Project 015 Aircraft Operations Environmental Assessment: Cruise Altitude and Speed Optimization (CASO)

Massachusetts Institute of Technology

Project Lead Investigator

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University Participants

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- P.I.(s): Prof. R. John Hansman
- FAA Award Number: Lincoln Laboratory P.O. 7000213564
- Period of Performance: September 1, 2012 to June 30, 2017
- Task(s):
    1. Identify operations with high fuel reduction potential from CASO
    2. Present results and discuss operational considerations with stakeholders
    3. Develop set of recommended operating procedures to improve fuel performance in domestic operations through cruise altitude and speed optimization
    4. Extend analysis to specific long-haul operations
    5. Explore potential applications for CASO in NextGen concepts
    6. Support Lincoln Labs on refinements to Delayed Deceleration Approach analysis

Project Funding Level

Project Funding Level: MIT is performing as a subcontractor under Lincoln Laboratory which received FAA funding for this project. The MIT subcontract Award Value is $329,724.08 of which $313,196.18 has been released to MIT, and $18,527.90 is identified as Future Funding. No matching funds are required for this contract.

Investigation Team

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Henry Tran (Graduate Student)
Sarah Folse (Graduate Student)

Project Overview

This purpose of this project is to examine the potential fuel burn benefits of altitude and speed optimization in the cruise phase of flight for domestic operations in the United States and certain long-haul operations. In addition, the project aims to identify practical and implementable applications for CASO in NextGen concepts (cockpit, ATC, or dispatch).

Airlines can achieve cost reductions and mitigate environmental impact by making small modifications to the cruise phase operating condition. With coordination between air traffic controllers, pilots, and airline dispatchers, the efficiency of air transport activities can be improved. The first phase of this project built off prior work in this area to establish best-case benefits from cruise optimization. High-benefit operations and implementation considerations within the NAS were identified. In order to achieve these objectives, cruise-phase fuel burn estimation software was developed using publicly-available radar tracks and weather data. This estimator was used to examine over 200,000 flights from 2012 and 2015 for optimization potential, with additional follow-on analysis of more recent data from domestic and international operations.

The fuel efficiency of an aircraft at any point along its flight path is a function of weight, altitude, speed, wind, temperature, and other second-order effects. At a fixed weight, there exists a combination of speed and altitude at which instantaneous fuel efficiency is maximized, as shown in **Figure 1** for a typical widebody long-range airliner. For a full flight, this becomes an optimal sequence of speeds and altitudes to minimize fuel consumption [3]. The speed and altitude at which aircraft are actually flown may differ from this optimal point for a variety of operational and practical reasons. Integrated fuel consumption depends on effective trajectory planning in speed and altitude as well as in lateral flight path. Several examples in the literature demonstrate potential techniques and applications for single-flight trajectory optimization in lateral, vertical, and temporal dimensions (e.g. [4]–[11]). This project aims to perform retrospective analysis using single-flight optimization methods and develop potential operational applications.

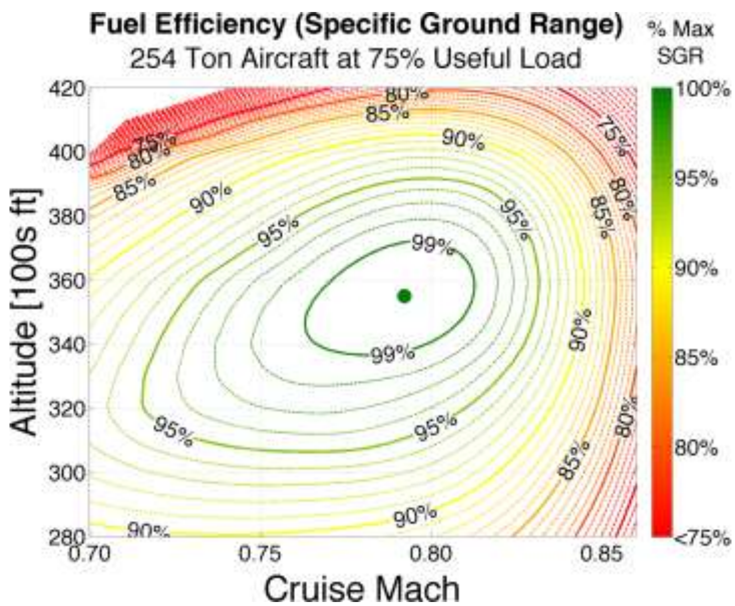

Figure 1. Instantaneous fuel efficiency of a typical long-haul aircraft at a fixed weight (calm winds, standard atmosphere)

