OPERATIONAL IMPLICATIONS OF CRUISE SPEED REDUCTIONS FOR NEXT GENERATION FUEL EFFICIENT SUBSONIC AIRCRAFT

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Abstract

Future reductions of green house gas emissions from commercial aviation will, in part, be achieved through the development and use of more fuel-efficient aircraft. One approach which has the potential to yield significant fuel burn and emissions reductions is to open up the design space to consider slightly lower cruise speeds (on the order of 4 to 8%). This paper investigates the potential impacts of cruise speed reductions on airline operations and schedules as well as ways to mitigate these impacts. Using parametric network and schedule model, the results of sensitivity analyses to cruise speed reductions of 4 to 8% suggest that current schedule patterns could be maintained with limited operational changes (i.e. slight shift in departure time for 30 to 65% of flights by a few minutes corresponding to an overall lengthening of daily schedule of 5 to 25 min.). The magnitude of these changes indicated that fuel savings and emissions reductions could offset the adverse effects of reduced cruise speeds particularly if the effective cost of fuel or emissions increase in the future. The paper also investigates ways to mitigate these impacts. It was found that trading a few minutes of from padded schedules by mitigating airport and in-flight congestion or designing aircraft that allow shorter turnaround times could offset these impacts of cruise speed reduction.

1. Introduction

1.1 Motivation

Air transportation has proven critical to sustained economic growth regionally and globally, by providing fast and reliable access between travel points. Worldwide development in economic activity and a shift towards faster modes of travel resulted in tremendous growth of demand for commercial aviation. Historically, commercial aviation grew at a rate of 4.5 to 5% annually and numerous forecasts estimate that future growth is to be expected.

With demand for air transportation worldwide growing faster that improvements in marginal fuel efficiency improvements (i.e. 1.2 to 2.2% annually based on Bureau of Transportation Statistics data), the contribution of aviation to emissions and climate change relative to other sectors is projected to increase in the future. Fig. 1 shows the historical trend in CO_2 emissions (normalized to 2005) as well as the industry (i.e. IATA and ICAO) and U.S. goals for future CO_2 emissions [1]. As shown on Fig. 1, the International Airline Industry Association (IATA) aims at achieving carbon neutral growth of aviation by 2020 and a 50% reduction by 2050, relative to 2005 levels [2]. The International Civil Aviation Organization (ICAO) has adopted a target of a "global annual average fuel efficiency improvement of 2%" for the airline industry through 2020 [3]. In the United States, if the national goals established during the COP15 conference were to apply uniformly across all industry sectors, reductions of greenhouse gas emissions from aviation by 17% below 2005 levels by 2020 and 83% by 2050 would be necessary [4].

In addition, Fig. 1 also shows the 2010-2030 forecast of future fuel consumption (i.e. combustion CO_2 emissions) for the United States [5].

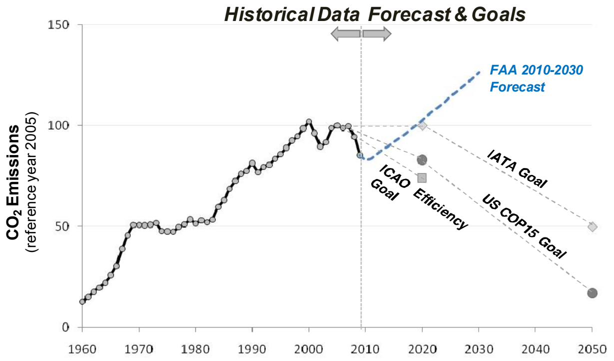

Fig. 1: Fuel Consumptions & CO_2 Emissions: Historical Data, Forecasts & Goals (Data sources: BTS [1], IATA [2], ICAO [3], FAA Forecast 2010-2030 [4]).

The contrast between this forecast and the long-term goals shows the magnitude of the challenge for aviation to reduce its green house gas emissions. Furthermore, any net increase of CO_2 emissions from aviation is likely to reinforce public and political pressure on the industry to reduce its environmental impacts.

There are several approaches to reducing these emissions; (1) aircraft design and technological efficiency improvements, (2) operational efficiency improvements, and (3) the use of alternative fuels. This paper focuses on the aircraft design and technology approach by expanding the aircraft design space to enable more efficient configurations and designs.

1.2 Emissions reduction potential from next generation aircraft designs

The current generation of commercial jet aircraft was generally designed for high cruise speeds. As the relative importance of fuel burn and emissions increases, non-traditional areas in the design space such as slightly lower cruise speeds may become attractive. At cruise Mach numbers around 0.72 un-swept configurations become feasible resulting in potential aerodynamic and structural advantages such as higher aspect ratio, slightly thicker airfoils with higher Lift-to-Drag ratios and less need for high lift devices. Lower cruise speed also may enable more efficient engine configurations.

1.3 Approach and paper outline

While the reduction in cruise speed may yield to fuel burn benefits, it also has a direct impact on the airlines' operations by lengthening the flight time, which also impacts crew (i.e. labor) time and cost.

