Report on on-line monitoring of user-centric efficiency and equity indicators

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AURORA

ADVANCED USER-CENTRIC EFFICIENCY METRICS FOR AIR TRAFFIC PERFORMANCE ANALYTICS

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Abstract

This document describes the process followed to analyse the influence of using AURORA's efficiency indicators in the application of STAMs. These indicators provide a new view on efficiency that may differ from the Network Manager's view on efficiency, providing solutions whose global efficiency based on Airspace Users expectations are met. Thus the document provides examples of actual STAM application compared to the most efficient solution according to AURORA's indicators, together with different analysis based on this scenario.

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Executive summary

This document describes the experiment performed to analyse the influence of using AURORA's efficiency indicators in the application of STAMs. The Exercise presented in this document will analyse the added value of AURORA's indicators in the processes for the identification and assessment of hotspots continuously. If the hotspot is declared in the en-route phase, the fact of continuous on-line monitoring of efficiency indicators will facilitate the analysis of the hotspots from the perspective of the Airspace Users (AUs). These processes should also consider the results from the monitoring of the existing ATM metrics such as Occupancy Counts and Entry Counts. This will allow selecting the most suitable STAM measure by balancing Air Traffic Management decisions together with Airspace Users' needs.

The scenario selected for the validation performed in this document is comprised by the flights initially flying through the sector LECMDGU (Domingo Upper) the day of July 2nd of 2017 at 11:30. This sector, from the Spanish airspace, suffered an imbalance of demand vs capacity at that time, and 2 STAMs were applied in order to keep the ATCo's workload. These flights were reconstructed following the same methodology as the one defined in the off-line validations in [3] and then generated trajectories were evaluated to assess whether AUs' view on efficiency was met through the STAM selection process. This AUs' view on efficiency is mainly based on fuel consumption and cost, which is different from the current Network Manager (NM) view on efficiency, which is based on horizontal distance deviations according to the indicator that is currently used i.e. KEA.

Several studies were performed in order to accomplish the different validation objectives previously defined in the Experimental Plan [2]. One of them designs all the potential STAM solutions to be applied and compares the STAM measures that were actually applied with the optimum measures considering AURORA's indicators. Another one defines the deviations of all these possible STAM solutions with respect to an agreed target of efficiency, which currently is assumed to be the flight plans without any deviation. Finally, we also analyse the impact of progressively increasing the number of flights affected by the STAM measures, together with an assessment of how the different types of STAM (Level-Capping and Re-Routing) are impacting the efficiency indicators.

1 Introduction

1.1 Purpose of the document

This document provides the report on testing the on-line monitoring of efficiency proposed by AURORA described in [1]. It describes the results of one of the exercises defined in the Experimental Plan [2] and how it was conducted. This exercise addressed the validation of the expected benefits of on-line monitoring these new indicators. These benefits are expected to support the decision-making process under the application of STAM at local level.

The document also provides the degree of achievement of the objectives through the assessment of the success criteria defined in [2].

1.2 Intended readership

This document is intended to be used by AURORA members and by the SJU reviewers.

1.3 Structure of the document

This document is organized in the following sections:

- Section 2: This section describes the context where the validation of the exercise to be performed takes place from [2]. This context includes summary of the experimental plan, summary of validation results, summary of experimental scenarios, summary of assumptions and the deviations found with respect to the planned activities;
- Section 3: This sections describes the results for Exercise 2-2 (STAM process with on-line monitoring of efficiency indicators). The success criteria are assessed for each validation objective defined for the exercise depending on the results obtained during the experiments performed;
- Section 4: This section is devoted to introduce the conclusions achieved as well as recommendations in terms of operational benefits;
- Appendix A: This appendix includes a description of the indicator set to be tested in this Exercise.
- Appendix B: This appendix includes figures of the horizontal and vertical profiles of the STAM trajectories defined for the execution of the Exercise.

1.4 Acronyms and Terminology

Term	Definition
ADS	Automatic Dependent Surveillance
ADS-B	Automatic Dependent Surveillance - Broadcast

Term	Definition
ANSP	Air Navigation Service Provider
ATCO	Air Traffic Control Operator
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
AU	Airspace User
AURORA	Advanced User-centric efficiency metRics for air traffic perfORmance Analytics
ECAC	European Civil Aviation Conference
FL	Flight Level
HMI	Human-Machine Interface
KPA	Key Performance Area
KPI	Key Performance Indicator
LC	Level-Capping
NM	Network Manager
RFL	Reference Flight Level
RR	Re-Routing
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking (Agency of the European Commission)
STAM	Short-Term ATCFM Measures

Table 1: Acronyms and terminology

2 Context of the Validation

As it is described in the Experimental Plan [2], the scope of this validation report is to demonstrate how AURORA's indicators can be used to monitor air traffic and support the decision-making process in the tactical phase when applying STAM at local level.

2.1 Summary of the Experimental Plan

This section provides a brief description of the overall aim of the Experimental Plan [2]. The Experimental Plan describes the experiment that will be carried out in AURORA to study the operational benefits of application of STAM at local level by means of the indicators described.

This document deals with the second use case defined in [2], whose main objectives are the facilitation of analysis of hotspots and the proposal of the most suitable STAM to balance them. This use case describes how to identify and assess hotspots continuously to help in the decision-making process of STAM application. If the hotspot is declared in the en-route phase, the fact of continuous on-line monitoring of efficiency indicators will facilitate the analysis of the hotspots and the decision-making process to apply a STAM measure. This process will also consider the results from the monitoring of the existing ATM metrics such as Occupancy Counts and Entry Counts. This will allow selecting the most suitable STAM measure by balancing Air Traffic Management decisions together with Airspace Users' needs.

2.1.1 Summary of indicators tested

The set of indicators tested in this validation is fully described in Appendix A.

2.2 Summary of Validation Results

Validation Exercise ID	Obj. ID	Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Objective Status
EXERCISE 2-2	VAL-OBJ-STAM-2.2.1	Validate that the NM and ANSP will solve hotspots through STAM measures that improve Fuel Efficiency, Flight Efficiency and Cost-Effectiveness of the flights affected	Success Criteria 2.2.1-1	The total fuel consumption of the flights affected by the STAM measures using AURORA's indicators is less than the total fuel consumption of actual STAM measures.	AURORA's based STAM selection has resulted in less fuel consumption than the reference STAM selected	OK
			Success Criteria 2.2.1-2	The total cost of the flights (fuel and time) affected by the STAM measures using AURORA's indicators is less than the total cost of actual STAM measures.	AURORA's based STAM selection has resulted in less flight cost than the reference STAM selected	OK
			Success Criteria 2.2.1-3	Deviation of the efficiency target per flight when implementing a STAM measure using AURORA's indicators is less than deviation with actual STAM measures	The deviations from the efficiency target (flight plan indicators) has been found smaller in the AURORA's based STAM selection than in the reference scenario	OK
	VAL-OBJ-STAM-2.2.2	Validate that the STAM measures based on AURORA's indicators is not influencing negatively other ATM performance areas	Success Criteria 2.2.2-1	Other KPAs are not negatively impacted by the new STAM measures based on efficiency and equity indicators	See Section 2.5	NOK
	VAL-OBJ-STAM-2.2.3	Validate that the NM and ANSP will solve hotspots through STAM measures that improve Equity and Fairness of the AUs affected	Success Criteria 2.2.3-1	Equity indicators allow taking decisions on the resolution of hotspots by better distributing the inefficiencies between them.	See Section 2.5	NOK
			Success Criteria 2.2.3-2	Equity & Fairness are increased with respect to today.	See Section 2.5	NOK

Validation Exercise ID	Obj. ID	Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Objective Status
	VAL-OBJ-STAM-2.2.4	Validate that the monitorization and decision-making processes are enhanced thanks to the ATM information provided by the system composed by: • Online measurement of the status of the efficiency indicators; • Online forecast of the KPIs future values based on the current state for each solution given by the system; • Alarms when deviations with respire to the efficiency target are detected.	Success Criteria 2.2.4-1	The system can integrate and display the ATM information required to monitor current operations based on efficiency indicators.	See Section 2.5	NOK
			Success Criteria 2.2.4-2	The actors involved in making the decision on the STAM measure to solve the hotspot, will consider the AUs preferences as well as the solution closer to the agreed value targets on efficiency and equity.	See Section 2.5	NOK

Table 2: Summary of Validation Results

2.3 Summary of Experimental Scenarios

One single operational scenario is tested in this Exercise as non-nominal scenarios are not considered.

