REDUCING AIRPORT SURFACE OPERATION ENVIRONMENTAL IMPACTS

By Hamsa Balakrishnan and R. John Hansman

Flight delays and aircraft taxiing contribute significantly to fuel burn and emissions. AeroAstro researchers are seeking ways to reduce these problems.

Greenhouse gas emissions are a significant and increasing concern for the aviation industry, which contributes 2-3 percent of total manmade emissions, and accounts for about 12 percent of the transportation sector's fuel burn and emissions. In 2007, the 7.4 million U.S. domestic passenger flights were responsible for 142.1 million metric tons of carbon dioxide emissions. Air traffic demand is rapidly increasing and there is growing regulatory and societal pressure to mitigate aircraft noise and emissions.

Air traffic delays have traditionally been the primary concern of the airline industry. In 2007, domestic air traffic delays in the United States cost airlines more than $19 billion and had an estimated $41 billion impact on the nation's economy. Recently, there has been much focus on passengers confined to aircraft during long taxi delays (more than 1,500 flights in 2007 had taxi-out times greater than three hours, although there were only about 600 such flights in 2009), resulting in new Department of Transportation policies such as the Three-hour Tarmac Delay Rule, by which aircraft that do not return to the gate after three hours on the tarmac can incur fines of $27,500 per delayed passenger. A frequently overlooked fact is that flight delays, in addition to inconveniencing passengers and airlines, have a significant environmental cost. Domestic delays in 2007 consumed 740 million gallons of jet fuel and released 7.1 billion kilograms of carbon dioxide into the atmosphere — about 5 percent of the

An MIT team conducting research at Boston's Logan Airport is exploring how modifying ground operations could reduce aircraft fuel burn and engine emissions. Team members (from left) Tom Reynolds, Ioannis Simaiakis, John Hansman, Hamsa Balakrishnan, Harshad Khadilkar, and Diana Michalek use colored cards to suggest to air traffic controllers various rates at which they should allow aircraft to leave their gates. By optimizing this number, planes proceed efficiently with less time spent sitting on taxiways with engines running. (William Litant/MIT photo)

Visualizations of Boston Logan Airport surface surveillance data showing aircraft taxiing on the ground. Red icons denote arrivals and green icons denote departures. Researchers note the formation of queues at various locations on the surface, such as the aircraft waiting to cross an active runway on which an aircraft is coming in to land, and aircraft queuing by the side of the departure runway to await their turn to take off.

annual CO_2 emissions from domestic commercial aircraft. Because airborne delays are more expensive than ground delays, most delays (85 percent in 2007) occur on the ground. About 60 percent of the delays are at the gate before departure, while another 20 percent occur as aircraft are taxiing to the runway for takeoff.

TAXIING A MAJOR CONTRIBUTOR TO FUEL BURN, EMISSIONS

Taxiing aircraft contribute significantly to the fuel burn and emissions at airports. The quantities of fuel burned, as well as pollutants such as carbon dioxide, carbon monoxide, hydrocarbons, nitrogen oxides, sulfur oxides, and particulate matter, are proportional to the taxi times of aircraft, in combination with other factors such as the throttle settings, number of engines that are powered, and pilot and airline decisions regarding engine shutdowns during delays. In 2007, aircraft in the United States spent more than 63 million minutes taxiing to their gates, and more than 150 million minutes taxiing out from their gates. And, the number of flights with lengthy taxi-out times (e.g., more than 40 minutes) has increased. The trends are similar at major European airports, where it is estimated that aircraft spend 10-30 percent of their flight time taxiing, and that a short/medium range Airbus A320 aircraft expends as much as 5-10 percent of its fuel on the ground.

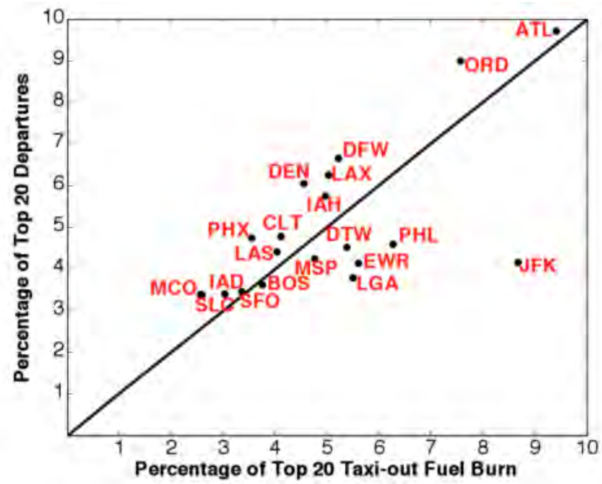
Domestic U.S. flights emit about 6 million metric tons of CO_2, 45,000 tons of CO, 8,000 tons of NO_x, and 4,000 tons of HC taxiing out for takeoff; almost half of these emissions are at the 20 most congested airports in the country. These pollutants contribute to low-altitude emissions, directly impact local nonattainment of air pollution standards, and represent a concern for human health and welfare. The severity of this problem varies from airport to airport, and is particularly acute in the congested New York area airports. Airport operational data analysis suggests that a significant portion of these emissions can be reduced through measures that limit airport surface congestion.