In order to evaluate the impact of cruise speed reduction on airlines' schedules, a sensitivity analysis was performed using data from the Bureau of Transportation Statistics (BTS). This analysis was performed by computing the effects of gradual increases in cruise flight time for each flight contained in the itineraries flown by a set of representative aircraft. From these flight time changes, schedule conflicts between arriving and departing flights were identified and resolved by rescheduling flights to accommodate the increase in flight time of the previous flight. In order to assess the effects of various types of networks and schedules, the sensitivity analyses were performed for two types of networks/schedules; (1) a point-to-point network with tight schedule (i.e. with short turn-around times and limited slack), and (2) a hub and spoke type network with longer turnaround times and more slack. In addition, ways to mitigate these impacts were explored and are discussed.

This paper first presents some details and background information on potential advanced concepts for next generation of fuel-efficient commercial jets and the trade between cruise speed and fuel burn. It then presents the analysis of the potential impacts of cruise speed reduction on airline networks and schedules for two airlines (i.e. JetBlue's A320 network and American Airlines' MD80s network). The potential impacts of cruise speed reduction on airlines' operating economics are then discussed followed by a discussion on strategies for mitigating the operational impacts of cruise speed reductions.

2. Trade between Fuel Burn and Cruise Speed for Potential Advanced Concepts for Next Generation of Commercial Jets

2.1 Historical perspective on aircraft design choices

The current generation commercial jet aircraft were generally designed for high cruise speeds. Narrow body jets and wide body jets generally have long range cruise around M0.77 and M0.82 respectively. Recent generation of regional jets have comparable long range cruise speeds as narrow body jets. Fig. 2 depicts the historical evolution of cruise speeds (Long Range Cruise) as a function of year of Entry Into Service (EIS). The long-term trends of cruise speed for wide body, narrow body and regional jets point towards increase in speeds.

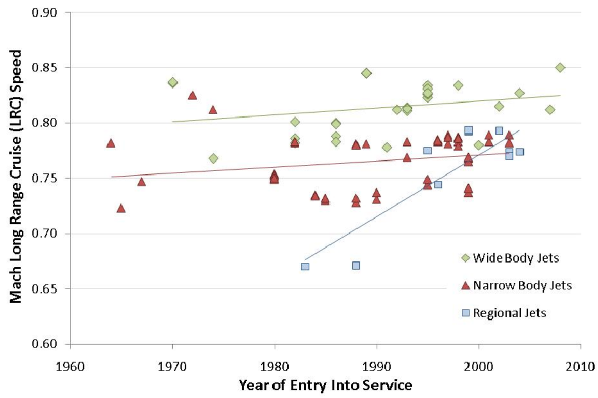

Fig. 2: Trends in cruise speed by type of aircraft (Data sources: Piano-X 2008 [6] and Jane's All the World Aircraft 2010 [7])

In order to operate at these high cruise speeds and reduce the effects of wave drag, the use of swept wings was required. For example, a narrow body aircraft such as the B737-800 that cruises at approximately M0.78 has a wing sweep angle of 25° (see Fig. 3). Wide body aircraft that tend to cruise faster e.g. M0.84 for the B777 have higher wing sweep angles (i.e. 32° for the B777).

A B747 that cruises at M0.88 has a sweep angle of 37°. On the other end of the spectrum, turboprops aircraft for which the cruise speed is limited to M0.4-0.5 -due to propeller wing tip speeds- generally do not need swept wings.

As the relative importance of fuel burn and emissions increases, non-traditional areas in the design space such as slightly lower cruise speeds may become attractive. At cruise Mach numbers around M0.72 un-swept configurations become feasible resulting in potential aerodynamic and structural advantages such as higher aspect ratio, slightly thicker airfoils with higher lift to drag ratios (L/D) and less need for high lift devices. Lower cruise speed also may enable more efficient engine configurations.

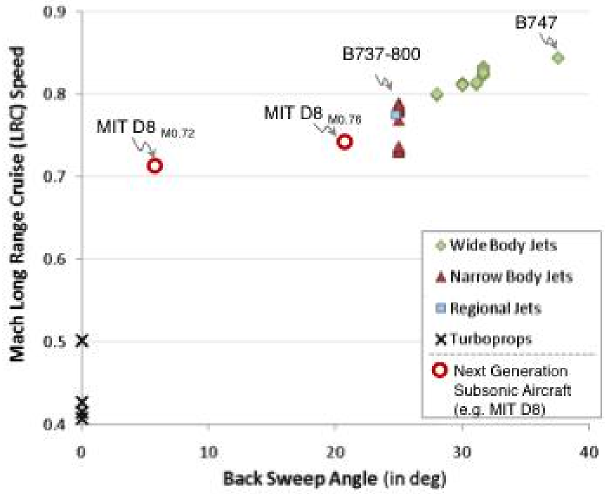

Fig. 3: Empirical Relationship between Mach Long Range Cruise Speed and Back Sweep Angle (Data sources: Piano-X 2008 [6] and Jane's All the World Aircraft 2010 [7])

A NASA's Fundamental Aeronautics Program investigated aircraft concepts that may enter into service in the 2030-2035 timeframe [8]. One of the common themes identified across all four aircraft concepts was slower cruising at about Mach 0.7, which is 5 percent to 10 percent slower than today's aircraft. At these speeds the proposed concepts were able to deliver significant fuel savings.

