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The influence of emission thresholds and retrofit options on airline fleet planning: An optimization approach

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ABSTRACT

The global framework for aviation is given by growth expectation (growth rates of 2–5% p.a.) in combination with the challenge to reduce the environmental impact. Especially airlines are under increasing pressure due to ambitious CO_2 reduction targets. To reduce fleet emissions, airlines can purchase modern and fuel efficient aircraft or apply retrofits to the existing fleet (e.g., blended winglets). Decisions on these alternatives are part of airline fleet planning where the development of fleet size and composition is determined. Focusing on the transition towards energy-efficient aviation, this paper investigates the influence of emission thresholds and retrofit options on airline fleet planning by making use of an optimization model. Based on real-world data, the model is applied to two major European airlines for a planning horizon between 2016 and 2025. The results indicate that emission thresholds and retrofits can make a significant contribution to achieving short term emission targets. However, the potential is limited due to existing investment budget constraints and the fact that retrofits are only available for short- to medium-haul aircraft. This calls for the development and certification of further retrofit programs as well as the deployment of further measures such as bio-/electrofuels or hybrid electric aircraft.

1. Introduction

The climate impact of aviation is mainly based on emissions of carbon dioxides (CO_2), nitrogen oxides (NO_x), aerosols (soot and sulphate), and increased cloudiness in the form of linear contrails as well as cirrus clouds in the upper troposphere (Burkhardt and Kärcher, 2011; Lee et al., 2009; Macintosh and Wallace, 2009). On a global scale, CO_2 and NO_x emissions are the greatest contributors to climate change with the former contributing thousands of times more emissions than other products of fuel burning in aviation (Timmis et al., 2015). Since 1980, fuel-combustion-related CO_2 emissions from aviation have increased at 3.6% per year, i.e., almost twice the world's total growth rate of CO_2 emissions (IEA, 2016). Today, the aviation sector accounts for approximately 12% of transport-related emissions and 2% of all human-induced emissions (ATAG, 2017). In order to cap and eventually lower the sector's emissions despite expected growth rates of 2–5% in air traffic (Airbus, 2017a; Meleo et al., 2016), the European Commission, two US government agencies, the International Air Transport Association (IATA), and the International Civil Aviation Organization (ICAO) have begun to explore or implement mitigation measures and reduction targets for CO_2 emissions (Schäfer et al., 2016). For instance, IATA seeks to improve global fleet fuel efficiency by an annual average of 1.5% until 2020, stabilize net emissions as of 2020, and reduce net emissions by 50% until 2050 compared to 2005 levels (ATAG, 2017).

In order to meet these ambitious targets, IATA has established a four-pillar strategy based on (1) fuel-efficient aircraft technologies, (2) efficient flight operations, (3) improved airspace and airport infrastructure, and (4) market-based instruments. A large contribution to emissions reduction is expected to come from the implementation of fuel-efficient airframe and engine technologies through the introduction of modern aircraft by the continuous fleet renewal process (IATA, 2013). The latest generation of aircraft offers technological improvements (geared turbofan, use of composite materials), which allow for significant fuel burn and therefore CO_2 emission reductions of up to 15% with respect to the previous aircraft generation. However, these technology improvements generally take a long time to percolate into the fleet in sufficiently large numbers to generate a relevant system-level impact due to the long use phase of aircraft (Cansino and Román, 2017). An early replacement of a sufficient number of aircraft would mean a substantial economic burden for airlines due to the high investments required. In addition, the adoption of new aircraft is limited to their production rate and can therefore only take place slowly. For the above-mentioned reasons, the existing emission reduction potential of the new aircraft generation will not be fully exploited unless fleet

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renewal is stimulated or alternative measures are applied.

Retrofits at the existing fleet can be a viable alternative to early replacement of aircraft in order to modernize fleets and reduce emissions in a short to medium timeframe. Several technologies that have recently been introduced can also be retrofitted into in-service aircraft. Hereby, fuel burn reductions of 5–12% can be realized (IATA, 2013). Blended winglets, for instance, which were introduced for the Airbus A320 in 2012, allow for fuel burn reductions of up to 4%. Since retrofits do only require small investments and can generally be carried out during maintenance checks, thus eliminating the need for leasing an aircraft during that time, they can make a significant contribution to achieving short term emission targets at reasonable costs (Schäfer et al., 2016).

Against this background, it is the objective of this paper to assess the impact of CO_2 emission constraints on airlines' fleet planning decisions with a special focus on the contribution of retrofit options. In particular, we examine the following questions: (1) What is the impact of different CO_2 emission thresholds on airline fleet planning? (2) To what extent can retrofit options contribute towards achieving CO_2 emission reductions in airline fleet planning? From this, recommendations on the deployment of retrofit programs and the appropriate design of CO_2 emission constraints in aviation are derived.