FUEL CONSERVATION ATTITUDES

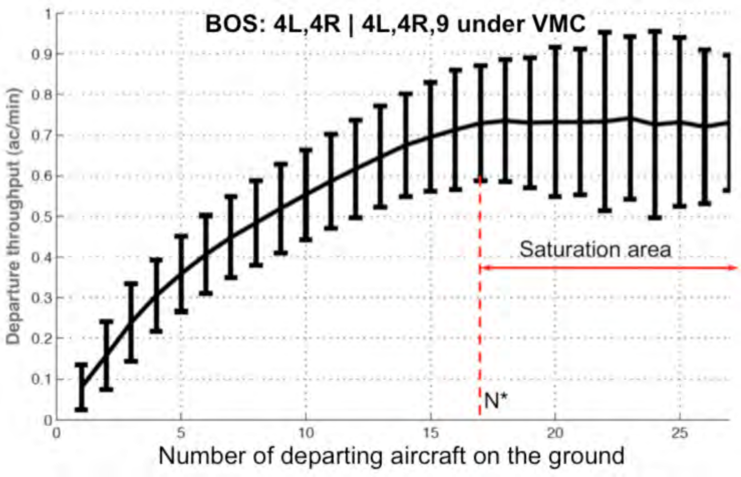
Given increasing fuel prices and concern about aviation-related environmental impacts, airlines have implemented practices to reduce fuel burn during ground operations. Such strategies include single-engine taxiing, minimizing aircraft auxiliary power unit use, controlling speed on the taxiway system, and holding aircraft at the gate during long delays.

Between August and December 2009, with the cooperation of the Massachusetts Port Authority, MIT AeroAstro researchers from the Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER), a nine-university research collaboration headquartered at MIT and sponsored by the FAA, surveyed airline pilots at Boston Logan International Airport to assess their attitudes towards fuel conservation during taxi operations and to document current fuel conservation practices, particularly single-engine taxi procedures.

This study found that the majority of pilots believe that fuel conservation is important; their motivation to conserve fuel is mainly driven by concerns about their airlines' economic viability, as well as the environmental impacts of aviation. The study also found that a majority of airlines appear to encourage single-engine taxi procedures as well as a variety of other fuel conservation measures. The survey found that single-engine taxi procedures were widely used on arrivals; 52 percent of pilots reported using them more than 75 percent of the time. They were infrequently used on departures; 54 percent of pilots reported using them less than 10 percent of the time. When pilots were asked whether they would be willing to wait at the gate if their position in



Plot depicting departure demand at the top 20 U.S. airports as a percentage of the total number of operations vs. the fuel burn as a percentage of the total departure taxi fuel burn.



Boston Logan Airport departure throughput as a function of the number of departures post-pushback. We note how the departure throughput initially increases, but saturates once the number of departures on the ground exceeds 17 aircraft. The vertical bars denote one standard deviation.

a takeoff queue could be guaranteed, a majority indicated a willingness to wait, suggesting that pushback control strategies, implemented correctly, have the potential to succeed in easing congestion and decreasing the environmental impacts of taxi operations.

REDUCING TAXI-OUT TIMES, FUEL BURN, EMISSIONS

At MIT, PARTNER is pursuing research on reducing taxi-out times, fuel burn, and emissions. The main motivation for our proposed approach to reduce taxi times is an observation of the performance of airport departure throughput. As more aircraft pushback from their gates onto the taxiway system, the throughput of the departure runway initially increases because more aircraft are available in the departure queue. However, as this number exceeds a threshold, the departure runway capacity becomes the limiting factor, and there is no additional increase in throughput. Any additional aircraft that pushback increase their taxi-out times, decrease the predictability of operations, and contribute to queues on the airport surface.

This phenomenon, in which the departure throughput saturates when the number of departures on the surface exceeds a threshold, is characteristic of congested airports, and suggests that limiting the buildup of queues on the airport surface by controlling the pushback times of aircraft could be a relatively simple way of decreasing taxi times and emissions. Using simulations of Logan Airport, we have estimated that if this policy were in effect during the most congested times of operation, flights during these periods would experience nearly a 20 percent decrease in taxi-out times. This benefit arises because flights taxiing during periods when the surface traffic exceeds this threshold experience long taxi times. Of course, there are practical challenges to overcome to achieve these benefits, such as the availability of gates, ATC workload, tug coordination, and passenger movement. Additionally, airline competitive factors such as on-time performance statistics, crew pay policies, and ground crew coordination pose significant challenges to surface movement optimization, and are being addressed in this project. As we go to press, we have just completed a reduced fuel burn and emissions demonstration at BOS, with the overall goal of initiating wider adoption of the methods throughout the United States. Early results from field tests, conducted between August 23 and September 23, 2010, show that during eight four-hour demonstration periods, more than 15,000 kg of fuel were saved, at the rate of 50-60 kg per gate-held flight. Moreover, these savings were achieved with average gate-hold times of only four minutes.

The problem of coordinating airport surface operations presents a range of exciting intellectual challenges that include understanding the cognitive processes of air traffic controllers, modeling the dynamics of various flows (both physical ones consisting of aircraft, as well as information flows between various components) using surface surveillance data, developing algorithms that determine the control strategies, and trading off the objectives and incentives of multiple stakeholders. But these challenges are accompanied by the wonderful opportunity to tackle some of the most critical problems being faced by air transportation today, and to significantly decrease the environmental impacts of airport operations.

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