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Detailed estimation of fuel consumption and emissions during aircraft taxi operations at Dallas/Fort Worth International Airport

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ABSTRACT

This paper presents a detailed estimation of fuel consumption and emissions during taxi operations using aircraft position data from actual operations at Dallas/Fort Worth International Airport. Making assumptions of the thrust level during each state, fuel flow and emission index values from International Civil Aviation Organization's databank are extrapolated. This provides a relative comparison of all the taxi phases and their contribution to the total effect. Analysis reveals that stop-and-go situations, resulting primarily from congestion on airport's taxiway system, account for approximately 18% of fuel consumed. The states of idling and taxiing at constant speed or braking were found to be the two largest sources of fuel burn and emissions, and the model estimates are sensitive to the thrust level assumptions for these states.

1. Introduction

Efficient planning of airport surface operations is one of the goals identified in research towards the Next Generation Air Transportation System (NextGen) in the US (Joint Planning and Development Office, 2007). As a part of this research, considerable effort has been put into the capacity and delay aspects of planning, but with little quantification of environmental effects. Taxi operations, however, are often the largest source of emissions in a standard landing take-off (LTO) cycle around airports, but many studies that focus on aircraft emissions on the airport surface (Levine and Gao, 2007; Simaiakis and Balakrishnan, 2009) assume an average value for fuel flow during taxi without explicitly accounting for fuel consumption during idling, accelerating from a stop position, etc. We address this gap by developing a method for detailed estimation, and applying it to the Dallas/Fort Worth International Airport (DFW) as a case study.

2. Methodology

The estimation of fuel consumption and pollutants emitted on the airport's taxiway system is done in four steps:

1. Using detailed surface operations data, calculate the amount of time each aircraft spent on the taxiway partitioned in four states (stopping, turning, accelerating, moving at constant speed or braking).
2. Assuming a certain thrust level during each of the four states, extrapolate fuel flow values from International Civil Aviation Organization (ICAO)'s databank.
3. Multiply fuel flows with time spent in each state to give the estimate of fuel consumed by each aircraft.

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4. Multiply the fuel burn estimates with emission indices, corrected for atmospheric conditions at DFW, to compute the amount of pollutants emitted per aircraft.

2.1. Use of positioning data

The ASDE-X database provides detailed position data information about each flight that arrived or departed from DFW. Processing this data with the Surface Operations Data Analysis and Adaptation (SODAA) tool[1] yields information about aircraft type, time from spot to runway threshold, number of stops during taxi, duration of each stops, and number of turns on taxiway. The data processing is very similar to that done in Kistler and Gupta (2009).

The aircraft position data, however, does not provide the time spent in acceleration after a stop and in perpendicular turns; it just provides a count for such events. To address this, an average duration of 8 s is assumed for acceleration after a stop, consisting of 4 s to overcome inertia and 4 s to reach taxi speed. Additionally, 6 s are assumed as the average duration for a perpendicular turn throttle setting. As a result, the time each aircraft spent on the taxiway can be partitioned into four parts:

1. Time stopped.
2. Time accelerating.
3. Time turning.
4. Time taxiing at constant speed or braking.

While the aircraft type for every arrival and departure is included in the data, the engine type installed on each aircraft is not. To use the ICAO Databank's for fuel flow values and emission indices, each aircraft was mapped to a single engine type.[2]

2.2. Thrust level assumptions

Although the ICAO's databank assumes an aggregate 7% of take-off thrust for all operations on the ground, Wood et al. (2009), DuBois and Paynter (2006) and others argue "true ground idle" is approximately 4%. Further, 'breakaway thrust', accelerating from stop, has been found as high as 9% in a study by British Airways (Morris, 2005). Estimates of engine thrust levels for "taxi at constant speed or deceleration" and "turning," however, are not readily available. Assuming the taxiing thrust level to be slightly higher than idle thrust and turning thrust to be slightly lower than breakaway thrust, 5% and 7% are used as taxiing and turning thrust levels respectively.

2.3. Extrapolating ICAO values to analyze different taxi phases

In estimating aircraft emissions, the engine performance models for each aircraft would ideally be used. Such data, however, is usually proprietary. The need for publicly available aircraft performance data has led to development of engine emissions inventories, which provide fuel flows and emission indices as a function of engine thrust. The two widely used inventories are the Aircraft Engine Emission Databank, developed and maintained by the International Civil Aviation Organization (1995), and the Base of Aircraft Data (BADA), developed and maintained by the Eurocontrol Experimental Centre (Eurocontrol, 2004). The latter is used in estimating fuel consumption as a function of thrust and airspeed primarily for the airborne phase; using it for calculating aircraft fuel consumption on the ground may not be meaningful.

The ICAO Databank is based on engine performance and emissions data obtained from full-scale engine tests at sea level. For the vast majority of jet and turbofan commercial engines, it provides values of fuel flow (kg/s) and emission indices (g of pollutant emitted per kg of fuel burnt) taken at 7%, 30%, 85% and 100% rated outputs. The pollutants included in the Databank are HC, CO, and NO_x.

Each aircraft's surface trajectory is decomposed into four states: stop, accelerating after stop, turning, taxi at constant speed or braking, thus giving the fuel consumed by aircraft i from the spot until the runway threshold as:

$$TF_i = \sum_{m=1}^{4} t_{m,i} \cdot f_{m,i} \tag{1}$$

where TF_i is the fuel consumed from spot to runway threshold from aircraft i, $t_{m,i}$ is the time spent from aircraft i on state m, and $f_{m,i}$ is fuel flow while aircraft i is on state m.

Similarly, the amount of pollutants emitted by aircraft i is estimated as:

$$TE_i^p = \sum_{m=1}^{4} t_{m,i} \cdot f_{m,i} \cdot EI_{m,i}^p \tag{2}$$

[1] http://www.mosaicatm.com.

[2] For turboprops and piston aircraft, a representative jet engine was assigned.