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Noise and emission targeted economic trade-off for next generation single-aisle aircraft

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A B S T R A C T

A methodology focusing on the evaluation of noise and emission specific direct operating cost components for future aircraft concepts is presented and applied to compare a geared turbofan versus an open rotor powered single-aisle aircraft. High uncertainties in the future development of airline environmental regulations, restrictions and charges complicate the noise and emission related evaluation of new aircraft. The implementation concept is based on the combination of classical procedures for economic aircraft evaluation with scenario techniques.

1. Introduction

Whereas aircraft noise and local air quality associated with air transport have been regulated for many years, CO_2 emissions are in the process of standard development and regulation. Noise related airport charges are increasingly widespread and supplementary landing charges for gaseous emissions have already been established in Germany, Switzerland, Sweden, UK and elsewhere, measuring local air quality in terms of NO_x and HC emissions. The integration of aircraft CO_2 emissions in the EU emissions trading system only came into effect in 2012. The challenge is that there may be conflicts when trying to limit noise and gaseous emissions at the same time, as well as for the optimal development of both policies.

Although open rotor engines will likely produce significant fuel savings, noise levels are unlikely to be reduced compared to current turbofan powered aircraft. In addition to the technical issues, there are economic considerations, and while it may be, for example, economically viable to reduce one environmental impact it may involve heavy expenditures to contain the other. This paper evaluates the merits of alternative aircraft with regard to noise and CO_2 emissions looking at two future aircraft concepts using geared turbofans (GTF) and open rotor (OR) engines.

2. Approach

It is often challenging to assess the implications of major new technologies when, as with aircraft, long economic life-cycles are involved and when the technologies are continually being developed and refined. Added to this, *ex ante* assessments are inevitably based on assumptions on background conditions regarding such things as competing technologies, changing economic and regulatory environments as well as shifts in social preferences. In these conditions, the standard approach is to make use of scenario analysis.

Here we focus on the implications for aircraft direct operating costs as listed in Table 1 of adopting alternative technologies. To estimate fuel and emission trading costs the Eurocontrol Base of Aircraft DAta (BADA) aircraft performance model is adopted (Eurocontrol, 2010).

The fuel consumed by an aircraft flying a specific route allows fuel costs (C_{Fuel}) to be estimated based on market kerosene prices. The CO_2 emissions $(D_P)_{CO_2}$ are derived by multiplying the fuel amount with the emission factor 3.15 (European Commission, 2009). ETS cost are the product of CO_2 emissions, the CO_2 allowance price C_{CO_2} and the percentage of free emission certificates (f_{ETS}).

$$C_{Fuel} = \text{Fuel} \cdot \text{FP} \tag{1}$$

$$(D_P)_{CO_2} = \text{Fuel} \cdot 3.15 \tag{2}$$

$$C_{ETS} = (D_P)_{CO_2} \cdot C_{CO_2} \cdot (1 - f_{ETS}) \tag{3}$$

The noise-related charging system proposed in the EU Directive COM (200) 683 is used as a generic noise charge substitution model (European Commission, 2002). A differentiation of noise values during takeoff and landing is available as is the potential for adjustment for the differences in pricing levels for diverse arrival times. By varying the threshold noise values T_a and T_d, individual

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Table 1
Evaluation criteria and influencing aircraft parameters.

Evaluation criterion	Main aircraft parameters influencing the criterion
Aircraft cost of ownership	Aircraft utilization, flight speed
Fuel cost	Engine and aerodynamic efficiency, mass, flight speed
Emission trading cost	Engine and aerodynamic efficiency, mass, flight speed
Noise cost	Aircraft noise certification value
Local emission cost	Engine emission indices

noise nuisances associated with operating aircraft fleet mixes are taken into account.

$$C_{\text{Noise}} = C_U \cdot \left(10^{\frac{L_a - T_a}{10}} + 10^{\frac{L_d - T_d}{10}}\right) \cdot f_{\text{noise}} \tag{4}$$

where: L_a and L_d are the ICAO certified noise levels for arrival and departures.[1] T_a and T_d are noise thresholds at departures and at arrivals corresponding to categories of relatively quiet aircraft using an airport, and are fixed at 16 dB below the upper thresholds corresponding to 95% of the noise energy emitted at the airport. The methodology is not used for specific airports but for each Official Airline Guide (OAG) region. f_{noise} is the percentage of landings affect by noise charges in each region. The unit noise charge C_U of the generic noise charge function is derived using three-dimensional regression analysis. Because actual noise charges differ not only by region but also by individual airport, this enables the calculation of an average noise C_U including airport and aircraft weightings for a selected region.

