Transportation Research Part D 63 (2018) 362–376

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Probabilistic assessment of aviation CO_2 emission targets

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ARTICLE INFO

Keywords:
Aviation system
Aviation fuel consumption
Aviation carbon dioxide emissions
Aircraft technologies
Operational improvements
Aviation biofuels

ABSTRACT

Passenger demand for air transportation is expected to continue growing into the future. The increase in operations will undoubtedly lead to an escalation in harmful carbon dioxide emissions, an adverse effect that governing bodies have been striving to mitigate. The International Air Transport Association has set aggressive environmental targets for the global aviation industry. This paper investigates the achievability of those targets in the US using a top-down partial equilibrium model of the aviation system complemented with a previously developed fleet turnover procedure. Three 'enablers' are considered: aircraft technologies, operational improvements and sustainable biofuels. To account for sources of uncertainty, Monte Carlo simulations are conducted to run a multitude of scenarios. It was found that the likelihood of meeting all targets is extremely low (0.3%) for the expected demand growth rates in the US. Results show that biofuels have the most impact on system CO_2 emissions, responsible for an average 64% of the total savings by 2050 (with aircraft technologies and operational improvements responsible for 31% and 5%, respectively). However, this impact is associated with high uncertainty and very dependent on both biofuel type and availability.

1. Introduction

The prospects of the US commercial aviation sector remain positive with a long-term outlook of growth, driven by US and world economies. According to the International Civil Aviation Organization (ICAO), the aviation industry has been reporting strong growth performance as it continues to recover from the recent economic recession (ICAO, 2015). Worldwide air traffic reached a record 3.53 billion passengers in 2015, up 7% from 2014 and 30% from 2010 (ICAO, 2015). This current trend of aviation growth is expected to continue in the future. In order to accommodate the increase in air traffic, the worldwide passenger fleet size is projected to double by 2035 (Boeing, 2016; Airbus, 2016). In the US, air carrier operations are expected to increase from an average of 37 000 flights per day in 2015 to 65 000 by 2035 (FAA, 2016a). Without intervention, this huge number of additional flights will likely increase pressure on the US National Airspace System (NAS). The NAS is anticipated to become congested and delays are likely to propagate throughout. Environmental consequences include an escalation in harmful nitrogen oxide (NOx) and carbon dioxide (CO_2) emissions, and an increase in noise levels near airports (NASA, 2013). Aviation fuel consumption in the US is forecast to rise approximately 40% by 2035 relative to 2010 levels (FAA, 2016a).

In order to mitigate the adverse environmental impacts of operational growth, and to enhance the overall efficiency and safety of

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https://doi.org/10.1016/j.trd.2018.06.006

Table 1
NASA targeted improvements in aircraft metrics (NASA, 2017).

Technology benefits	Near term 2015–2025	Mid term 2025–2035	Far term Beyond 2035
Noise[a]	22–32 dB	32–42 dB	42–52 dB
LTO NOx emissions[b]	70–75%	80%	> 80%
Cruise NOx emissions[c]	65–70%	80%	> 80%
Aircraft fuel consumption[c]	40–50%	50–60%	60–80%

[a] Reduction in cumulative margin below FAA Stage 4 noise limit.
[b] Reduction relative to ICAO CAEP/6 standard.
[c] Reduction relative to 2005 best in class.

the NAS, the US —through its Federal Aviation Administration (FAA)— has invested heavily in the Next Generation Air Transportation System (NextGen). From 2010 to 2016, total expenditures on NextGen programs amounted to 6.31 billion dollars (DOT, 2016). The various programs seek to transform the current NAS by improving its operational capacity, efficiency, and resilience (FAA, 2018). Alongside the FAA efforts, the National Aeronautics and Space Administration (NASA) has been investing in the development of technologies that will either enable the implementation of NextGen or enhance the environmental performance of commercial aircraft (Table 1) (NASA, 2017). From 2010 to 2016, total expenditures on NASA aeronautics research totaled 3.98 billion dollars (NASA, 2016). NASA has set forth an implementation plan to guide its aeronautics research along six strategic thrusts that will enable a sustainable, efficient, safe, and autonomous future for aviation (NASA, 2015).