Three different types of validation scenarios are proposed and defined:

- Nominal scenario, composed by the initial flight plans presented to the NM by the different AUs. This scenario by itself presents the hotspot by exceeding the capacity of the sector.
- Reference scenario, with current operations dealing with how a hotspot is detected, analysed, coordinated and how a STAM is implemented. Nowadays, the only indicators considered are the occupancy and entry counts and the congestion level (complexity). AUs preferences as well as efficiency indicators are usually out of the scope when hotspots are identified and solved through STAMs.
- Solutions scenarios, which consider the use of on-line AURORA's efficiency indicators to address the AUs preferences.

The traffic sample in this Exercise corresponds to the flights initially planned to be flying through the LECMDGU sector on July 2nd 2017 at 11:30 in the morning. This traffic sample and related operational environment was selected based on the following criteria:

- Previous SESAR work had already identified STAM applicability in European airspace [5][6][7] together with occupancy capacity of different sectors.
- Airspace Users suggested in the 3rd AURORA Workshop that new scenarios generated should address high-congestion summer days.
- Different STAM measures were identified for that traffic sample based on historical data.

The traffic sample addresses a total amount of 21 flights, and 12 of them are eligible for the application of a STAM. The summary of flights is the following:

Callsign	Origin	Destination	Eligible for STAM
AVA018	SKBO	LEBL	NO
DLH61J	EDDM	LPPT	YES
DLH88H	LEZL	EDDM	YES
EXS24A	LEMG	EGBB	NO
EXS34D	LEMG	EGPF	NO
EZY73WK	LEMG	EGCC	NO
LGL742	GCRR	ELLX	YES

Callsign	Origin	Destination	Eligible for STAM
MON35MK	LEAL	EGKK	YES
NJE426E	LEMD	EGHQ	NO
NJE662K	LFQG	LPPR	NO
PRW111	BIKF	LEMG	YES
RYR32FV	EGCC	LEMG	NO
RYR58A	GMFF	EHEH	NO
RYR6LV	LPPT	LIRA	YES
RYR7UC	GCLP	LIMC	YES
RYR9XU	EGSS	GMFF	YES
TAP491M	LFBO	LPPT	YES
TAP938L	LPPR	LSGG	YES
TOM5MG	LEMG	EGNT	NO
TVF09HR	LFLL	LPPR	YES
TVF09KA	GMMX	LFPO	YES

Table 3. Summary of traffic sample

2.4 Summary of Assumptions

This section shall provide an overview of the experimental assumptions applicable to the exercises.

The assumptions detailed will apply only to those needed for this deliverable. The rest of assumptions held, i.e. for trajectory calculation, are described in [3] and [4].

Table 4 provides an overview of the assumptions applicable to this exercise.

Identifier	Description	Justification
A-1	The reference scenario is the one adopted in the real operation.	Two STAMs were identified to have been applied. This solution will be taken as reference for future analysis and comparisons.
A-2	The indicators are computed for the whole trajectory inside the ECAC area.	Flights with part of its track outside the ECAC area will not be taken into consideration due to lack of surveillance

Identifier	Description	Justification
		data information.
A-3	The flight plan will be taken as the actual flown trajectory.	This way the indicators will reflect the actual deviations of performing the STAM measures in the area under analysis. Other deviations that can be shown by the ADS-B data will not be considered.
A-4	Every flight will have a STAM assigned of the two types: Level Capping and Re-Routing.	The flights identified with the possibility of having a STAM will be able to implement either type in order to increase the possibilities of actuation.
A-5	Level Capping STAM types will be performed at FL340.	The idea of applying a level capping is to avoid the entrance to a superior sector of the airspace. The vertical limit between LECMDGU and LECMDGL sectors is FL345, so the Level Capping should happen at FL340.
A-6	Efficiency will be measured using only the flights that are STAM eligible.	As the rest of the trajectories will always remain the same, its indicators will not affect the final results.
A-7	Indicators of actual STAMs will not be computed with ADS-B tracks.	If the calculation of the indicators of actual STAMs were made with the ADS-B tracks, the results would not be comparable with the rest of solutions resulting of applying different STAM measures.
A-8	Efficiency target will be the efficiency indicator for the flight plan.	Nominal trajectories will follow the flight plan unless a STAM is applied, so the efficiency target agreed between NM-ANSP and the Airspace Users is considered to be the efficiency of the flight plan.

Table 4: Validation Assumptions overview

2.5 Deviations from the planned activities

The following deviations had to be performed with respect to the activities planned to be executed and defined in the Experimental Plan [2] of the project:

- A deviation from the experimental plan had to be performed due to lack of official information of the use of STAM. In the Experimental Plan [2], it was stated that the reference scenario will be selected as a hotspot is detected and then analysing how STAM were implemented. However, STAM applicability is not officially documented and its use is not currently registered.
  Due to this issue, the total number of scenarios to be tested will be reduced to 1 instead of the “several” that were stated in the Experimental Plan to be considered.
- Another deviation had to be performed to the set of indicators to be tested. As already discussed in [3], the set of indicators to be analysed was reduced to improve and perform integral analysis on specific indicators instead of keeping the whole set defined in [1]. Then by both the expectation of the Airspace Users and the own needs of this Exercise, a new subset of indicators were defined with the flight plan as reference. The total amount of indicators to be tested is summarized in Appendix A.
- The evaluation of validation objective VAL-OBJ-STAM-2.2.2 was discarded due to the impossibility of performing a fast-time simulation of the network. The characteristics of the scenario selected would completely bias the results achieved, as only one hotspot would be evaluated instead of the ECAC area.
  The evaluation of the impact of one hotspot under the global network is not plausible, as other network hotspots would then appear that would require evaluation and solution.
- Another deviation performed is the analysis of Equity indicators. The last definition developed for Equity indicators can be found in [3], and according to this definition, the applicability of the Equity principles in the scenario selected is not plausible. This definition requires a minimum number of flights per Airspace User in order to be considered for the analysis, which is not a fulfilled requirement in the hotspot available (only 1 Airspace User reaches the 5 flights).
  Thus, Equity indicators are removed from the set of indicators to be tested and VAL-OBJ-STAM-2.2.3 will not be tested.
- The last deviation performed is the discard of VAL-OBJ-STAM-2.2.4 from the validation objectives to be tested. This validation objective is focused on the applicability of AURORA’s indicators on a real operational environment, and the success criteria were focused on the evaluation of HMI interfaces and operational solutions based on actual decisions from a simulation in real time.
  Due to this reason, the validation objective will not be tested as the validation scenario is not suitable to be tested on a real time simulation and neither a HMI has been defined previously to deal with this objective.

3 Validation Exercises Results

3.1 Validation Exercise 2-2 description and scope

Validation Exercise 2-2 is named "Benefits on the STAM process with on-line monitoring of efficiency indicators", and aims to assess hotspots and solve them by the evaluation of AURORA indicators. In this Exercise, the process described in [1] and [2] will be performed in order to evaluate this objective.

The traffic sample to be used encompasses the flights that initially were planned to be occupying sector LECMDGU the day 2nd of July of 2017 at 11:30. This presents a deviation from [2], as already described in Section 2.5.

This traffic sample is composed by a total amount of 21 flights, with 12 of them being eligible for the application of STAM. The results presented in the following sections will only be evaluated for the 12 flights with STAM applicability (as the rest will always remain the same).

VAL-OBJ-STAM-2.2.2, VAL-OBJ-STAM-2.2.3 and VAL-OBJ-STAM-2.2.4 will not be evaluated (See Section 2.5).

3.1.1.1 VAL-OBJ-STAM-2.2.1 Results

This validation objective addresses: "Validate that the NM and ANSP will solve hotspots through STAM measures that improve Fuel Efficiency, Flight Efficiency and Cost-Effectiveness of the flights affected" through three success criteria identified in [2].

Success Criteria 2.2.1-1: "The total fuel consumption of the flights affected by the STAM measures using AURORA's indicators is less than the total fuel consumption of the actual STAM measures".