One of these aircraft concepts is MIT's D-Series (e.g. D8 "Double Bubble" Series) that consists of a double-bubble fuselage with lifting nose and a pi-tail and with boundary layer ingesting engines flush mounted at the rear of the fuselage and un-swept wing [9]. These changes to the configuration of the aircraft are expected to provide a 39% improvement in aircraft fuel intensity (originating from a decrease of 14% in structural weight, 38% increased of L/D and a reduction of engine TSFC of 6%). If in addition to configuration changes advanced technologies could be used.

This would generate an additional 41% of aircraft fuel intensity improvements.

Fig. 4 shows how opening up the design space to allow slightly slower cruise speed achieves significant fuel burn reductions compared to the previous and current generations of aircraft.

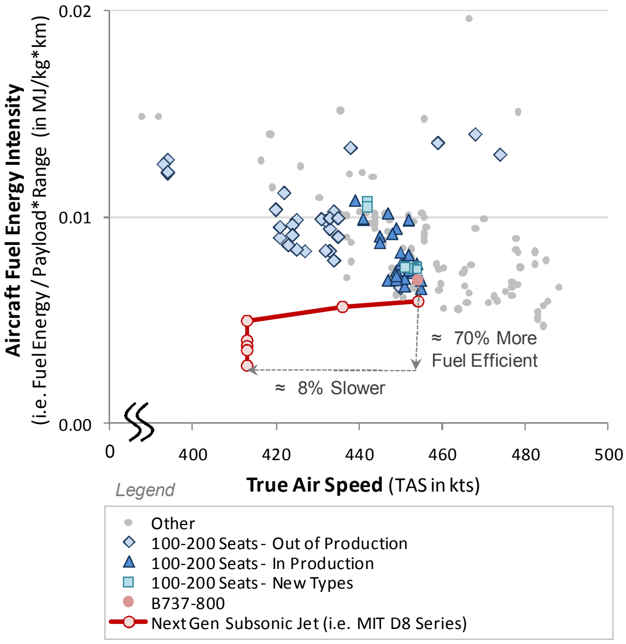

Fig. 4: Aircraft Fuel Energy Intensity vs. Cruise Speed (Data sources: Piano-X 2009 [6], Greitzer et al. 2010 [9])

3. Potential Impacts of Cruise Speed Reduction on Airline Schedules

3.1 Motivation and scope of applicability of cruise speed reduction approach

Changes in cruise speed only affect the cruise portion of flight profiles. As a result, the impact of cruise speed on the total trip time (i.e. defined as the block-to-block time plus the turnaround time) is a function of the stage length of the flight. Fig. 5 shows the sensitivity of total trip time to reductions (i.e. 8% corresponding to a reduction from a B737-800 Long Range Cruise of M0.78 to M0.72 which is the design speed of the MIT D8 Series) in cruise speed for a set of representative sample missions. As shown on Fig. 5, a reduction of 8% in the cruise speed on a 600 km flight segment yields to a 1.5 min. increase in total trip time (i.e. relative increase of 1.4%). As the stage length increases the trip time increases in absolute as well as relative terms. For long-range flights (e.g. 4000 km), a cruise speed reduction to M0.72 would yield to a 22 min. increase in total reduction (i.e. 6.2%). These flight time increase remain relatively minor for narrow body aircraft with missions below 4000km. Fig. 5 also shows the result of the sensitivity of trip time for a wide body aircraft (i.e. B777-300ER) flying a 13,000 km mission. In this case, the cruise speed reduction adds almost one hour of flight time. To limit absolute changes in flight time to reasonable amounts, it is believed that aircraft with lower cruise speed reductions are more likely to be accepted by the industry in the narrow body short to medium range segment of the market.

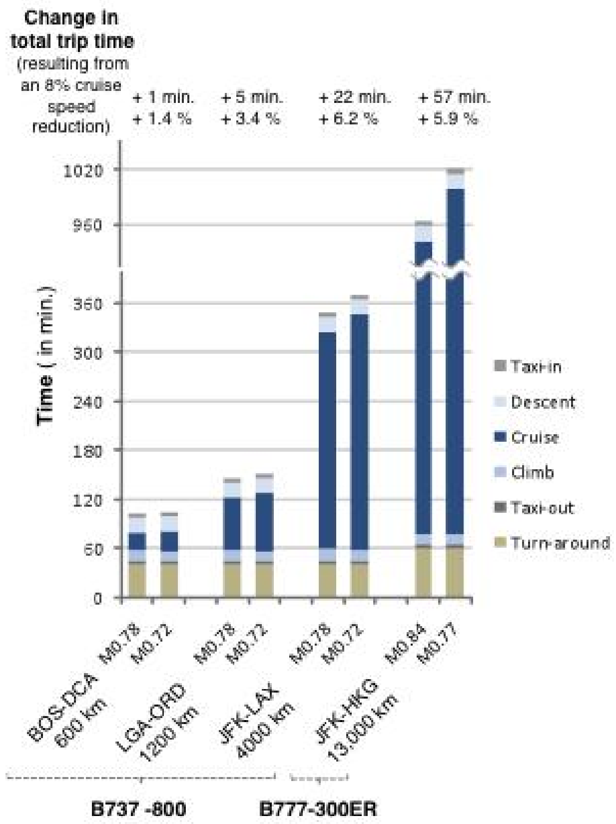

Fig. 5: Effect of Cruise Speed Reduction on Sample Missions (Data source: Piano-X 2009 [6])

As a result, the analyses of the implications of cruise speed reductions on airline networks have focused on network and schedules flown by short to medium range narrow body jets (i.e. 130-180 seat segment such as the B737s, A320s, MD80s, etc.).

