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Airport emissions reductions from reduced thrust takeoff operations

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ABSTRACT

Given forecast aviation growth, many airports are predicted to reach capacity and require expansion. However, pressure to meet air quality regulations emphasises the importance of efficient ground-level aircraft activities to facilitate growth. Operational strategies such as reducing engine thrust setting at takeoff can reduce fuel consumption and pollutant emissions; however, quantification of the benefits and consistency of its use have been limited by data restrictions. Using 3336 high-resolution flight data records, this paper analyses the impact of reduced thrust takeoff at London Heathrow. Results indicate that using reduced thrust takeoff reduces fuel consumption, nitrogen oxides (NO_X) and black carbon (BC) emissions by 1.0–23.2%, 10.7–47.7%, and 49.0–71.7% respectively, depending on aircraft-engine combinations relative to 100% thrust takeoff. Variability in thrust settings for the same aircraft-engine combination and dependence on takeoff weight (TOW) is quantified. Consequently, aircraft-engine specific optimum takeoff thrust settings that minimise fuel consumption and pollutant emissions for different aircraft TOWs are presented. Further reductions of 1.9%, 5.8% and 6.5% for fuel consumption, NO_X and BC emissions could be achieved, equating to reductions of approximately 0.4%, 3.5% and 3.3% in total ground level fuel consumption, NO_X and BC emissions. These results quantify the contribution that reduced thrust operations offer towards achieving industry environmental targets and air quality compliance, and imply that the current implementation of reduced thrust takeoff at Heathrow is near optimal, considering operational and safety constraints.

1. Introduction

1.1. Context

The rapid growth of global aviation in recent years is widely forecast to continue at an average annual rate of 5% (Boeing, 2014; Masiol and Harrison, 2014). This has led to concerns regarding the capacity of many components of the air traffic system, including the airport (Gelhausen et al., 2013). Several international hub airports, including London's Heathrow, are currently described as being effectively 'full' (DfT, 2013) and many more are expected to reach maximum capacity by 2030 (Weiszer et al., 2015). However, proposals for UK airport expansion, to meet both current and future demand, are increasingly constrained on the grounds of adverse environmental impacts (Mahashabde et al., 2011); consequently airport

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operations are subject to increasing scrutiny (Airports Commission, 2015; Simonetti et al., 2015). Airport operations emit pollutants deemed harmful to human health including nitrogen oxides (NO_X), black carbon (BC), hydrocarbons (HC) and carbon monoxide (CO) (Lee et al., 2009) and these contribute considerably to the degradation of local air quality (LAQ) (Yim et al., 2013). For example, air quality around London Heathrow currently exceeds EU limit values for NO_X (Masiol and Harrison, 2015), and it has estimated that airport operations contribute to 27% and up to 15% of annual mean NO_X concentrations at the airport boundary and 2–3 km downwind, respectively (Carslaw et al., 2012). Of all the airport pollutant emission sources, expected additional local air pollution from increased landing and takeoff (LTO) operations is of primary concern for many airports (Levy et al., 2012; Masiol and Harrison, 2014). Other sources are either outside the direct influence of airport operators, such as road traffic, or contribute relatively small amounts of pollutant emissions, such as ground support equipment (GSE). Consequently, aircraft operators face increasing pressure to adopt lower-emitting LTO operations to enable continued traffic growth within environmental limits (Heathrow Airport Ltd., 2010). Furthermore, at the European regulatory level, the Single European Sky Air Traffic Management Research (SESAR) has emphasised the importance of reducing aviation-related local emissions. As a high-level target, SESAR seeks to achieve an improvement in LTO cycle fuel efficiency of 2.8% per flight through the optimisation 3D aircraft trajectories (latitude, longitude and altitude) by 2020 (SESAR, 2012). Furthermore, SESAR states that solutions towards improving aviation efficiency must have no negative impact on air quality (SESAR, 2015).