This effort has recently focused on the development of a prototype decision support tool (DST) for use in pilot tactical enroute planning decisions. This DST incorporates feedback from multiple stakeholders including pilots, air traffic controllers, and airline dispatchers to provide timely and pertinent data to pilots pertaining to optimal altitudes and speeds, altitude planning, weather, and path change scenario testing. The DST prototype interface is shown in Figure 2**Error! Reference source not found.**. Next steps include further development, user refinement and testing of this tool as a means to realize benefits from CASO in an operational setting.

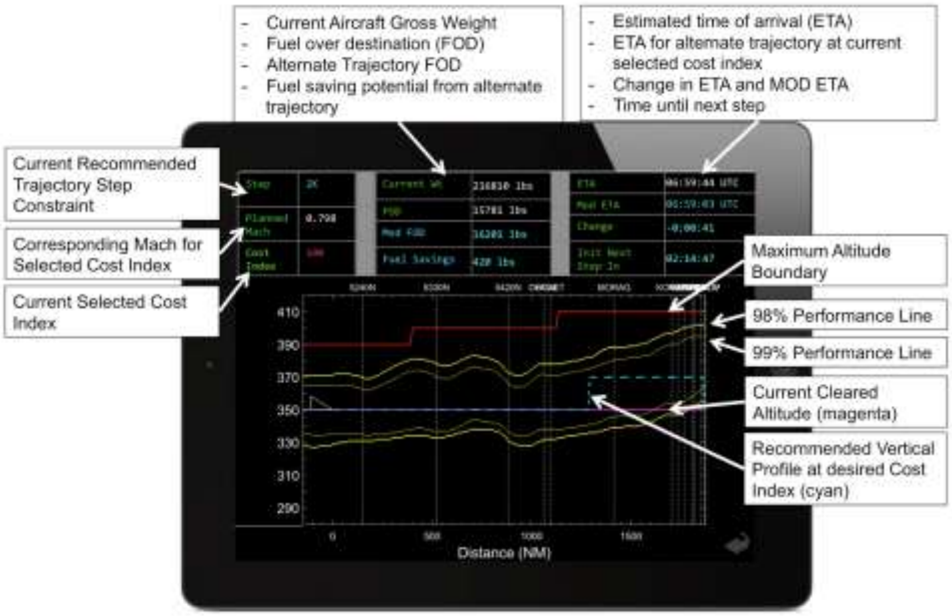

Figure 2. Prototype interface for a tablet-based CASO Decision Support Tool

Task Progress and Plans

Task 1: Identify operations with high fuel reduction potential from CASO
Based on the distribution of benefits evident in the first part of this project, it was clear that some types of operations (i.e. airlines, aircraft types, and routes) had larger benefit potential from CASO implementation than others. Therefore, one objective of this phase of the project is to characterize current operations by type and identify particularly high-benefit candidates for cruise phase optimization. Potential drivers for off-optimal flight conditions, such as airspace congestion or weather impacts, can be investigated at this stage to inform discussions with stakeholders. This task has involved data analysis of cruise fuel saving potential decomposed by airline, aircraft type, origin and destination, and ATC sector. Results based on 2011 and 2015 data showed reduced fuel saving potential from speed optimization in 2015 than in 2011 but more from altitude optimization. A second analysis approach has also identified flights with fuel saving potential because they arrived at their destination early relative to the scheduled time. These flights had the potential to slow down to a more fuel efficient speed without impacting the airline schedule in any way.