3.2 Methodology

In order to evaluate the impact of cruise speed reduction on the schedules, a sensitivity analysis was performed using data from the Bureau of Transportation Statistics (BTS) [10].

First, the airlines' schedules were reconstructed based on individual flight information. This involved; (1) tracking flights by tail number, (2) constructing daily and then weekly sequences of flights (i.e. itineraries), (3) converting local times to GMT times to allow the computation of scheduled flight times and allow consistent schedule adjustments.

The sensitivity analysis was performed by computing the increase in cruise flight time for each flight contained in the itineraries. It was assumed that the cruise speed reduction would only affect the cruise phase of flight (i.e. excluding the climb and approach phases). A flight time adjustment algorithm was then used to generate modified schedules. Schedule conflicts between arriving and departing flights were identified and resolved by rescheduling flights to accommodate the increase in flight time of the previous flight. A sensitivity analysis was then performed to evaluate the effects of various scenarios of cruise speed reductions. For each of the simulations, a minimum turn-around time was set as a simulation parameter.

3.3 Characteristics of baseline networks and schedules

In order to evaluate the effects of cruise speed reductions on various types of airlines' operations, the schedule adjustment simulation model was applied to two types of schedules; (1) the American Airlines network flown by MD80s which is characteristic of a major network carrier that embeds a fair amount of slack time in its schedule and (2) the JetBlue A320 network which is characteristic of a low cost carrier tight network with high aircraft utilization, shorter turnaround time and less slack. Both schedules were constructed using data for a full week of operations from March 10th to 16th 2008.

Table 1 shows the details of the characteristics of airlines' networks, schedules and aircraft used for the sensitivity analyses. On average, the JetBlue network exhibits longer segments than the American Airlines (AA) network and therefore longer cruise portions that are affected by the cruise speed reductions. Logically, these longer segment distances translate into longer block-to-block times and air times. However, it appears that the difference between scheduled and actual times (block-to-block) is comparable between both networks. This is potentially indicative of similar schedule padding behaviors.

Table 1: Characteristics of Airlines' Networks, Schedules and Aircraft used for the Sensitivity Analysis (Data source: BTS [10])

	Airline	JetBlue	American Airlines
Network	Number of Flights	2908	4425
	Average Segment Distance (km)	1452	984
Schedule	Average Scheduled Block-Block Time (min.)	200	146
	Average Air Time (min.)	169	120
	Average Actual Block-Block Time (min.)	197	144
	Difference Actual vs. Scheduled Block Time	-1.6%	-1.5%
Aircraft Utilization	Aircraft Types	A320	MD-82
	Average Utilization (hr / day)	13 h 42	9 h 42
	Average Number of Flights (per aircraft per day)	4.1	4.0
	Average Air Speed (i.e. Distance/Air Time) (km/hr)	499	483
Aircraft Characteristics	Long Range Cruise Speed* (Mach)	0.78	0.75
	Percent Change in Speed to Reach M0.72	-7.8%	-4.3%
	Fuel Efficiency (kg fuel / ASK)	0.019	0.026

Note: *Designed Long Range Cruise Speed based on mission at maximum structural payload (MSP) and maximum range (R_1) at MSP. Data source: Piano-X [6].

The JetBlue network also exhibits significantly (i.e. +41%) higher aircraft utilization –measured in hour per day per aircraft-. This high utilization of the JetBlue fleet imposes bounds on the ability to stretch the schedules to accommodate the cruise speed reductions (see Section 3.4).

Both networks are also illustrative of the operations of two very different types of aircraft. The JetBlue network operates newer and faster aircraft (i.e. LRC=M0.78) compared to American Airlines' MD80s (that cruise at M0.75). The implications of this 4% cruise speed difference at the aircraft design level can be observed at the operational level by a 3.3% lower air speed (defined as segment distance/air time). This difference in aircraft cruise speed suggest that in order to reach M0.72 –which was the proposed design cruise speed for the MIT D8 Series- the aircraft from the JetBlue network would have to be slowed down by approximately 8% while the American Airlines aircraft would only need to slow down by 4%.

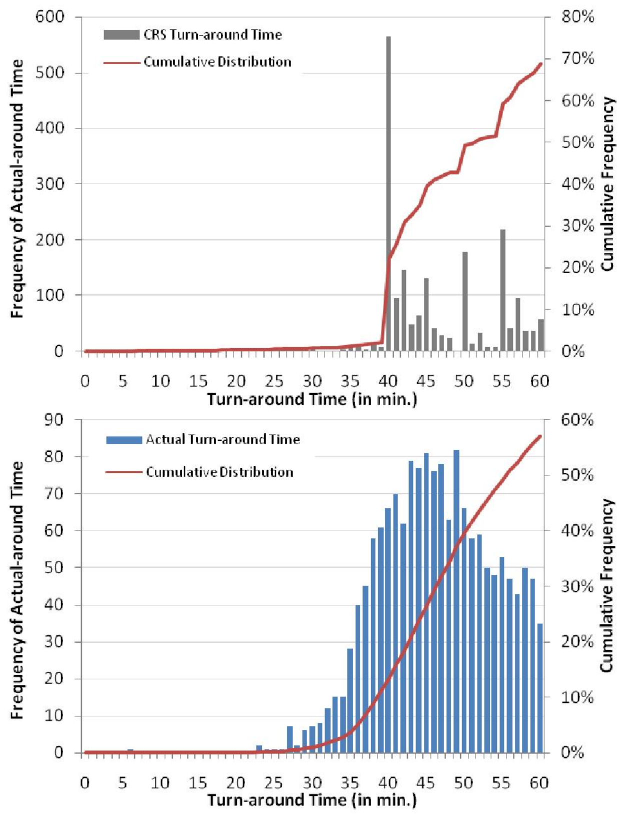

Fig. 6: Scheduled (CRS) Turn-around Time and Actual Turn-around Time for JetBlue Network (Data source: BTS [10])

