Final Project Report

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Abstract

The project deals with optimization of aircraft vertical flight profile in order to save costs. Two approaches - Continuous Climbing Cruise and En-route Optimization Technique - were investigated with respect to safety, operational compatibility, available savings, and implementation complexity. Based on the results, electronic flight bag has been selected as viable target platform. Prototype application has been created and evaluated in simulated environment. The resulting evaluation report summarizes recommendations regarding functional requirements and concept of operations.

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This deliverable consists of SJU foreground.

Acronyms

Acronym	Definition
ATM	Air Traffic Management
ATC	Air Traffic Controller
CCC	Continuous Climbing Cruise
CONOPS	Concept of Operations
EFB	Electronic Flight Bag
EOT	En-route Optimization Technique
HMI	Human-Machine Interface
MEOT	Multistep En-route Optimization Technique
OIS	Operational Improvement Step

1 Project Overview

The project investigated algorithms for optimization of aircraft vertical flight profile with respect to safety, operational compatibility, available savings, and implementation complexity, including prototype application (i.e., En-route Optimization Technique or EOT) development running on an Electronic Flight Bag (EFB) and its evaluation in simulated environment.

1.1 Project progress and contribution to the Master Plan

Initially, the project concentrated on investigation of Continuous Climbing Cruise (CCC) technique. An OIS AUO-0304 “Initiating Optimal Trajectories through Cruise-Climb Techniques” was linked to the project in order to reflect CCC needs. The deliverable D05 “Operational Safety Analysis” identified operation hazards, together with their basic causes and operational effects. As a mitigation, candidate safety requirements were formulated.

There were means needed helping the pilot fly the aircraft along the CCC vertical profile. Two possibilities were investigated:

1) Advisory solution, telling the flight crew how to initiate and maintain the CCC by proper usage of available avionics functions. This approach is represented by an enabler A/C-09a Flight management and guidance to provide advisory for climbing cruise. V2 maturity has been reached by implementation of the technology in an electronic flight bag.

2) Integrated solution, leaving the whole process of flying CCC on the integrated avionics, represented by an enabler A/C-09b Flight management and guidance to perform automatically climbing cruise. Evolution of this solution has been later stopped as not economically viable.

Code	Name	Project contribution	Maturity at project start	Maturity at project end
A/C-09a	Flight management and guidance to provide advisory for climbing cruise	Advanced EFB mockup created, tested in simulated environment and evaluated with pilots	V1	V2
A/C-09b	Flight management and guidance to perform automatically climbing cruise	Benefit and feasibility analysis	V1	V1

1.2 Project achievements

The main project goal is to increase flight efficiency by optimizing aircraft vertical trajectory. According to the state-of-the-art information available at the time of project initiation, Continuous Climbing Cruise has been selected as a basis for computation of vertical profile. Operational safety analysis together with the fact that approaches very similar to CCC are being used already today by some airlines confirmed that CCC is viable from operational point of view in remote airspace.

Cost and benefit analysis indicated fuel savings of up to 0.19% for mainliners and 1.7% for business jets that are not sufficient to justify costly implementation of CCC into integrated avionics. For that

reason an alternative solution was proposed, based on auto-thrust disengagement and constant speed setting. Because the thrust is not automatically reduced, as the aircraft weight decreases due to fuel burn, the aircraft climbs slowly to maintain the constant speed. However, auto-thrust disengagement was unacceptable for safety reasons.

Further research finally led to another method called En-route Optimization Technique, essentially different from CCC. While the vertical profile computed using CCC depends mainly on aircraft weight, the new solution is considering weather as well, especially wind and temperature. While similar strategies are already available in current Flight Management Systems, presented method differs in two ways – results are globally optimal and computation is based on more precise weather model.

In general, vertical trajectories computed by EOT are arbitrarily curved, which requires block altitude reservation. That usually implies lower acceptability rate from ATC side. Moreover, guidance along such trajectory would again require avionics upgrade. However, such arbitrarily curved vertical profile may be approximated by a sequence of step-climbs and descents using a method called Multistep En-route Optimization Technique. Benefit analysis has shown that even if such approximation reduces available savings, they are still high enough to be attractive for airlines – expected value is in average about 1% depending on aircraft type, weather and flight parameters.

The main advantage of MEOT is that it may be completely offloaded to an EFB, which has several important implications, when compared to integrated avionics:

- Today's EFB hardware usually offers much higher computational power, thus allowing use of advanced and computationally intensive algorithms
- Software development process is easier and cheaper compared to the integrated avionics
- Availability of user-friendly Human-Machine Interface based on the use of touch screen

Project has further concentrated on the preparation of concept of operations and design of HMI. First, the CONOPS and basic HMI design patterns were presented to the group of test subjects (pilots). Based on their response, a paper mock-up was created and reviewed again by the same group. Feedback from pilots was used for development of prototype implemented on a real EFB. Functionality has been limited to the most important features, in order to test especially the application workflow and evaluate the added workload.

1.3 Project Deliverables

The following table presents the relevant deliverables that have been produced by the project.