Recent studies have sought to model aircraft LTO emissions and quantify the benefits of adopting reduced pollutant-emitting operations, primarily during taxiing activities. Weiszer et al. (2015) applied a holistic optimisation framework to several airside ground movement elements to minimise fuel consumption and identified reductions of between 19 and 31%, however they did not consider variability in takeoff thrust setting. Ravizza et al. (2013) identified a fuel consumption difference of 1.2% when optimising aircraft taxi activities for taxi time or fuel consumption efficiency. Simonetti et al. (2015) quantified an increase in pollutant emissions from additional takeoff activity (90% for NO_X) due to a theoretical runway redevelopment and a 40% increase in air traffic at Amerigo Vespucci airport, however the planned expansion caused a relative reduction in aircraft taxi emissions. Without empirical data, assumptions regarding aircraft operations including engine thrust setting and the duration of different LTO phases, referred to as time-in-mode (TIM), are often required. These assumptions tend to be simplified versions of reality, such as the International Civil Aviation Organisation (ICAO) LTO reference cycle (ICAO, 2011), and consequently inaccurately represent operations and fail to acknowledge airport operating constraints (Kurniawan and Khardi, 2011), which in turn reduces the applicability of such research to aircraft operators. Weiszer et al. (2015) explicitly referred to their model's inability to deal with airport operational uncertainty (for example due to weather conditions and external delays) and real-time scheduling as research limitations, which compromised their results with regards to optimisation planning. These factors are mitigated through the use of recorded data. For example, Khadilkar and Balakrishnan (2012) used flight data records (FDRs) to show that taxi fuel consumption was significantly dependent on the number of acceleration events and that using recorded operational data improved fuel consumption; fuel flow estimates using the ICAO method over predicted fuel burn by up to 35% compared to the FDRs.

At London Heathrow, the takeoff roll is responsible for approximately 22% of total ground level fuel consumption and CO_2 emissions, 60% of NO_X emissions and 50% of BC emissions (Stettler et al., 2011). Furthermore, Carslaw et al. (2012) states that airport-related emissions account for 23% of NO_X measured at receptor locations near London Heathrow (13.5 $\mu g/m^3$). Reduced thrust takeoff is an operation intended to reduce this through the adoption of less-than-maximum thrust settings during the takeoff roll. The rates of engine fuel consumption are reduced at lower engine thrust settings. Since the mass of CO_2 emitted per kg of fuel burned, referred to as the emissions index (EI), is constant dependent on the hydrogen to carbon ratio(approximately 3160 g/kg for aviation fuel) (Stettler et al., 2011), CO_2 emissions are reduced in line with fuel consumption. NOx and BC emissions may be reduced to a greater degree as the EIs for these pollutants generally increase non-linearly with increasing engine thrust setting (King and Waitz, 2005; Timko et al., 2010a,b). Reduced thrust takeoff also reduces engine wear (Chenghong, 2002). The thrust setting chosen by the pilot is dependent on several factors, of which aircraft takeoff weight (TOW) is the most critical (FAA, 2014; Suchkov et al., 2003). The relationship between thrust and TOW will alter the aircraft takeoff roll trajectory (e.g. TIM, rate of acceleration, required speed at lift off) in addition to the fuel flow rate and EI of the aircraft engines. Quantification of the benefit of reduced thrust takeoff has been limited by the aforementioned data restrictions and inadequate modelling methodologies (Romano et al., 1999). Furthermore, the extent and consistency to which reduced thrust takeoff is used in practice, has not been well characterised.

1.2. Research objectives

In the light of the above discussion, this paper aims to quantify the potential benefits for fuel consumption, NO_X and BC emissions enabled by the consistent adoption of reduced thrust takeoff for six commonly used aircraft-engine combinations at London Heathrow, which could improve ambient air quality around the airport. Aircraft TOW, fuel consumption, NO_X and BC emissions are modelled using high-resolution (1 Hz) FDRs for 3336 aircraft takeoff rolls. The objectives of this paper are to (i) quantify the observed reduction in fuel consumption and NO_X emissions due to the adoption of reduced thrust takeoff, relative to 100% thrust at takeoff, (ii) analyse the relationship between thrust setting and aircraft TOW in order to quantify the distribution of engine thrust settings adopted for different aircraft-engine combinations; (iii) identify the engine thrust setting corresponding to the minimum fuel consumption and emissions for different TOWs and different aircraft-engine