With regard to the schedule characteristics, the JetBlue operations exhibited a scheduled turn-around time peak at 40 min. as shown on Fig. 6. This value of turnaround time and the distribution is indicative of a tight schedule.

On the opposite, the American Airlines MD80s scheduled turn-around time exhibited several peaks at 40, 45, 50, 55 and 60 min. As shown with the distribution on Fig. 7, this schedule has slightly more slack built into it.

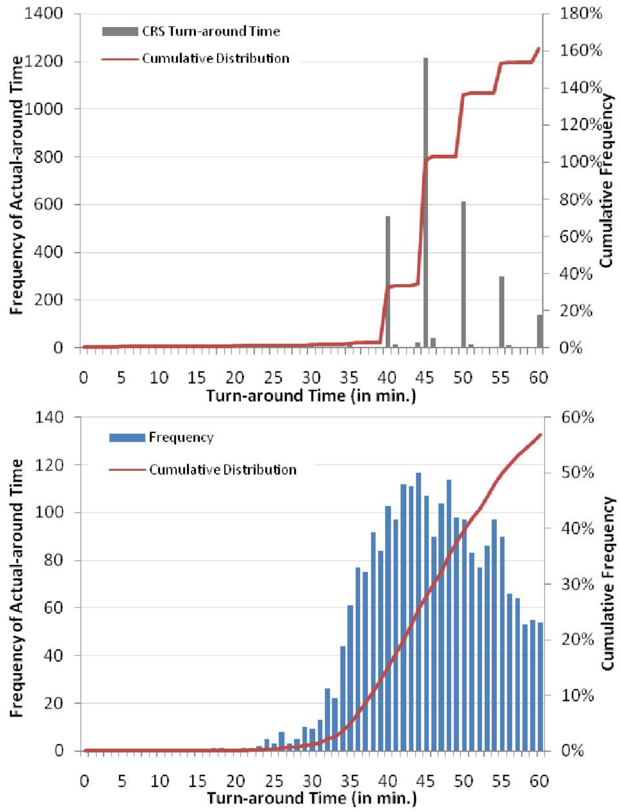

Fig. 7: Scheduled (CRS) Turn-around Time and Actual Turn-around Time for American Airlines Network (Data source: BTS [10])

3.4 Results of sensitivity analysis of schedules to cruise speed reductions

In order to evaluate the impacts of cruise speed reductions on airlines' schedules, a sensitivity analysis was performed for both schedules. Key impacts were tracked by computing the percentage of flights affected by a schedule conflict (i.e. the percentages of flights that needed to be shifted by a short amount of time due to the increase in flight time of the previous flight) and the average daily schedule shift required to accommodate these small schedule shifts.

Fig. 8 shows the results for the JetBlue A320 network and schedule. As shown, as the cruise speed reduces the number of flights affected by schedule conflicts increases. In addition, the schedule shift required to accommodate this change in cruise speed increases as well. The non-linear patterns are due to the specificities of the schedule (i.e. peaks in turnaround times). The figures also depict the impacts of assumptions of several minimum turn-around times in the event when rescheduling is required. The longer the minimum turn-around time, the more slack is permitted in the schedule. Allowing reduction in turn-around time increases the tightness of the schedule.

As shown on Fig. 8, a reduction of cruise speed by 8% from the current cruise speed, implies that the scheduled times of approximately 65% of the flights would have to be modified. However, the average daily schedule shift required to accommodate these speed changes is not significant when cumulated into a daily value.

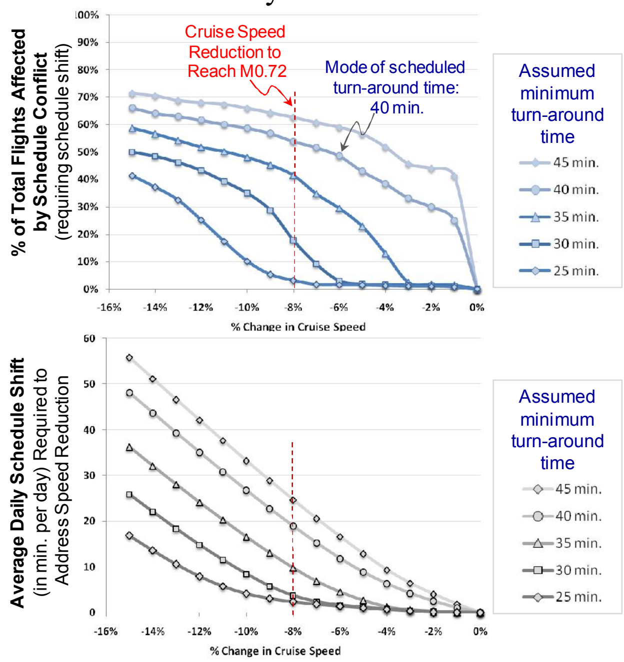

Fig. 8: Operational Impacts of Reduced Cruise Speed Cases of JetBlue A320 fleet

For the JetBlue network, this 8% cruise speed reduction would yield to a 24 min. cumulated shift. It should be noted that this schedule shift is an average value and that in some cases large schedule shifts combined with the high utilization of this fleet (see Table 1) could require some adjustment in the aircraft routing and tail number assignments.