For the assessment of the introduction of emission-related charging systems, the European Civil Aviation Conference's (2001) ERLIG model is applied to the majority of emission charges levied airports in Europe.

$$C_{\text{Emission}} = (D_P)_{NO_x} \cdot C_U \cdot f_{\text{emission}} \tag{5}$$

The emission charge is based on the amount of NO_x during a defined landing and takeoff cycle, an average unit charge C_U, and f_{emission} as the percentage of landings affected by emission charges in each region. Table 2 summarizes the status quo with the generic charge models derived for each OAG region. The charging model cannot be used unconditionally for individual airports but is more a model for the generic calculation of the average environmental charges incurred in a region. For the EU region different function parameters are derived for day, evening and night, but this is not done for other regions because their environmental charges do not differentiate between day and night.

The cost of aircraft ownership (COO) is the sum of depreciation, interest and insurance costs. Depreciation costs are a function of utilization, U, and block speed, v_{Block}, and are normalized to Euros per passenger nautical mile. Because utilization may be influenced by regional noise restrictions, such as night curfews, the cost of aircraft of ownership is also indirectly dependent on the noise level. Depreciation, interest and insurance cost are impacted by specific factors f as well as the depreciation time $t_{\text{Depreciation}}$. Typical values can be found in Clark (2001).

$$\text{COO} = \frac{C_{\text{Investment}}}{U \cdot v_{\text{Block}}} \cdot \left(\frac{f_{\text{Depreciation}}}{t_{\text{Depreciation}}} + f_{\text{Interest}} + f_{\text{Insurance}}\right) \tag{6}$$

[1] Ld is the arithmetic mean of the sideline and takeoff noise certification level.

Fuel prices, CO_2 allowance prices, as well as aircraft emission restrictions and charges will vary according to the constraints and opportunities provided by the external environment. Workshops embracing internal and external experts from stakeholders in the aviation industry (original equipment manufacturer, airport, airline, air traffic management) were used to support the scenario analysis.

The "Baseline Scenario" in Table 3 is based on economic and air transport development assumptions published in *Boeing Current Market Outlook 2010–2029*. The "Between green and growth" scenario represents a world with much stricter aircraft environmental policies leading to a regional constraint of air traffic growth. The "Rapid Aviation Growth" scenario, on the other hand, has higher growth rates than the baseline, but with enhanced technology underpinning environmental policies. The time frame for the analysis is to 2030.

2.1. Storyboard "Baseline Scenario"

After recovery from the recession of 2008–2010, the global economy gains momentum, albeit with fluctuations, at an average of about 3.2% p.a. driven in particular by the BRIC countries. The increased use of alternative energy provides more secure long-term energy supply, although with periodic speculation resulting in volatility in fuel prices. Airfares increase slightly because of higher demand. Continued economic growth puts pressure on resources, and man-made climate change is not stabilizing. Although new technologies help to increase efficiency, carbon-neutral aviation growth is still not reached by 2020. These developments lead to an increasing environmental awareness regarding noise and emission. Politicians are under pressure to develop policies that will slow and eventually stop climate change, but have not been fully implemented, due to the economic interests of industries and countries, and especially the BRIC nations, and the pressures of the aviation sector. Where implemented, regional regulations are fragmented, making them politically and ecologically not as efficient as intended, leading to only modest increases in internalization of aviation environmental impacts. Continued pressure for commercial efficiency of air traffic management and ground handling, however, does produce some significant increases in fuel efficiency.

2.2. Storyboard "Between Green & Growth"

As with the baseline case, after recovery from the recession, the global economy gains momentum at an average global growth of about 3.2% p.a. mainly driven by the BRIC countries. But in this case, growing awareness of aviation's contribution to climate change as well as an increasing sensibility toward noise and local emissions result in increased public pressure concerning the environment and increasingly environmental conscious travel behavior, especially in the private sector. Politicians financially support environmental motivated RT&D especially involving stationary energy and increasing levels of environmental related taxes and command-and-control measures forces industry to invest in green products and technologies. The aviation industry responds by adopting new technologies that are particularly effective for a global industry as the world adopts more standardized approaches to environmental policy, including emissions trading. The incentive is to investments in low emission aircraft, and if possible quieter ones as more airports introduce noise quota systems and curfews. These trends result in a constrained aviation growth, especially in Europe, North America and the Asia/Pacific region. Major efficiency improvements, particularly in the stationary sector and ground based transport in combination with a carbon neutral aviation growth,