This section consolidates the results obtained from the analysis and evaluation of the indicators defined within the AURORA project and its applicability in the resolution of a hotspot. This analysis will be performed in 3 different blocks, one per indicators subset. The first block will be devoted to the evaluation of Flight Efficiency indicators (KEA, KEA_P, KEA_C1 and KEA_C2). The second block will be devoted to the evaluation of Fuel Efficiency indicators (FEA_P, FEA_C1 and FEA_C2). The third and last block will be devoted to the evaluation of Cost-Effectiveness indicators (CEA_P, CEA_C1 and CEA_C2).

This Exercise stated that the scenario to be tested required that there were actual STAMs identified in order to be compared with new STAM in application considering AURORA indicators. In the selected scenario, two STAMs were actually implemented. These two STAMs were two Level-Capping measures that allowed the flights to avoid the sector LECMDGU and fly through the sector LECMDGL. Figure 1 and Figure 2 show the vertical profile of both flights according to ADS-B data extracted, and compared to the initial flight plan vertical profile of the flight.

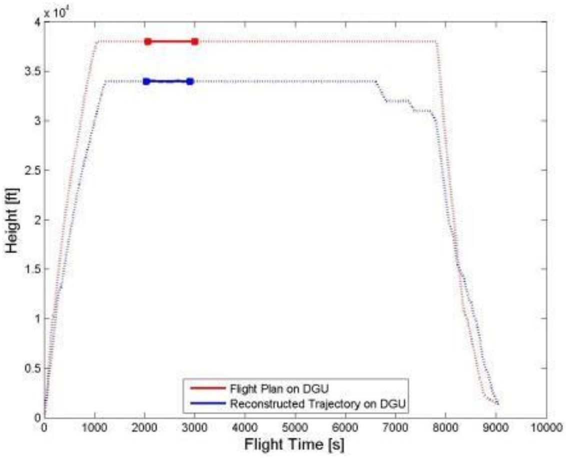


Figure 1. Vertical profile - DLH88H ADS-B track and Flight Plan

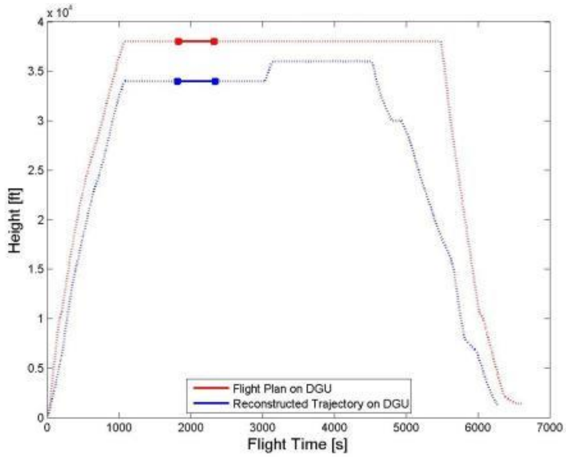


Figure 2. Vertical profile - TAP938L ADS-B track and Flight Plan

Two different behaviours are observed from the vertical profiles of the actual STAMs applied, one for each flight:

- On one hand, the flight DLH88H has a RFL in the flight plan of FL370, which is completely included in LECMDGU. In the STAM applied, the flight goes through a cruise flight level of FL340, which falls in sector LECMDGL. However, this flight does not climb after having passed the sector and stays on FL340 (and thus in lower sectors) for the rest of the flight. The reasons for the flight not to climb are unclear and may be due to many reasons: pilot's request, ATC constraints, etc.

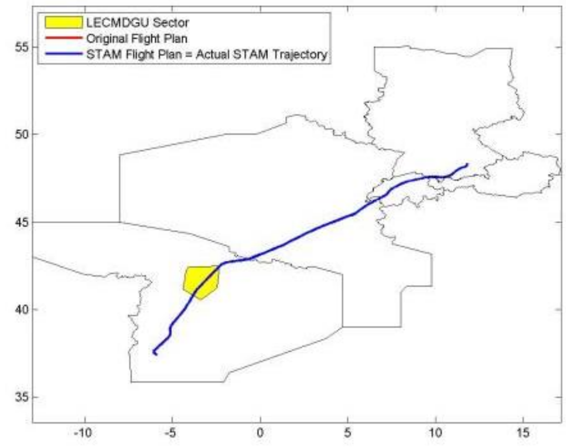
- On the other hand, the flight TAP938L with its RFL on FL370 in the flight plan will remain in lower sectors for a portion of the flight. Then it climbs to reach FL360 (which is already in upper sectors) but once passed the sector LECMDGU.

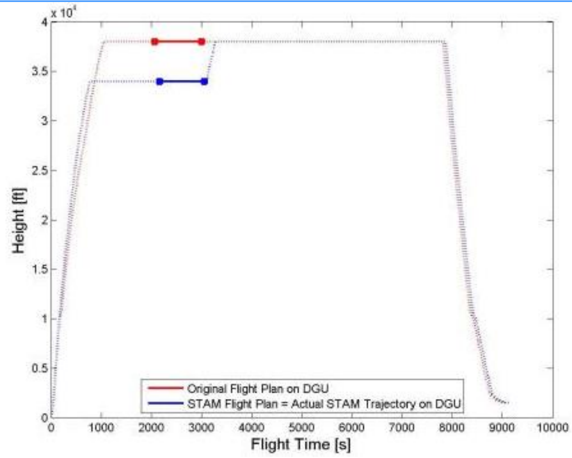
These were the two identified STAMs and, as specified in Section 2.4, in order to avoid incomparable results and trajectories, the two applicable STAMs for those two flights will be the ones defined in Table 5. These two new trajectories keep the same principles of application than for the rest of flights. These principles are:

- Level-Capping: Every possible Level-Capping will be performed at FL340, with its initial Top of Climb on FL340. This means that there is no descends from cruise flight level to the level-capping level, which implies that the flight ascends up to FL340. Then after having surpassed the sector LECMDGU, the flight is cleared to ascend until reaching its RFL from the flight plan.

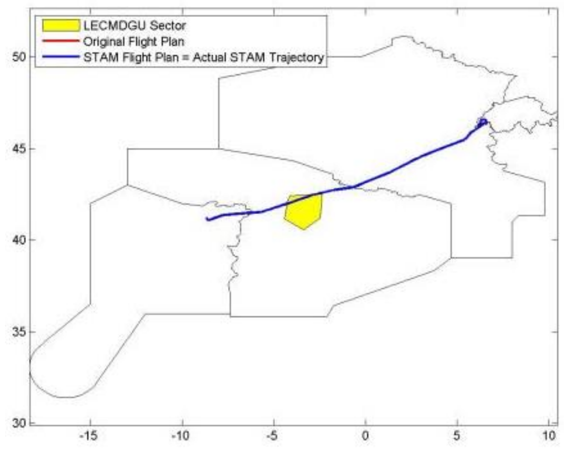
- Re-Routing: The Re-Routings will be performed according to the already defined possibilities from [5], [6] and [7]. In the case there is not a pre-defined Re-Routing for a flight, similar routes will be taken as references.

DLH88H, LEZL-EDDM





TAP938L, LPPR-LSGG



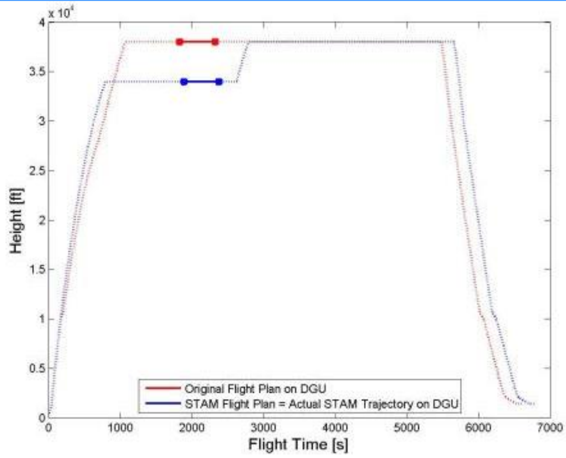


Table 5. STAM applied in the reference scenario. Solid line in the vertical profile mark the crossing of LECMDGU sector

The whole set of possible STAM to be applied are shown in Appendix B.

From all these flights, together with their nominal trajectories (which are in fact their flight plan trajectories), all possible solutions are extracted. As two STAMs were identified, it is assumed that two STAMs must be applied in order to solve the hotspot.