While the JetBlue network illustrated the impacts of significant cruise speed reduction on a tight schedule with aircraft utilization, the impacts on a schedule such as the American Airlines MD80 are expected to be marginal. To reach M0.72 the American Airlines' MD80s schedule needs to be slowed down by only 4%. As shown on Fig. 9, a 4% reduction in cruise speed would impact 32% of the flights and impose an average of 5 min. of schedule shift (based on a 45 min. minimum turnaround time assumption).

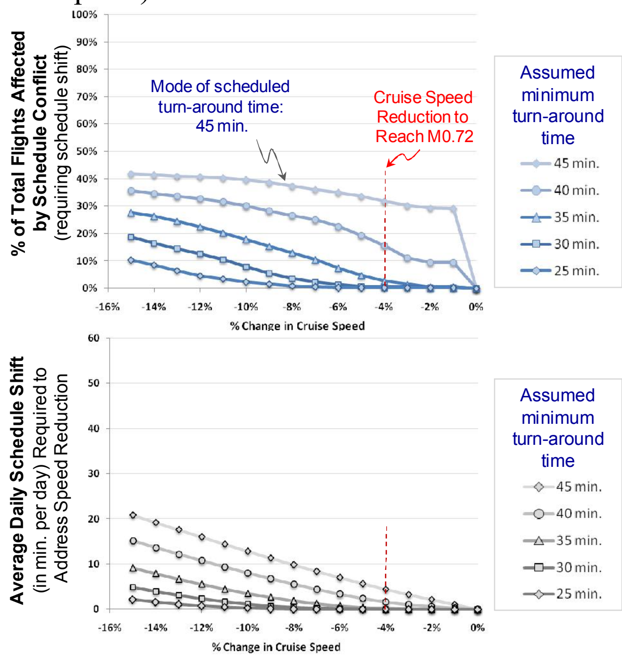

Fig. 9: Operational Impacts of Reduced Cruise Speed Cases of American MD80 fleet

As a result, from a purely schedule impact perspective, the required cruise speed reductions to reach M0.72 seem to be manageable with current airlines' schedules. These disadvantages also need to be evaluated in the perspective of fuel burn reductions and the associated airlines' economic impacts.

4. Potential Impacts of Cruise Speed Reduction on Airlines' Operating Economics

The economic evaluation of the costs and benefits of reducing the cruise speed such as increased crew costs, aircraft utilization, etc.

4.1 Airlines operating economics

Change in cruise speed affect a key trade between "time related costs" and "fuel related costs". Airlines have a long history of managing this trade at the operational level on a day-to-day basis [11]. Both the cost of fuel and the labor costs (that is a key component of the time related costs) vary over time. Fig. 10 shows the historical trends in cost of fuel and labor costs from 1971 to 2009 as well as their ratio also known as the cost index. Depending on the relative importance of both costs, airlines adjust the speed. When the cost index (i.e. ration of labor vs. fuel costs) is low (i.e. when fuel prices are high) speed is reduced closer to a fuel-efficient speed (i.e. Maximum Range Cruise) [11].

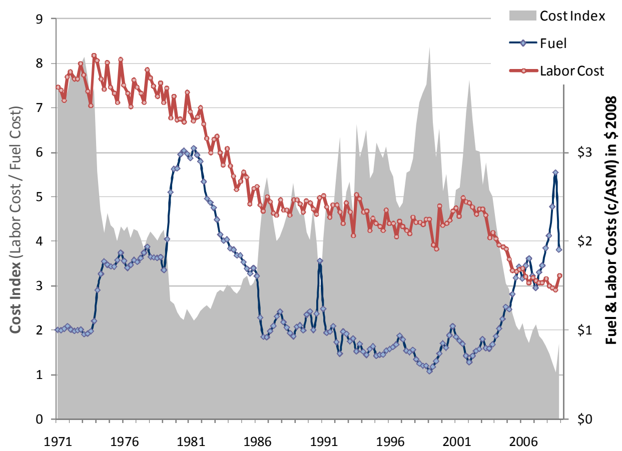

Fig. 10: Relative Cost of Fuel vs. Labor (i.e. Cost Index) from 1971 to 2009 (Data source: ATA 2010 [12])

As shown on Fig. 10, fuel costs have increased significantly over the past 5 to 10 years (i.e. peaked in July 2008). This results in fuel being the largest cost items on airlines' balance sheets. Fig. 11 shows the details and breakdown of the cost portion of U.S. airlines' balance sheet for Q3 2007 and 2008. In 2007, fuel cost and labor costs were the two largest cost items with equal relative importance. In 2008, when crude oil prices rose leading to an increase of Jet fuel prices, the fuel component of operating cost increased by 67% resulting in fuel cost being by far the largest cost item on airlines' balance sheets.