Task 2: Present results and discuss operational considerations with stakeholders (airlines and air traffic controllers)
In order to implement CASO concepts in operational contexts, it is necessary to understand system efficiency drivers from the airline and ATC perspectives. Therefore, an objective of this research is to meet with airline operational departments, dispatchers, pilots, and air traffic controllers to discuss the cruise efficiency analysis results generated under Task 1. Based on these meetings, the reasons for particular airline-specific or type-specific results can be understood and incorporated into implementation suggestions. Opportunities for improvement in meaningful, short-term operational contexts can be identified based on these meetings. This task is consisting of a series of in-person and/or remote meetings where results from relevant CASO analysis is being presented in a manner tailored to the specific stakeholder to communicate the opportunity and gather feedback on operational barriers. Results of the analysis have been presented to a number of airlines over the past year, In particular, consultations with Delta Airlines and United Airlines are on-going. This task also entails communicating key findings in technical publications and discussions with other sponsor-recommended groups.

Task 3: Develop set of recommended operating procedures to improve fuel performance in domestic operations through cruise altitude and speed optimization

Based on analysis of historical flight records and discussions with airlines, operational procedures to improve cruise-phase altitude and speed efficiency are being proposed. Areas of potential application include flight planning, tactical altitude and speed assignment, and cockpit procedures. This objective may include development of cockpit and/or controller decision support tools, efficiency evaluation algorithms, or other tools that can be integrated within the existing air transportation infrastructure based on stakeholder input. One particular implementation opportunity being pursued includes utilizing Electronic Flight Bag (EFB) technologies. These could provide improved situational awareness to pilots of current cruise status and potentially more efficient cruise altitude and speed options which could be requested from ATC. EFB display concepts for this use have been developed, and a web survey to elicit input from pilots on EFB functionality has been conducted. Next steps include further development, user refinement and testing of this tool as a means to realize benefits from CASO in an operational setting.

Task 4: Extend analysis to specific long-haul operations
The initial phase of this project focused on domestic US analysis. International and long-haul operations consume a larger amount of fuel in cruise, on an absolute and percentage basis, than short-haul small-gauge flights. Therefore, the environmental and economic impact of fuel burn reduction for these operations may be significant. The analysis framework has been expanded to incorporate data sets other than the FAA flight records and domestic NOAA weather models used in the early stages of the project. Analysis of the cruise altitude and speed efficiency of the North Atlantic Tracks have been conducted under this task based for 4033 flights over 12 days from 2014-2015. It was found that operation at optimal altitude and speed led to a 2.83% fuel reduction potential in average, and 1.24% reduction with optimal altitude alone. These compare to 3.7% from combined altitude and speed optimization and 1.96% from altitude optimization alone in domestic operations.

Task 5: Explore potential applications for CASO in NextGen concepts
Fuel benefits from CASO exist in both current and future operations. This project has potential applications to several concepts in the NextGen ATM framework. Specifically, optimal speed and altitude allocation can be applied to Time-based flow management (TBFM) and four-dimensional trajectory based operations (4DTBO). For example, many flights currently fly faster than their fuel-optimal speed only to incur delay when nearing the destination airport. One concept of operations which could be explored under this task involves using a 4D-TBO procedure which imposes a Required time of Arrival (RTA) at the arrival TRACON with sufficient lead-time to allow operators to plan departure times and/or flight speeds at nearer to the fuel-optimal point while still achieving the same wheels-ON time. With effective information sharing and technology infrastructure, efficiency can play a role in congestion management. The priority level of this was reduced by the sponsor and as such no detailed analysis of these opportunity areas has been conducted.

Major Accomplishments

- Met with technical pilot groups from multiple airlines (United, American, Southwest, Jetblue, Lufthansa).
- Completed retrospective data analysis of nearly 500,000 domestic US and long haul flights on the North Atlantic Tracks.
- Extended CASO domestic analysis to include 2015 data.
- Developed prototype interface for tablet-based cockpit decision support tool.
- Developed online human-in-the-loop (HITL) interface survey for airline pilots, obtained preliminary feedback.