The need now is to compute the different indicators for every possible solution with two applied STAMs. The total number of possible solutions ascends to 264. The best solution will be selected from these solutions and compared with the reference solution.

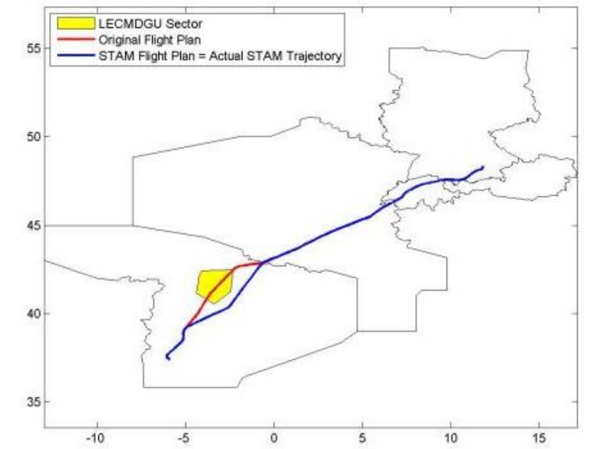
Table 6 shows the results of the indicators extracted from the actual STAM applied. As specified, these indicators correspond to the trajectories of Table 5, assuming that no changes are implemented for the rest of the flights involved in the capacity imbalance.

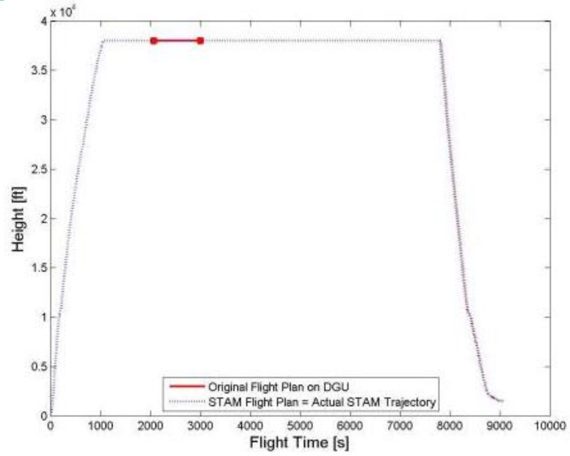
KEA	KEA_P	KEA_C1	KEA_C2	FEA_P	FEA_C1	FEA_C2	CEA_P	CEA_C1	CEA_C2
7.089	0.172	7.181	-0.527	0.450	5.980	2.509	0.356	8.359	3.543

Table 6: Indicators results of the reference scenario

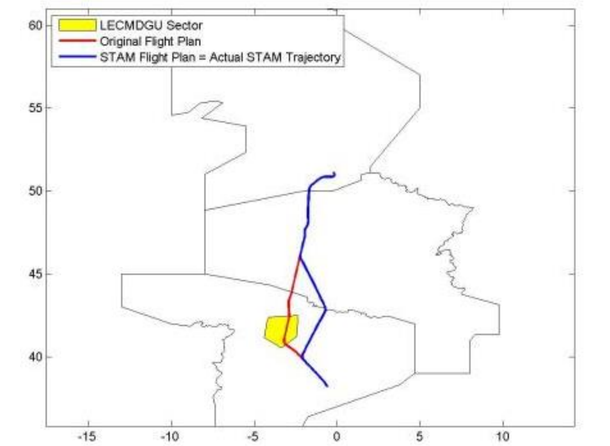
Based on AURORA indicators, a new solution is proposed. This solution is the optimum one in terms of efficiency. In this case, the solution is optimum for each of the indicators. However, to ensure consistency, only 2 STAMs are applied and the solution for each indicator is common. Table 7 shows the STAMs that have been found to be optimum.

DLH88H, LEZL-EDDM





MON35MK, LEAL-EGKK



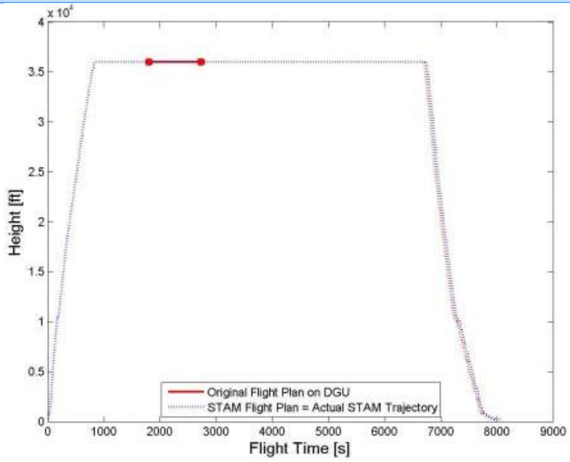


Table 7. STAM applied in the optimum scenario based on AURORA indicators. Solid line in the vertical profile mark the crossing of LECMDGU sector

Table 8 shows a summary of the indicators for this optimum scenario. Improvements of each indicator with respect to the reference scenario are also shown.

KEA	KEA_P	KEA_C1	KEA_C2	FEA_P	FEA_C1	FEA_C2	CEA_P	CEA_C1	CEA_C2
6.845	-0.049	6.937	-0.745	0.031	5.563	2.107	0.015	7.994	3.205
-3.4 %	**-128.2 %**	**-3.4 %**	**-41.4 %**	**-93.1 %**	**-7.0 %**	**-16.0 %**	**-95.9 %**	**-4.4 %**	**-9.5 %**

Table 8: Indicators results of the best solution scenario

As it can be seen from the comparison of both Table 6 and Table 8, the actual solution and the "best solution" in terms of efficiency indicators provide different efficiency, with better results for the AURORA option. This implies that the STAMs implemented in the reality were not the best ones in terms of efficiency as what AURORA indicators refer.

Figure 3, Figure 4 and Figure 5 show the horizontal profile differences between the nominal scenario, the reference scenario and the AURORA optimum-based scenario.

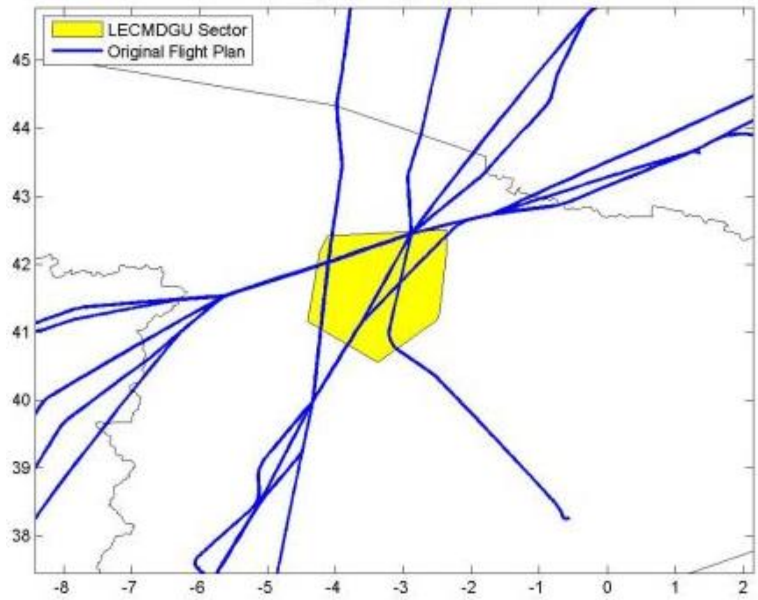


Figure 3. Horizontal profile of the trajectories that define the nominal scenario