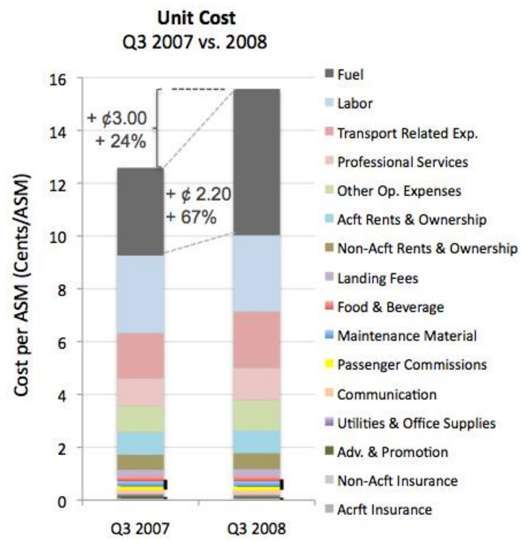

Fig. 11: Cost and Revenue per ASM (Excluding Taxes) - Q3 2007 and 2008 (Data source: ATA 2010 [13])

Due to demands for petroleum and its increasing cost of extraction and production, it is expected that the price of jet fuel will increase in the future. In addition, potential fuel taxes or cost from market-based mechanisms (e.g. Cap and Trade) will contribute to increase the effective cost of fuel. As a result, solutions that will improve the fuel efficiency of airlines' fleet will have a direct impact on their fuel fraction of their operating costs. The proposed technology solution (next generation fuel efficient aircraft e.g. MIT D8 Series) that can provide 50% fuel efficiency improvement in the medium term (and potentially 70% in the long term) would become an attractive proposition from an airline's operating cost perspective. Even if, in the worst-case scenario, this solution could result in an 8% increase in labor cost (due to cruise flight time lengthening), this impact would be marginal compared to a 50% to 70% reduction in fuel burn.

It should be noted that this discussion does not take into account the depreciation -related to the acquisition cost- given that there is no reliable cost estimate for these future products. However, it is believed that the net operating cost benefits would outweigh the relative depreciation costs.

5. Potential Strategies for Mitigating the Operational Impacts of Cruise Speed Reductions

While it was shown that slight decreases in cruise speed –that can yield to significant fuel burn and environmental improvements- have marginal impacts on airlines' schedules, several strategies can be envisioned to mitigate these impacts. The following section discusses several strategies based on interdependencies between aircraft design and operations as well as potential air transportation system modernization efforts that could help mitigate these impacts.

5.1 Mitigating airport capacity problem and reducing schedule padding dynamics

As shown on Fig. 12, delays in the US air transportation system have been increasing over time. Those reached a record level with 3.6 million minutes of delays in June 2008. Airport congestion was a key driver of the increase in national delays. New York's major airports also contribute for a significant part of the congestion problem with 30% of the national delays originating from three airports (i.e. LGA, EWR, JFK) in Q2 2008.

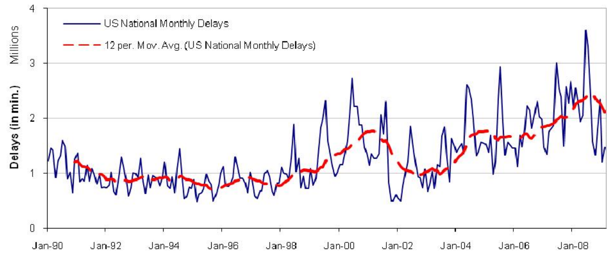

Fig. 12: U.S. National Delays (Data source: FAA Operational Network OPSNET [14])

Delays at key airports that propagate throughout the system impose operational/schedule uncertainty for airlines. As a response to these increases in delays, airlines' have "padded" their schedule by increasing the block-to-block time and building slack into their schedule. Fig. 13 shows how the scheduled block-to-block time evolved from 1996 to 2006 on the Houston (HOU) and Dallas (DAL) airport pair segment. Over ten years, the average block-to-block time has increased by approximately 8%.

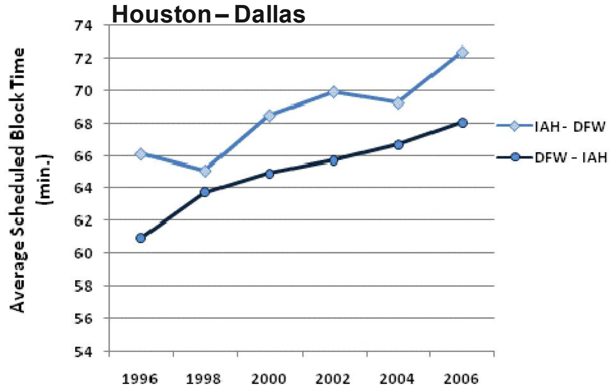

Fig. 13: Historical Evolution of Scheduled Block Time on the Houston Int. (IAH) to Dallas Fort Worth (DFW) market for the Month of April from 1996 to 2006 (Data source: BTS [15])

The extension of this analysis of historical evolution of block-to-block time to over 1950 origin-destination (OD) routes with uninterrupted service between 1996 and 2006 (that account for 76% of total passengers in the U.S. in 2006) suggested that on average the block-to-block time has increased by +0.5% per year.