Publications

Folse, S., Tran, H., Jensen, L., & Hansman, R. J. (2016). Cruise Altitude and Speed Optimization Implemented in a Pilot Decision Support Tool. In 16th AIAA Aviation Technology, Integration, and Operations Conference (p. 4211).
Jensen, L., Tran, H., & Hansman, J. R. (2015). Cruise Fuel Reduction Potential from Altitude and Speed Optimization in Global Airline Operations. In Eleventh USA/Europe Air Traffic Management Research and Development Seminar (ATM2015), Lisbon, Portugal.
Jensen, L., Hansman, R. J., Venuti, J., & Reynolds, T. (2014). Commercial airline altitude optimization strategies for reduced cruise fuel consumption. In 14th AIAA Aviation Technology, Integration, and Operations Conference (p. 3006).
Jensen, L., Hansman, R. J., Venuti, J. C., & Reynolds, T. (2013). Commercial airline speed optimization strategies for reduced cruise fuel consumption. In 2013 Aviation Technology, Integration, and Operations Conference (p. 4289).

Outreach Efforts

Meetings with Delta, United, American, and Jetblue technical groups (fuel efficiency, flight planning, and pilots). Additional outreach with USAF Air Mobility Command regarding potential military applications of CASO concepts.

Awards

Luke Jensen selected ASCENT 2014 Student of the Year.

Student Involvement

Graduate students have been involved in all aspects of this research and have been the key implementers.

References

[1] R. Kar, P. A. Bonnefoy, and R. J. Hansman, "Dynamics Of Implementation Of Mitigating Measures To Reduce CO2 Emissions From Commercial Aviation," 2010.

[2] K. B. Marais, T. G. Reynolds, P. Uday, D. Muller, J. Lovegren, J.-M. Dumont, and R. J. Hansman, "Evaluation of potential near-term operational changes to mitigate environmental impacts of aviation," *Proc. Inst. Mech. Eng. Part G J. Aerosp. Eng.*, Jul. 2012.

[3] H. H. Hurt Jr., *Aerodynamics for Naval Aviators*, no. January. Navair, 1965.

[4] J. T. Betts, "Survey of Numerical Methods for Trajectory Optimization," *Journal of Guidance, Control, and Dynamics*, vol. 21. pp. 193–207, 1998.

[5] G. Huang, Y. Lu, and Y. Nan, "A survey of numerical algorithms for trajectory optimization of flight vehicles," *Sci. China Technol. Sci.*, vol. 55, pp. 2538–2560, 2012.

[6] D. M. Pargett and M. D. Ardema, "Flight Path Optimization at Constant Altitude," *Journal of Guidance, Control, and Dynamics*, vol. 30. pp. 1197–1201, 2007.

[7] A. Filippone, "Cruise altitude flexibility of jet transport aircraft," *Aerosp. Sci. Technol.*, vol. 14, pp. 283–294, 2010.

[8] D. Rivas, O. Lopez-Garcia, S. Esteban, and E. Gallo, "An analysis of maximum range cruise including wind effects," *Aerosp. Sci. Technol.*, vol. 14, pp. 38–48, 2010.

[9] L. Delgado and X. Prats, "Fuel consumption assessment for speed variation concepts during the cruise phase," in *Conference on Air Traffic Management (ATM) Economics*, 2009.

[10] L. Delgado and X. Prats, "En Route Speed Reduction Concept for Absorbing Air Traffic Flow Management Delays," *J. Aircr.*, vol. 49, no. 1, pp. 214–224, Jan. 2012.

[11] E. T. Turgut, M. Cavcar, O. Usanmaz, A. O. Canarslanlar, T. Dogeroglu, K. Armutlu, and O. D. Yay, "Fuel flow analysis for the cruise phase of commercial aircraft on domestic routes," *Aerosp. Sci. Technol.*, vol. 37, pp. 1–9, 2014.