To answer the questions, we deploy a mixed-integer linear programming model that allows to study fleet planning decisions under different emission targets. Based on existing models for airline fleet planning from the literature, we develop a novel approach for fleet planning with CO_2 emission constraints under consideration of retrofit options for aircraft. We concentrate our analysis on two different airline types, namely a Full Service Network Carrier (FSNC) and a Low Cost Carrier (LCC). The FSNC offers flights in the short, medium, and long range with a diverse fleet (single-aisle, twin-aisle, and very large aircraft), whereas the LCC only offers flights in the short and medium range with a fleet composed of single-aisle aircraft. Four retrofit options, namely blended winglets, electric taxiing, cabin weight reduction, and re-engining are considered for certain aircraft types (especially Airbus A320 family). For the purpose of our analysis, we set the planning horizon to 10 years.

Our contribution is twofold. First, the application of the developed model allows for gaining a better understanding of the economic impact of different CO_2 emission thresholds on the evolution of airlines' fleet composition. This facilitates the formulation of suitable CO_2 emission constraints for decision makers from policy and supports airlines in their strategic investment decisions. Second, we extend existing optimization models for airline fleet planning to integrate retrofit options. This also holds true for fleet planning models from other industries (e.g., bus fleets for public transportation (Simms et al., 1984), truck fleets in the truck-rental industry (Wu et al., 2005), rail car fleets for freight transportation (Kallrath et al., 2017) or container ship fleets of liner shipping companies (Pantuso et al., 2016)).

The remainder of the paper is organized as follows: after the introduction, we briefly summarize the relevant literature in Section 2 and describe retrofit options for aircraft that are already available or will become available soon in Section 3. In Section 4, we describe the methodology and data used. The results of the analysis are presented and discussed in Section 5. Finally, recommendations for decision makers from industry and policy are derived in Section 6.

2. Literature review

Decisions on fleet renewal and modernization are part of airline fleet planning where the development of fleet size and composition over time is determined. To gain a better understanding of fleet planning decisions of airlines, diverse optimization techniques such as linear and dynamic programming have received increasing attention in the literature. New (1975) and Schick and Stroup (1981) develop and apply first linear programming models for airline fleet planning, which minimize the net present value of the cash flows for operating the aircraft in the fleet by deciding on the timing of investment and disposal of aircraft. Bazargan and Hartman (2012) present an extended model for this problem taking into account leasing of aircraft and Hsu et al. (2011) analyze the impact of demand fluctuations on the share of leased aircraft in the fleet. Khoo and Teoh (2014) and Rosskopf et al. (2014) present first models for airline fleet planning where not only economic but also environmental objectives are considered. To this end, Khoo and Teoh (2014) develop an indicator which measures the environmental performance of an airline including CO_2 emissions, noise emissions, and fuel efficiency. A bi-objective dynamic programming model is developed to maximize environmental performance and operational profit of an airline. Similarly, Rosskopf et al. (2014) develop a bi-objective linear programming model that balances the minimization of NO_x emissions with the maximization of the airline's asset value at the end of the planning horizon.

These studies are a valuable first step towards understanding the costs for airlines to mitigate emissions but possess two main limitations. First, these models do not consider retrofit options on the existing fleet and thus neglect a significant potential to reduce CO_2 emissions. Second, while the studies demonstrate the trade-off between economic and environmental objectives, they do not allow for an analysis of the impact of CO_2 emission constraints on airline fleet planning. This, however, is of utmost importance when discussing and setting up emission targets for aviation. The potential for and the costs of mitigating CO_2 emissions on an individual airline-level are mainly shaped by decisions made in airline fleet planning. Without a solid understanding of the interdependencies between emission constraints and the potential and costs of available mitigation options for the airline fleet, realistic and at the same time demanding emission levels for aviation cannot be identified.

3. Retrofit options

Aircraft are operated for a long time while the operational environment is changing steadily, e.g., due to new regulations or increasing fuel prices. Thus, older aircraft can often not fully comply with new regulations or be operated economically under changing conditions. To overcome this issue, new technologies are retrofitted into existing aircraft in order to improve the performance (Jesse et al., 2012; Schäfer et al., 2016). This section gives an overview of different retrofit options that can be applied in order to reduce fuel consumption and thereby CO_2 emissions of aircraft.

3.1. Blended winglets

Blended winglets are angled extensions installed at the wingtip of certain aircraft to reduce induced drag caused by airflow patterns over the wingtip. This improves fuel efficiency and thereby reduces emissions (The Flying Engineer, 2013). Boeing began to make winglets available in 2001 for business jets and the B737-800. Although blended winglets increase structural weight, the aerodynamic improvements result in net fuel burn reductions of 2–4% for a B737-800 depending on the stage length (Aviation Partners Boeing, 2017; Freitag and Schulze, 2009). In 2012, Airbus also introduced blended winglets under the name "Sharklets" with the first production unit of its A320ceo (current engine option). Compared to the traditional A320, blended winglets allow for fuel savings of 3.5% over stage lengths greater than 6500 km and approximately 1% for stage lengths of around 1000 km (Cansino and Román, 2017). Given the average single-aisle aircraft operating in 2015 without winglets, a fuel burn reduction of 3% translates into fuel savings of 83,000 gallons per year (Schäfer et al., 2016) or annual cost savings of about $108,000 assuming the 2016 jet fuel price of $1.31 per gallon (U.S. Energy Information Administration, 2017). Since jet fuel prices are expected to increase again, the cost benefits will be even higher in the future.

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