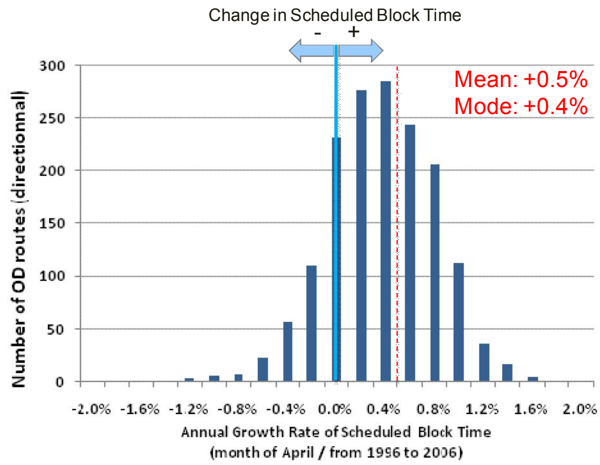

Fig. 14: Annual Growth Rate of Scheduled Block Time - top 1950 OD routes in the U.S. (Data source: BTS [15])

It is believed that if the airport congestion problem can be alleviated somewhat, through technology and operational improvements, a few minutes of delays and slack currently built into airlines' schedules could very well mitigate some part of the small increases in air time due to cruise speed reductions.

5.2 Reducing turn-around time through operational and technology strategies

While the previous strategy focused on improving the block-to-block phase of operations, other strategies that focus on improvements in the ground phase could be used. As suggested by the MIT team [9] and shown on Fig. 15, the particularity of the wide “double bubble” fuselage of the MIT D8 Series enables a twin aisle configuration. Properly sizing the aircraft door and exit to allow for an efficient flow of passengers in and out of the aircraft. This could reduce the aircraft boarding and de-boarding times.

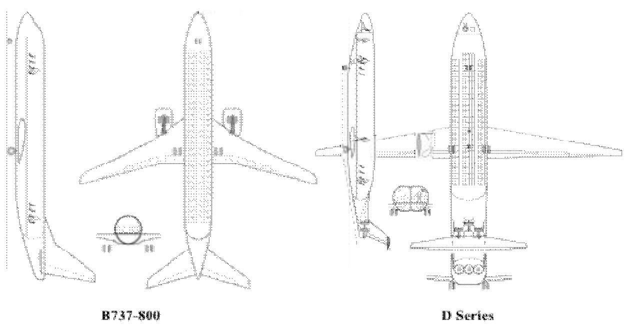

Fig. 15: 3D View of the B737-800 and the D8 Series (double-bubble) Configuration with 2010 Technology (Source: Greitzer et al. [9])

As shown on Fig. 6 and Fig. 7, select scheduled turnaround times peak around 35 to 40 min. and actual turnaround time are performed as little as 30 min. Assuming a combined de-boarding and boarding time of 20 min., if a twin aisle aircraft could cut by half this time (i.e. save 10 min. off the total turnaround times), whole or a fraction of the increase in block-to-block time due to cruise speed reductions could be mitigated. As shown on Fig. 5, a 10 min. decrease in turn-around could fully compensate the increase in block-to-block time for flights with stage lengths of 2000 km or less. It should be noted that these flights represent a significant fraction of all the commercial flights in the U.S. (i.e. average stage length of flights in the U.S. is approximately 1600km).

6. Summary and Conclusions

Future reductions of green house gas emissions from commercial aviation will, in part, be achieved through the development and use of more fuel-efficient aircraft. One approach which has the potential to yield significant fuel burn and emissions reductions is to open up the design space to consider slightly lower cruise speeds (on the order of 4 to 8%). One aircraft concept that would achieve have these performance characteristics is MIT’s D-Series (e.g. D8 “Double Bubble” Series) that consists of a double-bubble fuselage with lifting nose and a pi-tail and with boundary layer ingesting engines flush mounted at the rear of the fuselage and un-swept wing.

In order to evaluate the effects of cruise speed reductions on various types of airlines’ operations, the schedule adjustment simulation model was applied to two types of schedules; (1) the American Airlines network flown by MD80s which is characteristic of a major network carrier that embeds a fair amount of slack time in its schedule and (2) the JetBlue A320 network which is characteristic of a low cost carrier tight network with high aircraft utilization, shorter turnaround time and less slack.

Using parametric network and schedule models, the results of sensitivity analyses to cruise speed reductions of 4 to 8% suggest that current schedule patterns could be maintained with limited operational changes (i.e. slight shift in departure time for 30 to 65% of flights by a few minutes corresponding to an overall 5 to 25 min. lengthening of daily schedule). The magnitude of these changes indicated that fuel savings and emissions reductions could offset the adverse effects of reduced cruise speeds particularly if the effective cost of fuel or emissions increase in the future.

The paper also presented ways to mitigate these impacts. It is believed that if the airport congestion problem can be alleviated somewhat, through technology and operational improvements, a few minutes of delays and slack currently built into airlines’ schedules could very well mitigate some part of the small increases in air time due to cruise speed reductions. In addition, designing aircraft configuration (e.g. fuselage that can allow twin aisle configurations) could allow shorter turnaround time and offset the impacts of cruise speed reduction.

Acknowledgments

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