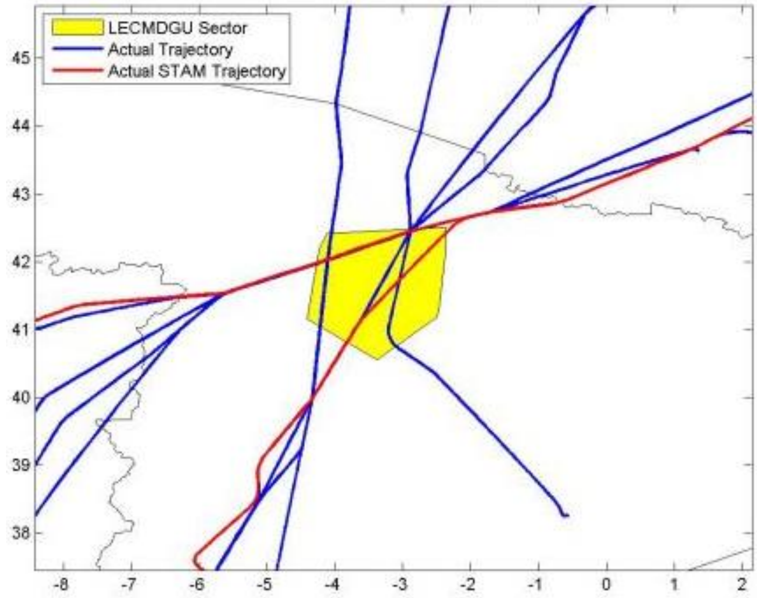


Figure 4. Horizontal profile of the trajectories that define the reference scenario

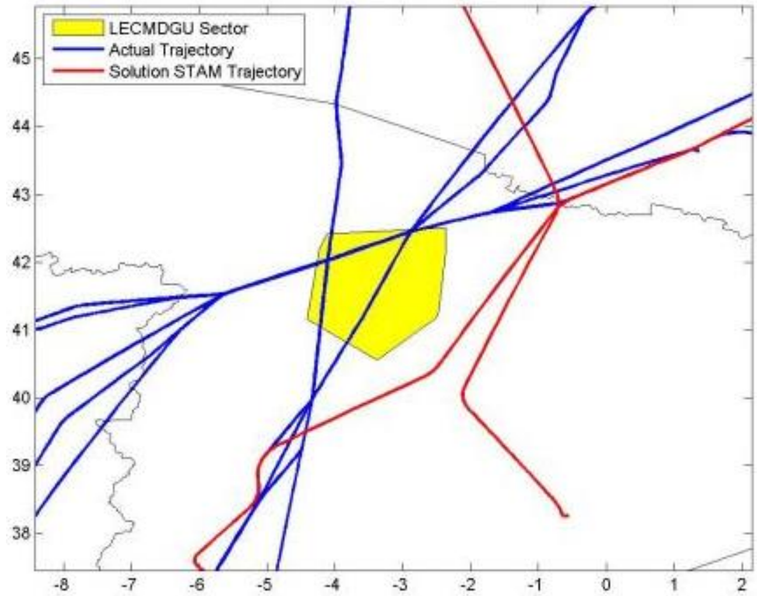


Figure 5. Horizontal profile of the trajectories that define the AURORA based-optimum scenario

Although the differences between the reference scenario and the optimum scenario based on AURORA indicators may seem small, it is true that the actual STAM implemented were not the worst selection in terms of efficiency. However, there were many more other possible solution scenarios where efficiency is greater, and thus better, than in the actual implementation.

Figure 6 and Figure 7 show all the possibilities of 2 STAM implementation ordered by its correspondent indicator value. As it can be seen in the figures, the actual STAM (which is indeed one of the possible solutions), can still be improved if efficiency was in charge of the decision taken.

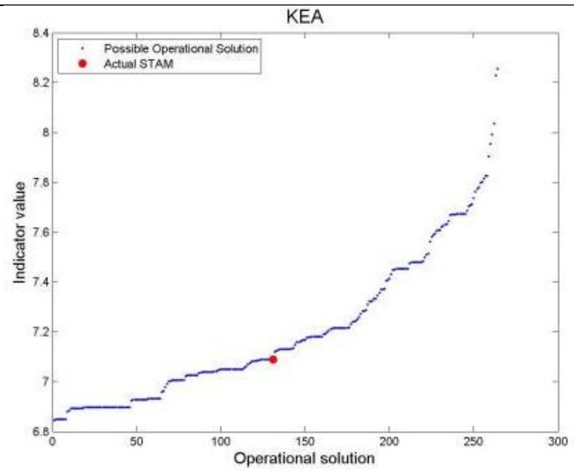


Figure 6. KEA indicator of every possible operational solution. Ordered by KEA value

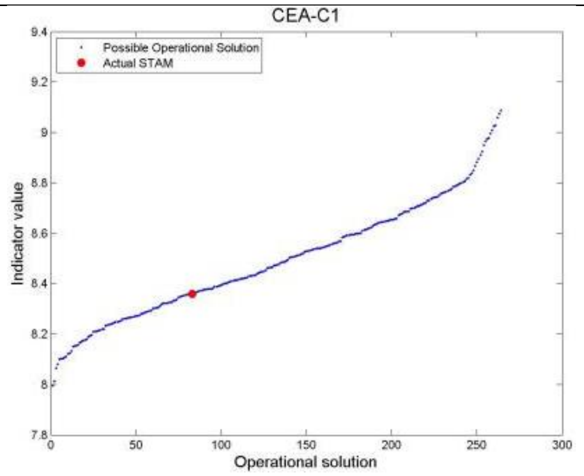


Figure 7. CEA_C1 indicator of every possible operational solution. Ordered by CEA_C1 value

In order to provide a better understanding on the effect that the implementation of a non-efficient STAM set produces on the overall efficiency of the hotspot resolution, Table 9 shows the optimum scenario indicators compared to the worst possible scenario in terms of efficiency. As it can be appreciated, in the resolution of a hotspot by applying only 2 STAMs, differences are significative.

[%]	KEA	KEA_P	KEA_C1	KEA_C2	FEA_P	FEA_C1	FEA_C2	CEA_P	CEA_C1	CEA_C2
Optimum	6.845	-0.049	6.937	-0.745	0.031	5.563	2.107	0.015	7.994	3.205
Worst	8.254	1.220	8.350	0.508	1.623	7.405	3.862	1.030	9.087	4.226
Difference	**1.410**	**1.268**	**1.414**	**1.253**	**1.591**	**1.842**	**1.755**	**1.016**	**1.093**	**1.022**

Table 9. Indicators of the optimum and worst case scenario based on AURORA indicators

Retaking the success criteria for this validation objective (Success Criteria 2.2.1-1), the new STAMs shall be improving (and thus reducing) the total fuel consumption compared with the actual STAMs applied. Comparing fuel consumption indicators for both scenarios, it can be extracted that, indeed, the STAMs applied based on AURORA indicators improve their fuel consumption with respect to the actual STAMs applied (See Figure 8).

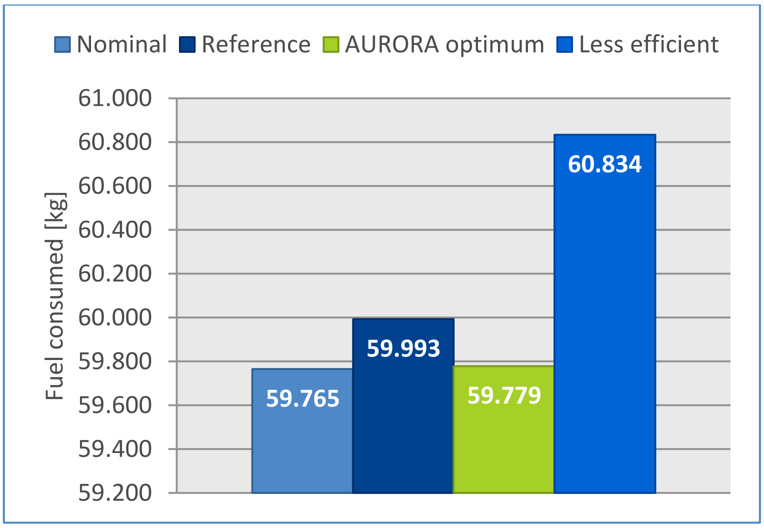


Figure 8. Fuel consumption comparison between nominal, reference and AURORA-based scenarios

The absolute difference in fuel consumption between the reference scenario and the AURORA-based scenario is of 213.88 kilograms. Considering that only 2 flights receive STAMs, the fuel reduction per flight could be higher than 100 kg (around 2-3 % of the total fuel consumption of those flights).

If the reference scenario was near of the less efficient scenario, the fuel reduction per flight could be higher than 500 kg (around 10-15 % of the total fuel consumption of those flights).

From this success criteria point of view, the validation objective is OK.

Success Criteria 2.2.1-2: "The total cost of the flights (fuel and time) affected by the STAM measures using AURORA's indicators is less than the total cost of actual STAM measures".