Globally, the International Air Transport Association (IATA) has defined high-level targets to address the projected increase in aviation-related CO_2 emissions. Those targets include a cap on carbon growth starting 2020 and a reduction of 50% in net carbon emissions by 2050 relative to 2005 levels. In September 2009, the IATA targets were endorsed by the aviation industry including aircraft manufacturers, airlines, airports, and air navigation service providers. At the 37th ICAO assembly in October 2010, governments resolved to adopt the targets as well (ICAO, 2010). Additionally, IATA has laid out a strategy that relies on new technology, efficient operations, effective infrastructure, sustainable biofuels, and economic measures[4] to enable its environmental vision (IATA, 2013). The whole aviation community, including ICAO member states, adopted the strategy as a guiding framework to achieve the aggressive targets.

Since the US is an ICAO member state, the 2010 resolution imposed additional requirements on domestic aviation investments to meet the global targets. While the US has invested billions of dollars in transforming its aviation sector, and future research commitments are expected to be of comparable figures, it still remains unclear whether the aviation environmental targets will be met. In fact, the near term target of achieving an average fuel efficiency improvement of 1.5% per year from 2009 to 2020, has not been met yet. Data reported by the Bureau of Transportation Statistics (BTS) show that the average US fuel efficiency improvement from 2009 to 2015 was approximately 0.7% per year (fuel efficiency metric being available seat miles per gallon) (BTS, 2015a). Furthermore, the mid term target of carbon neutrality starting in 2020 continues to be challenging given current improvement trends. In 2015, an FAA study concluded that carbon neutral growth will not be achieved with moderate system improvements (USG, 2015). The slow progress towards the targets has raised many concerns regarding the US aviation investment strategy.

At the request of the US Congress, the National Research Council (NRC) formed a committee to report on the status of NextGen and examine the technical activities related to its implementation. The report severely criticized the FAA for its management of NextGen, and emphasized that the current implementation strategy seeks an evolutionary upgrade of the NAS rather than the originally promised revolutionary transformation (NRC, 2015). The NRC report echoed previous warnings by the Inspector General of the US Department of Transportation who has been following the progress of NextGen closely (Scovel, 2013, 2014). Even more alarming is the 2015 study conducted by the FAA itself, which showed that NextGen improvements would contribute very little towards achieving the environmental targets, and that almost all savings in CO_2 emissions would come from vehicle technologies and sustainable biofuels (USG, 2015). Despite the previous research findings, the allocation of investment resources over the past few years has been skewed in favor of operational improvements. The aforementioned constitutes a basis to at least consider alternative investment strategies.

While the NRC report called on the FAA, US Congress, and all NAS stakeholders to “reset expectations” for NextGen, this paper investigates resetting the US aviation investment strategy altogether. By leveraging recent publications to set an upper limit on operational benefits, this study investigates how much is required from the other ‘enablers’ (technologies and biofuels) for the US to meet the IATA targets. Aircraft fuel consumption goals set by NASA (Table 1) are used for bench-marking. This work incorporates a complete fleet turnover model that accounts for aircraft retirements and replacements to examine numerous technology introduction scenarios in a probabilistic manner through Monte Carlo simulations. Uncertainties in aviation demand and fuel price are accounted for in the simulations, and the aviation system is assumed to seek partial equilibrium on a yearly basis. The primary research objectives are to investigate scenarios that meet the IATA targets, and to analyze the expected contributions from vehicle technologies, operational improvements, and sustainable biofuels.

[4] Unlike the other solutions, economic measures do not aim to directly limit aviation emissions, but rather to offset them. At the 39th assembly in October 2016, ICAO resolved to implement the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) as a global market-based measure (ICAO, 2016). Under CORSIA, aircraft operators of ICAO member states will be required to offset CO_2 emission units based on their annual fuel consumption.