Aircraft performance provides the aircraft and engine state, and its location in space. The source noise is only part of the equation, as the propagation of this noise to a host of observers ultimately defines the impact. To project noise to the airport-level, a modeling framework is applied that enables aircraft performance to be mapped through a set of coefficients. This approach enables modeling of specific aircraft without proprietary manufacturer data. Source noise levels are provided through noise-power-distance (NPD) curves, typically generated empirically from flyover measurements in the field. These curves are used to interpolate noise propagation to the observer locations around an airport. The flight profile is broken down into segments, where the propagated noise to each observer location is computed. These segments are then totaled together for each observer location to provide noise for a single flight. Atmospheric, terrain, and other absorption or reflection impacts are adjusted afterwards. This process is repeated for every unique aircraft, runway heading, and ground track (projection of the flight profile on Earth's surface). These combinations require specific computation because the three-dimensional aircraft location heavily impacts how noise propagates to any given observer location. Once all flight contributions to noise at each observer location are summed, these can be used to locate contours of constant noise levels, which define regions that are impacted by a certain minimum amount of noise. To provide a fleet-level estimate, a system of airports must be defined and the process must be repeated at each airport. This framework leads to long setup and modeling times, particularly at the airport and fleet-level, making it difficult to support rapid analysis of technology options.

In response to these challenges a generic approach to fleet-level environmental noise analysis has been proposed, rooted in the assumption that aircraft and airports can be modeled by subset of intelligently defined representative models. The aircraft-level noise at a grid of observer locations can be pre-computed under straight ground track and standard atmospheric assumptions, and then scaled to the airport-level depending on the flight schedule and runway layout. By pre-computing noise using detailed noise analysis tools, this time consuming task can be done off-line, allowing the computation of airport-level noise to execute more quickly (Bernardo et al., 2015a), (Bernardo, 2013). The inputs available are the aircraft types, number of flights in day-time or nighttime, approach and departure operation counts, the trip length, and the runway layout. This approach is sufficiently fast and accurate to provide screening-level studies, as well as automation of many possible scenario analyses. The speed of execution allows for strategic sampling via Design of Experiments (DOE) with the intent of developing surrogate models as a function of airport-specific factors such as total operations, fleet composition, trip-length

Table 1
NASA environmental goals increasing in stringency for future forecast years (Guynn et al., 2013).

Technology benefits[a]	Technology generations (technology readiness level = 4–6)		
	N+1 (2015)	N+2 (2020)	N+3 (2025)
Noise (cum margin rel. to Stage 4)	−32 dB	−42 dB	−52 dB
LTO NO_x emissions (rel. to CAEP 6)	−60%	−75%	−80%
Cruise NO_x emissions (rel. to 2005 best in class)	−55%	−70%	−80%
Aircraft fuel energy consumption (rel. to 2005 best in class)	−33%	−50%	−60%

[a] Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission. N+1 and N+3 values are referenced to a 737−800 with CFM56-7B engines, N+2 values are referenced to a 777−200 with GE90 engines (Guynn et al., 2013).