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Investigating actual landing and takeoff operations for time-in-mode, fuel and emissions parameters on domestic routes in Turkey

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ABSTRACT

Operational landing and takeoff standards developed by the International Civil Aviation Organization (ICAO) in the 1970s, have been widely-used in fuel consumption and emissions models or inventory studies. However, these generic standards may cause significant uncertainties due to changes in the air transport system over time and appear to remain highly conservative. To quantify the uncertainty caused by using generic operational standards, in this study, the effects of actual fuel flow and time-in-mode of more than 9000 different domestic flights, performed by five different narrow-bodied aircraft models with seven different engine, on the averages of landing and takeoff fuel burn and emissions are investigated. Compared to the simple approach, suggested by the ICAO, results indicate considerably lower time in mode averages, particularly during taxi-out (42%) and climb (45%) phases, even for high traffic volume airports. The greatest differences in fuel flow are observed during takeoff and approach phases. As a result of using actual time-in-mode and fuel flow data, the actual landing and takeoff fuel burn averages are found to be 35% lower than ICAO values. In addition, the effects of low altitude level flight on approach phase fuel flow, thrust reverser mode on taxi-in phase fuel flow, and stop and acceleration of aircraft on taxi ways on fuel flow are discussed. With regard to emissions, using actual time-in-mode and fuel flow data, landing and takeoff cycle hydrocarbon and carbon monoxide emissions are found to be 34% lower, while nitrogen oxide emissions are found to be 38% lower than those given by the ICAO database. Analyses related to the effects of aircraft mass on emissions indicate that the differences for carbon monoxide and nitrogen oxides between the lightest and heaviest aircraft are 3% and −26%, respectively. The analyses results reveal that uncertainties in landing and takeoff fuel burn and emissions caused by considering ICAO time-in-modes can be significantly higher compared to those caused by considering ICAO fuel flow standards.

Abbreviations: TIM, time-in-modes; FF, fuel flow; LTO, landing and takeoff cycle; ICAO, International Civil Aviation Organization.

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1. Introduction

Regarding airport emissions inventory studies, there have been several approaches, varying in the level of detail and accuracy of the aircraft, engine and emissions data. Using more specific data, uncertainty decreases, yet attainability is compromised.

The International Civil Aviation Organization (ICAO) emissions databank, with its fuel and emissions assumptions, has been one of the most comprehensive references for many emission studies. These studies generally require a number of tasks and assumptions, the performance of all of which is generally not possible by one study group and requires close collaboration between groups. In addition, in most cases, particular data, specific results or assumptions agreed by the wider research community are required. At this point, the ICAO emissions database exists as one of the most reliable data sources in terms of fuel flow (FF), fuel consumption, emission indices (EI) for regular emissions, time-in-mode (TIM) for landing and takeoff phases (LTO), engine power at these LTO phases, and so on. The FF parameter shows the fuel flow rate of the engine in kg/s and is measured by a transmitter located downstream of the fuel metering valve of the engine. It is a function of engine power, ambient conditions and engine bleed load. The EI can be defined as aircraft gaseous emissions in grams per kg of fuel. Since the FF value or the fuel air ratio in the combustion chamber changes with engine power, and thereby the flight phases, the EI values may be different for different flight phases. There are three main types of gaseous emissions, namely, unburned hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxides (NO_x). TIM can be defined as the duration of each flight phase in terms of minutes and greatly varies depending on traffic, airport characteristics or aircraft type.

In numerous studies, the ICAO emissions database is considered as one of the main contributors when finding desired economical or environmental indicators related to aircraft engines, such as the following: global inventory studies (Eyers et al., 2004; Kim et al., 2005); local inventory studies (Watterson et al., 2004; Pham et al., 2010; Fan et al., 2012; Song and Shon, 2012); airport emission analysis (Herndon et al., 2004, 2006; Unal et al., 2005; Kesgin, 2006; Schürmann et al., 2007; Elbir, 2008); ultrafine particulate matter measurements (Westerdahl et al., 2008; Hsu et al., 2012, 2013); PM measurements (Kinsey et al., 2010; Mazaheri et al., 2011; Lobo et al., 2012); emissions as a function of engine power and fuel composition (Anderson et al., 2006) and fuel flow (Wey et al., 2006); efficiency scores of airports (Martini et al., 2013); social cost of airports (Lu, 2011); air dispersion models (Farias and ApSimon, 2006); impact of capacity constraint at airports (Evans and Schäfer, 2011); and tradeoff possibilities for contrail reduction (Chen et al., 2012). However, as reported in a number of studies, using the ICAO emissions database in research might lead to overestimations (Carlier and Smith, 2004; Farias and ApSimon, 2006; Patterson et al., 2009; Song and Shon, 2012) or underestimations (Schäfer et al., 2003; Turgut et al., 2015).

To begin with, each tested engine has a single FF for each LTO phase and, combining a constant TIM, it has a single LTO fuel burn. Uncertainties caused by this basic assumption are stressed in various studies (O'Brien and Wade, 2003; Filippone, 2008; Herndon et al., 2009; Pham et al., 2010). Of these, Patterson et al. investigated the actual flight data records (FDR) of various aircraft and compared them to the basic standards of the ICAO for departure and arrival profiles, reporting that the total fuel burn for both departures and arrivals is overestimated by ICAO standards (Patterson et al., 2009). Carlier and Smith (2004) compare ICAO FF values and found that the FF of certain aircraft-engine combinations can be both underestimated and overestimated. Similar results have been reported by other researchers. For instance, the actual taxi TIM was found to be significantly lower than at the ICAO at Brisbane airport (Mazaheri et al., 2011). At Chicago O'Hare International Airport, taxi-in, taxi-out and approach TIMs agree well with ICAO standards, whereas climb-out TIM was found to be one minute lower (Rice, 2003). Chatterji (2011) addresses the difference in FF between actual and ICAO standards for aircraft climb and descent procedures, while others address the variations to differences in test bench setups and consideration of the new engines in the ICAO's basic standards (Patterson et al., 2009). Khadilkar and Balakrishnan (2012) developed a taxi fuel burn model based on numerous FDR considering input parameters related to stops and acceleration of aircraft during turning maneuvers.

Secondly, engine condition or deterioration are not considered since only new engines were tested for certification purposes. For instance, the ICAO itself reports that deterioration can affect fuel consumption and NO_x emissions by +3%, while no effect is reported observing CO, HC and smoke number (ICAO, 2013). Of other studies, Lukachko and Waitz (1997) report that the impact of deterioration, at only the compressor or only the turbine on EI NO_x may be different. They also note that deterioration at only the compressor can increase the EI NO_x, while only in the turbine can decrease the EI NO_x, yet the overall effect of deterioration on the EI NO_x can be −1% to 4%. Heland and Schafer (1998) report that engine-to-engine and day-to-day variations may cause differences in emissions production or the measurement of overall air-traffic emissions. Regarding the state of the engine, Lobo et al. (2012) studied particulate matter (PM) values of known commercial aircraft and found that early technology engines can produce as much as three times higher PM at the takeoff phase than that of newer engines. Aging effects have been partially addressed as a reason for the difference between the study results and the ICAO values elsewhere (Herndon et al., 2004; Anderson et al., 2006).

Apart from these drawbacks, it should be noted that the main function of the ICAO emissions database is to certify engines in accordance with requirements associated to environmental protection regulations. In other words, the ICAO emissions database was not established to investigate the environmental or climate impact of aviation in a research manner. However,