Reference	Title	Description
D03	High Level Requirements	Using the available inputs in terms of current operational environment, past relevant research, and discussions with operational experts, a set of assumptions was established in terms of operational environment and operational services supported by the CCC airborne capability. Based on these assumptions, initial functional requirements for the avionics have been identified and an initial safety analysis has been performed, resulting in high-level requirements. These functional and safety requirements were used to determine the avionics requirements.
D04	Cost & Benefit Analysis	Based on developed models (Business Aviation) or existing models (Mainline), the Cost & Benefit Analysis of the Continuous Climbing Cruise operation contains the assessment of all relevant factors (e.g. cost of avionics upgrade for Business Aviation aircraft, magnitude of savings, emission

		reduction) to make well supported decisions as the project continued towards the prototyping phase. Simulations in Santa Maria Oceanic airspace are described; costs and benefits are identified, structured, and evaluated.
D05	Operational Safety Analysis	The goal of the analysis was to verify if the CCC operation, as defined in the High Level Requirements document, is acceptably safe in normal and non-nominal operations. The main operation hazards were identified together with their basic causes and operational effects. The risk mitigation means, which would reduce the operational effects of operational hazards, and candidate safety requirements, were formulated.
D20	Benefit Analysis of En-Route Optimization Techniques for BizJets	The document contains the assessment of magnitude of fuel savings, cost savings, and emission reduction of vertical profile optimization techniques. The simulations are briefly described; benefits are identified, structured, and evaluated.
D23	Implementation opportunities studies & Benefit Analysis of EnRoute Optimization Techniques for Mainline	The document contains the assessment of magnitude of fuel savings of vertical profile optimization techniques for mainlines. The simulations are briefly described; benefits are identified, structured, and evaluated.
D22	Technical Approach Review	The document describes physical background, algorithms, technical implementation, operational framework and human factors aspects of Continuous Climbing Cruise. Main disadvantages of this approach – auto-thrust disengagement and block altitude need – are discussed. New method called En-route Optimization Technique is presented, which is based on global optimization and is additionally using wind forecast. This document was the main basis for decision about further project continuation towards EFB solution, instead of prototype using avionics upgrade.
D14	Advanced solution development	The document provides high level description and evaluation results of the proposed human machine interface. The objective of the evaluation is to assess how well the user interface design meets the overall system objectives and pilot expectations and to assess the concept of operations. Based on evaluation results an updated set of functional requirements is proposed.

1.4 Contribution to Standardisation

Project results did not have any impact on standards.

1.5 Project Conclusion and Recommendations

An important project result is the shift from CCC profile computed by integrated avionics to more advanced MEOT algorithm calculated by EFB. Selected optimization approach allows comparable or even better results than CCC and is not limited by factors such as need of block altitude clearance or auto-thrust disengagement. According to benefit analyses, the expected fuel savings are about 1%, depending on aircraft performance, flight conditions and weather. Implementation in EFB offers higher computational power needed by advanced optimization algorithms. It also means easier software development process compared to solution based on integrated avionics, allowing access to savings in short term with today's avionics.

Class 1 EFBs (meaning stand-alone EFBs) were selected as the first candidate for evaluation of the concept of operation and the human-machine interaction. Concept viability was confirmed. However, the necessity of entering aircraft status data for every optimization run was evaluated as suboptimal from a Human Factors perspective. Moreover, presentation of results in the simple textual form was not found sufficiently understandable. Therefore, the main recommendations resulting from the HMI evaluation are to implement MEOT in Class 2 EFB (meaning connected to the avionics) and use graphical representation of the vertical profile on the EFB display. Based on prototype evaluation results, an updated set of functional requirements was created.

However, even Class 2 EFBs lack the direct communication channel back to the avionics (for security reasons), complicating the data transfer from the EFB. In the future, these advanced optimization features must be more integrated with flight management systems. In the meantime, Class 2 EFBs running algorithms like MEOT together with graphical display of vertical profile remains the best trade-off.

2 References

[1] SESAR Programme Management Plan, Edition 03.00.01

[2] European ATM Master Plan

[3] Multilateral Framework Agreement ("MFA") signed between the SJU, EUROCONTROL and its 15 selected members on August 11, 2009, amended on 14 June 2010, 19 October 2010 and 2 July 2012

[4] P9.39, State of the Art - Operational Frame and Trajectory Management, D01, 00.01.00, 12/8/2010

[5] P9.39, State of the Art - Avionics, D02, 00.01.00, 12/8/2010

[6] P9.39, High Level Requirements, D03, 00.01.03, 7/4/2011

[7] P9.39, Cost and Benefit Analysis, D04, 00.01.00, 14/12/2011

[8] P9.39, Operational Safety Analysis, D05, 00.00.02, 27/2/2012

[9] P9.39, Benefit Analysis of En-Route Optimization Techniques for Business Jets, D20, 00.01.01, 11/11/2013

[10] P9.39, Implementation opportunities studies and Benefit Analysis of En-Route Optimization Techniques for Mainline, D23, 00.01.01, 3/7/2014

[11] P9.39, Technical Approach Review, D22, 00.01.00, 17/7/2014

[12] P9.39, Advanced Solution Development, D14, 00.01.00, 25/1/2016

[13] Integrated Roadmap Dataset 14

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