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Comparison of emerging ground propulsion systems for electrified aircraft taxi operations

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ABSTRACT

Aviation is a mode with high fuel consumption per passenger mile and has significant environmental impacts. It is important to seek ways to reduce fuel consumption by the aviation sector, but it is difficult to improve fuel efficiency during the en-route cruise phase of flight because of technology barriers, safety requirements, and the mode of operations of air transportation. Recent efforts have emphasized the development of innovative Aircraft Ground Propulsion Systems (AGPS) for electrified aircraft taxi operations. These new technologies are expected to significantly reduce aircraft ground-movement-related fuel burn and emissions. This study compares various emerging AGPS systems and presents a comprehensive review on the merits and demerits of each system, followed with the local environmental impacts assessment of these systems. Using operational data for the 10 busiest U.S. airports, a comparison of environmental impacts is performed for four kinds of AGPS: conventional, single engine-on, external, and on-board systems. The results show that there are tradeoffs in fuel and emissions among these emerging technologies. On-board system shows the best performance in the emission reduction, while external system shows the least fuel burn. Compared to single-engine scenario, external AGPS shows the reduction of HC and CO emissions but the increase of NO_x emission. When a general indicator is considered, on-board AGPS shows the best potential of reducing local environmental impacts. The benefit-cost analysis shows that both external and on-board systems are worth being implemented and the on-board system appeals to be more beneficial.

1. Introduction

Fuel cost represents about 32% of the airline industry's operations budget, the second highest expense after labor (Jordan, 2013). According to the statistics from the International Aviation Transport Association (IATA), the airline industry spent $209 billion on fuel in 2012, which was $33 billion higher than in 2011. The industry is expected to pay an additional $7 billion in 2013 (IATA, 2013a). Despite the easing of fuel prices in recent weeks, the airline industry remains concerned with high and volatile fuel prices. IATA launched a Fuel Action Campaign to assist airlines with mitigating the impact of rising fuel prices. One way of doing that is to encourage airlines to improve their operating efficiencies, such as opening new and more direct routes, realigning inefficient routes, and improving ground traffic flows (IATA, 2013b). Another method that has been implemented to reduce fuel consumption and noise is Continuous Descent Approach (CDA) (Cao et al., 2011; Zhao et al., 2013). Instead of approaching an airport in a stair-step fashion, throttling down, and requesting permission to descend to

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each new (lower) altitude, CDA allows for a smooth, constant-angle descent to landing and consumes less fuel than conventional descent. Nevertheless, more innovative ways are needed to further alleviate the dependence of airlines on fuel prices.

Flight phases can be categorized into two major parts: en-route cruise and Landing and Take Off cycle (LTO). It is especially difficult to reduce jet fuels in en-route cruise because environmental and economic aspects must yield to safety rules. Safety regulations require aircraft to carry fuel beyond the minimum needed to fly from origin to destination to allow for unforeseen circumstances or for diversion to another airport if the planned destination turns unavailable. Furthermore, under the supervision of air traffic control, aircraft flying in controlled airspace must follow predetermined routes known as airways, even if such routes are not as economical as a more direct flight (Khurana, 2009). Since it is much harder to control fuel consumption in the en-route cruise of flight, researchers and practitioners are beginning to seek fuel-economic control strategies for aircraft ground movement during LTO. LTO includes all activities near the airport that take place below the altitude of 3000 feet (1000 m), which consists of taxiing out, taking off, and climbing out for departures, and descending, touching down, and taxiing-in for arrivals, as illustrated in Fig. 1. Besides the aforementioned CDA, which has been implemented at many U.S. airports, another innovative solution is to apply other power resources for aircraft taxiing on airport surface.