Using the same methodology as in the previous Success Criteria, but based in this case on the Cost-Effectiveness indicators (CEA_P, CEA_C1 and CEA_C2), Figure 9 compares the results achieved for the actual STAMs applied and the best solution in terms of AURORA's indicators.

Similar to what happened in the fuel consumption case, the selection of STAM based on efficiency may mark a significant difference in the cost of each flight. The costs showed in Figure 10 are computed as a sum of the fuel cost, the time cost and the route charges (further analysis on [3]).

Following the same trend of fuel consumption, the absolute difference of cost between the reference scenario and the AURORA-based scenario is of 200.48 €. Considering that only 2 flights receive STAMs, the cost reduction per flight could be higher than 100 € (around 2-3 % of the total cost of those flights).

If the reference scenario was near of the less efficient scenario, the cost reduction per flight could be higher than 250 € (around 5-7.5 % of the total cost of those flights).

From this success criteria point of view, the validation objective is OK.

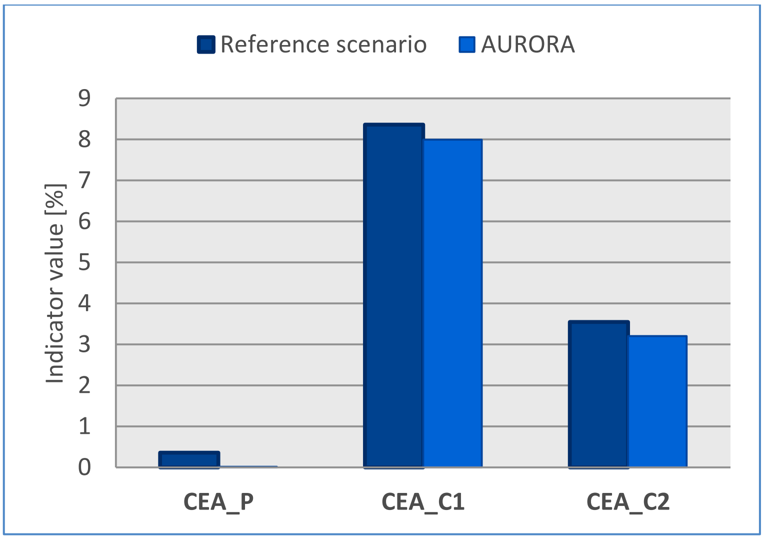


Figure 9: Cost-Effectiveness indicators comparison

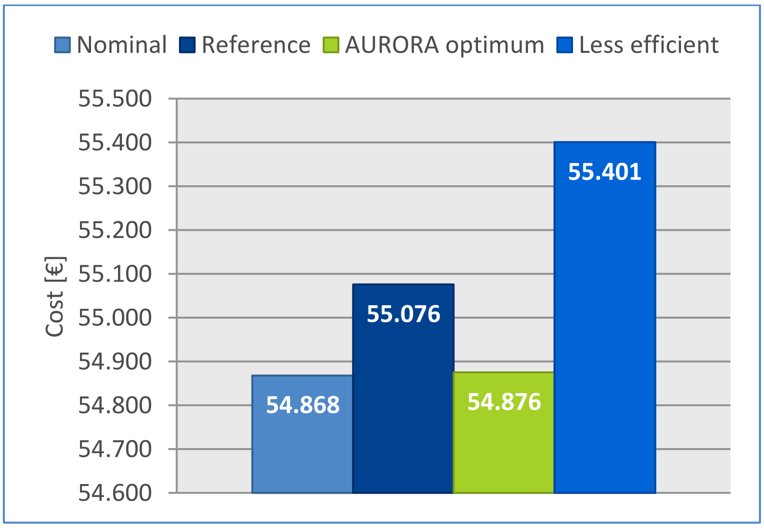


Figure 10. Flight cost comparison between nominal, reference and AURORA-based scenarios

Success Criteria 2.2.1-3: "Deviation of the efficiency target per flight when implementing a STAM measure using AURORA's indicators is less than deviation with actual STAM measures".

As specified in Section 2.4, the efficiency target for a flight is the efficiency of the flight plan, as assumed to have been agreed between the NM-ANSP and the Airspace Users.

Figure 10 summarizes the efficiency of the nominal trajectories (flight plans) if no hotspot was to be solved, compared with the actual STAM applied scenario and the AURORA's indicators-based best scenario.

Comparing both rows of deviations, it can be extracted that the efficiency deviation from the target is smaller in the AURORA's STAM scenario than in the actual STAM scenario. Actually, with AURORA's STAM scenario, the indicators themselves may improve the efficiency targets agreed previously, as can be seen in "Dev. Nom-AURORA" row.

Every assessment provided in the previous pages has been performed assuming that only 2 STAMs were to be applied. However, from the assessment on the occupancy capacity performed in [5], the requirement is not that 2 flights had to receive STAMs, but instead 5 flights should to be readjusted, as the sector LECMDGU's occupancy capacity is 16.

An evaluation on how the optimum efficiency indicators may shift when the required number of STAM to be applied varies from 2 to 5 is shown in Table 11. Notice that huge deviations derive from very small indicators. Together with this table, Figure 11 and Figure 12 show the horizontal profile of the optimum AURORA-based scenario with 5 STAM applied in terms of the KEA and the CEA_C1 indicator. Despite to what happened in the 2-STAM case scenario; the optimum solution for the 5-STAM case scenario is not unique and depends on the indicator that is to be optimized. The indicators shown in Table 11 are the optimum one for each indicator.

CASE	KEA	KEA_P	KEA_C1	KEA_C2	FEA_P	FEA_C1	FEA_C2	CEA_P	CEA_C1	CEA_C2
Nominal	6.896	0.000	6.988	-0.697	0.000	5.531	2.077	0.000	7.977	3.189
Reference	7.089	0.172	7.181	-0.527	0.450	5.980	2.509	0.356	8.359	3.543
AURORA	6.845	-0.049	6.937	-0.745	0.031	5.563	2.107	0.015	7.994	3.205
Dev. Nom-Ref	2.8 %	-	2.8 %	24.4 %	-	8.1 %	20.8 %	-	4.8 %	11.1 %
Dev. Nom-AURORA	-0.7 %	-	-0.7 %	-6.9 %	-	0.6 %	1.4 %	-	0.2 %	0.5 %
Difference on deviations	- 3.5 %	-	- 3.5 %	- 31.3 %	-	- 7.5 %	- 19.4 %	-	- 4.6 %	- 10.6 %

Table 10. Efficiency deviations of the reference and the optimum AURORA-based scenario

NUMBER OF STAM APPLIED	KEA	KEA_P	KEA_C1	KEA_C2	FEA_P	FEA_C1	FEA_C2	CEA_P	CEA_C1	CEA_C2
2 STAM Optimum	6.845	-0.049	6.937	-0.745	0.031	5.563	2.107	0.015	7.994	3.205
5 STAM Optimum	6.844	-0.049	6.937	-0.746	0.381	5.936	2.464	0.309	8.307	3.505
Deviation	0.0 %	0.4 %	0.0 %	0.0 %	1120.3 %	6.7 %	16.9 %	2027.0 %	3.9 %	9.4 %

Table 11. Efficiency deviation for different number of STAM applied based on AURORA indicators

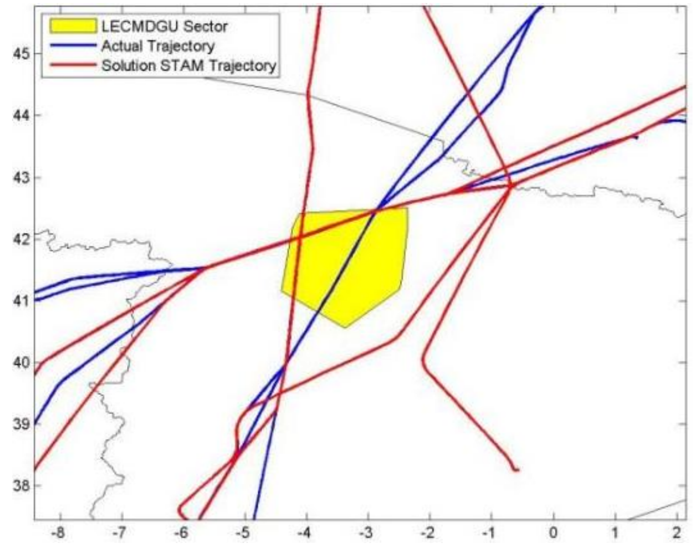


Figure 11. Horizontal profile of the trajectories that define the optimum AURORA-based scenario. Optimization based on KEA indicator. 5 STAM applied