During LTO, aircraft fuel consumption and emission amounts vary by aircraft operation phases (e.g., taxi-in phase, taxi-out phase, take-off and landing phase) and depend on the time spent at each phase. Taxiing is the movement of an aircraft on the ground using taxiways between the terminal gate and runway. Conventional taxiing-out usually includes push-back and engine-on taxiing. Pushback is a procedure during which an aircraft is pushed backwards away from an airport gate. Traditionally, pushbacks are carried out by special, low-profile vehicles called pushback tractors or tugs, or by the aircraft itself with engines on. Currently, an aircraft moves under its own power during most of taxi-out phase and the entire taxi-in phase. At low power settings during the current taxiing mode, combustion aircraft engines operate at lower fuel efficiency than at cruise power settings and generate a host of emissions at airports and adjacent areas.

From the system operational point of view, the taxi-out time of a departure flight is measured as the time difference between its gate-out time and wheel-off time, which include unimpeded taxi-out time and additional taxi-out time (called taxi-out delay) (Zhang and Wang, 2011a). Literature has shown the trend of the taxiing delay in recent years (a 21% taxi-out time increase was reported from 1995 to 2007 in the U.S.) and ways of benchmarking airport taxiing performance (Glover and Ball, 2013; Kuhn, 2013; Zhang and Wang, 2011b; Zhang et al., 2012). Overall, after controlling for air traffic demand and other inputs, U.S. airports shows longer taxiing time compared to their counterparts in Europe. Year 2007 is known as a high delay year in the U.S. air industry. Table 1 shows the 10 airports with the longest average taxi-out times in 2007 in the U.S. (Goldberg and Chesser, 2008). Taxiing time is not negligible compared to overall flight time; aircraft are estimated to spend 10–30% of their flight time taxiing in Europe (Deonandan and Balakrishnan, 2010). Elongated taxiing times lead to excessive fuel burn and emissions, which not only worsen the financial situation of airlines, but also the emissions from aircraft taxiing that escapes into the local environment and leads to public health concerns. Compared with other flight phases, the excess fuel burn during taxiing out in the U.S is estimated to be 165 lbs. (75 kg) per flight, accounting for about 26% of fuel savings among the estimated benefit pool actionable by Air Navigation Service (USDOT, 2013).

To reduce fuel consumption and emissions of aircraft surface movement at airports, innovative control strategies and technologies of fuel-efficient taxiing have emerged in recent years. There are two primary approaches to mitigating aircraft fuel usage and emissions for taxiing at airport surface. One is to develop a more ecofriendly operational procedure, such as single-engine taxiing (Deonandan and Balakrishnan, 2010; Airbus Customer Services, 2004; Heathrow Airport, 2012 and Gubisch, 2013a), Pushback Rate Control (PRC) (Simaiakis et al., 2011), Collaborative Departure Queue Management (CDQM) (Brinton et al., 2011), Spot and Runway Departure Advisor (SARDA) (Hoang et al., 2011) and so on. The other involves the development of aircraft technologies such as engineless taxiing, fuel-efficient engine design, and alternative jet fuels (Re, 2012b). Such improvements require significant technology breakthroughs and capital investment, among which engineless taxiing with innovative Aircraft Ground Propulsion Systems (AGPS) has shown the most promising progress and could be ready in the very near future (Gubisch, 2013a,b; Cleansky, 2013; WSJ, 2013).

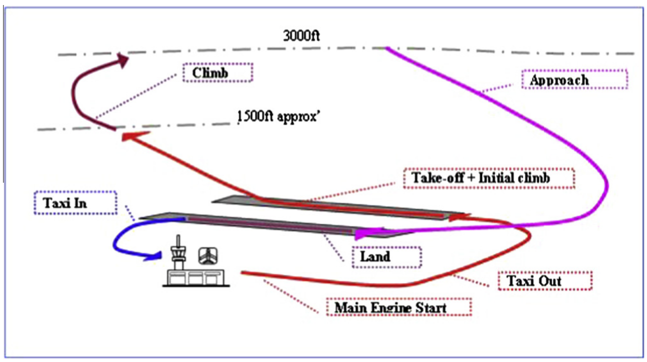

Fig. 1. Landing and take-off cycle at airport (*photo by Eurocontrol*).