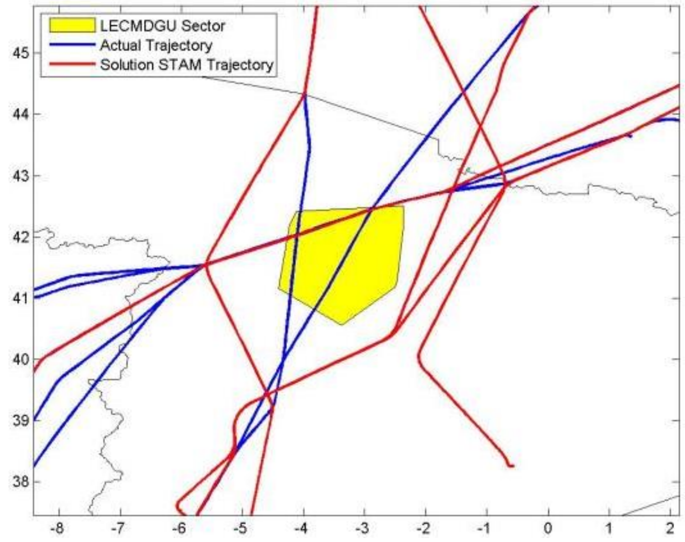


Figure 12. Horizontal profile of the trajectories that define the optimum AURORA-based scenario. Optimization based on CEA_C1 indicator. 5 STAM applied

As expected, larger deviations appear in the indicators as the number of flights that would require a STAM increases. This trend increases exponentially as the number of STAM increases. This trend can be appreciated in Figure 13 where the reference scenario is also shown.

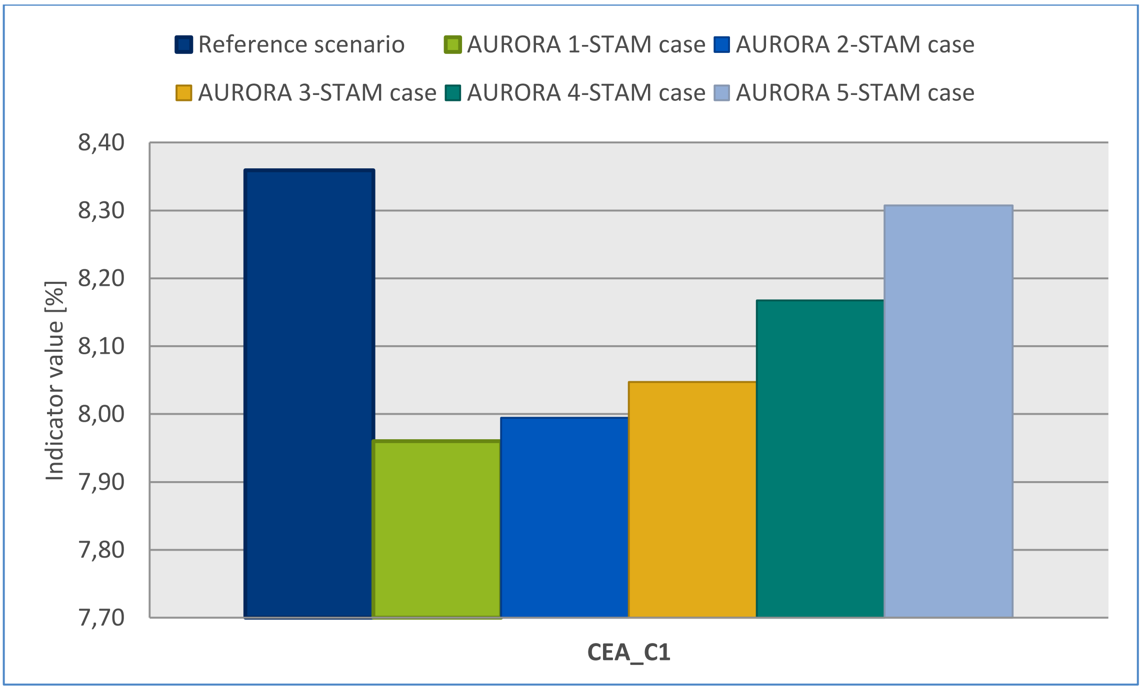


Figure 13. Impact of the number of STAM required to solve a hotspot on the CEA_C1 indicator

It is still remarkable that the solution adopted in reality holds a less efficient solution in terms of costs than the most efficient solution if 5 STAM were required to be applied. And one of the reasons to these differences between the reference scenario and the optimum scenarios is the difference in efficiency when applying different types of STAM.

Table 12 shows the deviations suffered by the optimum AURORA-based solution for a 5-STAM case depending on the types of STAM applied. "Combination" row refers to the possibility of applying any STAM on any case, while the "Only RR" and "Only LC" refer to the possibility of applied exclusively one type of STAM. Additionally, Figure 14 and Figure 15 introduce the values for fuel consumption and flight costs of the solutions.

As it can be extracted from the figures and table, Re-Routings provide higher inefficiencies in terms of the distance-based indicators, while lower inefficiencies in terms of the fuel-based and cost-based indicators are found. This contradicts the current view on efficiency, where higher efficiency in distance is the best option. In the case the hotspots were solved with a view on other types of efficiency (fuel and cost), the hotspot resolution may be more efficient based on AURORA's indicators.

From all the points of view discussed under these success criteria, the validation objective has been set as OK.

	KEA	KEA_P	KEA_C1	KEA_C2	FEA_P	FEA_C1	FEA_C2	CEA_P	CEA_C1	CEA_C2
Combination	6.844	-0.049	6.937	-0.746	0.381	5.936	2.464	0.309	8.307	3.505
Only RR	7.270	0.355	7.362	-0.345	0.488	6.044	2.572	0.390	8.397	3.587
Only LC	6.896	0.000	6.988	-0.697	0.918	6.468	2.977	0.617	8.641	3.822

Table 12. Impact of the type of STAM implemented. 5-STAM applied

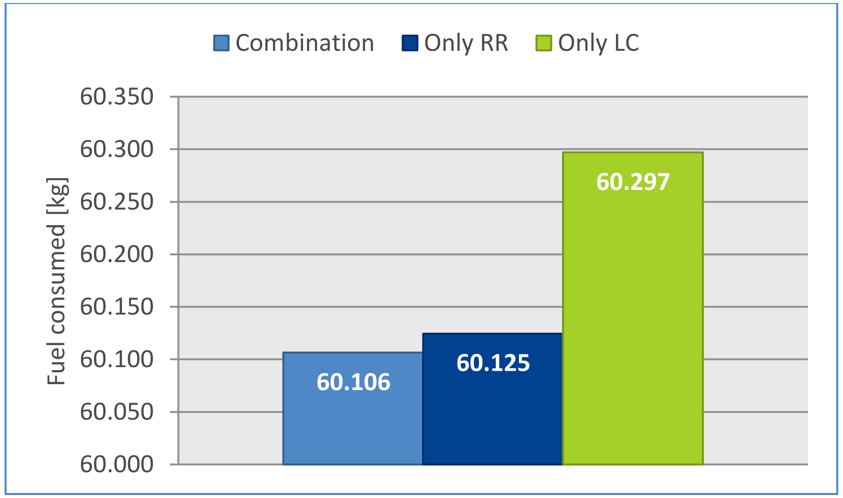


Figure 14.Fuel consumption comparison between different STAM applicability rules. 5 STAM scenario

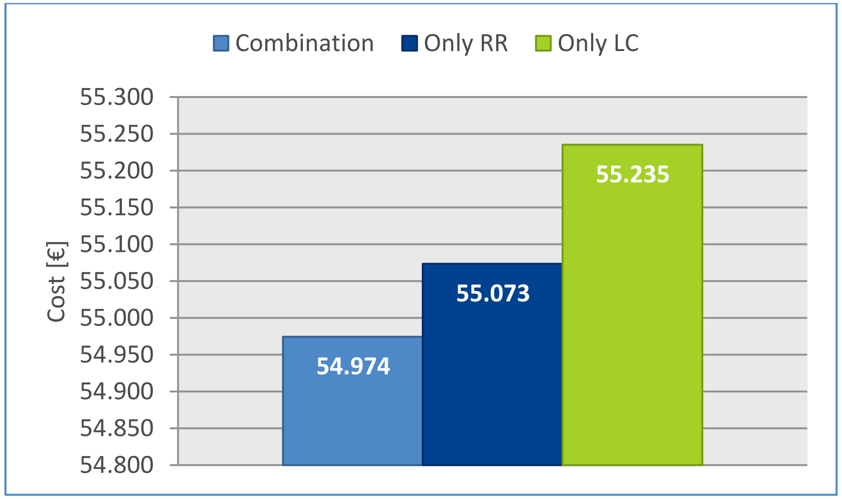


Figure 15. Flight cost comparison between different STAM applicability rules. 5 STAM scenario

4 Conclusions and recommendations

4.1 Conclusions

This section gives a summary of the conclusions of the analysis performed in this document. It prepares the recommendations.

The main conclusions extracted from the Exercise are the following:

- The introduction of AURORA's efficiency indicators improves the general efficiency view of hotspots. What's more, it was proved that there are a wide range of possible STAM solutions and each of them provides different efficiency values for AURORA's indicators. These indicators can be optimized to ensure that the selection of STAM is the most efficient one.
- Current view on flight efficiency for the NM and the PRU is based on flown distance, rather than in fuel consumption or flight cost, which suits better the expectations of the AUs. AURORA's indicators provide hotspot resolution in terms of fuel and cost efficiency instead of distance flown.
- The type of STAM to be applied is highly impacting the efficiency of flights that may receive a Level-Capping or a Re-Routing, depending on the NM decision. This decision weights better the application of a Level-Capping instead of a Re-Routing. AURORA's indicators have shown that in terms of fuel consumption and flight cost, Level-Capping is not always the best option when considering AUs' view on efficiency.
- The type of STAM to be implemented is impacting the fuel consumption and costs of the affected flights. Specifically, depending on the decision on which STAM to apply, the fuel consumption of the affected flights can provide reductions of 500 kilograms, and a cost reduction of 250 €.
- The number of STAM to be applied in a hotspot affects negatively the efficiency indicators. The more STAM required to be applied, the worse the efficiency indicators result. However, selecting the appropriate set of STAM to be implemented (which may be even higher than the required ones) may be more efficient than sticking to apply less STAM which are more inefficient.

4.2 Recommendations

This section captures the main recommendations to improve the operational benefits reached:

- Test another scenario with different number of STAMs applied and including a real case of Re-Routing application in order to determine the impact of these types of measures.
- Assess the impact of application of STAM using AURORA's indicators in the whole ECAC. The evaluation of all hotspots in a larger area will provide a more general view on efficiency, and will provide an optimum resolution of every hotspot for the sake of general efficiency rather than a local efficient resolution of a single hotspot.
- Evaluate the impact of STAM in the long-term for a hotspot. The constant resolution of hotspot in the same way may provide a deeper view on specific characteristics of the hotspot and why specific STAMs are applied. It will also provide a view on how Equity is share in the hotspot.

5 References

[1] AURORA D2.1, "Definition of User-Centric Air Traffic Efficiency Indicators", Edition 00.0.1.01, Feb 2017.

[2] AURORA D3.1, "Description of experimental plans", Edition 00.01.00, Feb 2017.

[3] AURORA D3.2, "Report on testing of user-centric air traffic efficiency indicators and local targets", Edition 00.01.00, Jul 2017

[4] AURORA D3.3, "Report on testing of advanced performance data model", edition 00.01.00, Mar 2018

[5] PJ13.02.03 VALP, "Validation Plan Step 1 Release 5", Edition 00.01.00, Sept 2015

[6] PJ04.07.01 VP-005 VALP, "Step 1 V3 Validation plan (Final Version Edition 2)", Edition 00.02.00, Dec 2015

[7] PJ.05.03 VP-804, "Validation Exercise Plan EXE-05.03-VP-804", Edition 00.02.01, Dec 2015

Appendix A Set of indicators tested

The following table summarizes the set of indicators that has been tested in this validation, together with their description, the required data and the specific formula used for its computation.

Code	Description	Formula
KEA	Horizontal flight efficiency of actual trajectory taking as reference the minimum flown distance	$KEA = (\frac{L_{AT}}{H} - 1)\%$ Where L_{AT} is the horizontal distance flown by the reconstructed trajectory based on surveillance data and H is the great-circle distance between origin and destination
KEA_P	Horizontal flight efficiency of actual trajectory taking as reference the flight plan flown distance	$KEA\_P = (\frac{L_{AT}}{L_{FP}} - 1)\%$ Where L_{FP} is the horizontal distance flown by the flight plan
KEA_C1	Horizontal flight efficiency of actual trajectory taking as reference the minimum cost trajectory in free flight	$KEA\_C1 = (\frac{L_{AT}}{L_{OCT1}} - 1)\%$ Where L_{OCT1} is the horizontal distance flown by the minimum cost trajectory in free flight
KEA_C2	Horizontal flight efficiency of actual trajectory taking as reference the minimum cost trajectory following horizontally the flight plan	$KEA\_C2 = (\frac{L_{AT}}{L_{OCT2}} - 1)\%$ Where L_{OCT2} is the horizontal distance flown by the minimum cost trajectory following horizontally the flight plan
FEA_P	Comparison between calculated fuel consumption of the actual trajectory and fuel consumption calculated of the flight plan	$FEA\_P = (\frac{\Delta m_{AT}}{\Delta m_{FP}} - 1)\%$ Where Δm_{AT} is the fuel consumption of the reconstructed trajectory based on surveillance data, and Δm_{FP} is the fuel consumption of the flight plan
FEA_C1	Comparison between calculated fuel consumption of the actual trajectory and fuel consumption of the minimum cost trajectory in free flight	$FEA\_C1 = (\frac{\Delta m_{AT}}{\Delta m_{OCT1}} - 1)\%$ Where Δm_{OCT1} is the fuel consumption of the minimum cost trajectory in free flight
FEA_C2	Comparison between calculated fuel consumption of the actual trajectory and fuel consumption of the minimum cost trajectory following horizontally the flight plan	$FEA\_C2 = (\frac{\Delta m_{AT}}{\Delta m_{OCT2}} - 1)\%$ Where Δm_{OCT2} is the fuel consumption of the minimum cost trajectory following horizontally the flight plan

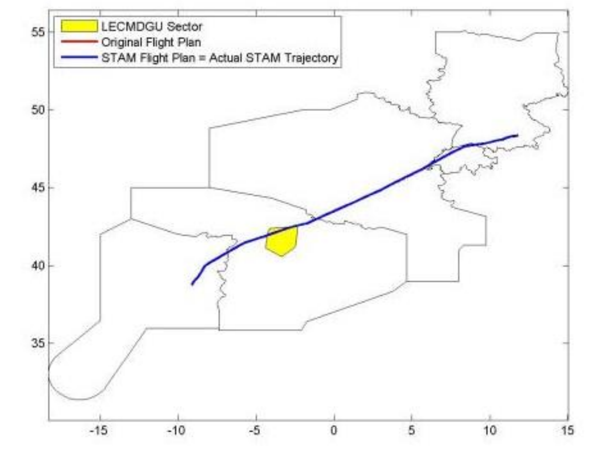
Code	Description	Formula
CEA_P	Comparison between calculated costs of actual trajectory and calculated costs of the flight plan	$CEA\_P = (\frac{C_{AT}}{C_{PF}} - 1)\%$ $C = p_{FUEL} \cdot (\Delta m + CI \cdot \Delta t) + RC$ Where C_{AT} is the calculated cost of the reconstructed trajectory based on surveillance data, C_{FP} is the calculated cost of the flight plan, p_{FUEL} is the average fuel price, CI is the Cost Index and RC are the route charges
CEA_C1	Comparison between calculated costs of actual trajectory and calculated costs of the minimum cost trajectory in free flight	$CEA\_C1 = (\frac{C_{AT}}{C_{OCT1}} - 1)\%$ $C = p_{FUEL} \cdot (\Delta m + CI \cdot \Delta t) + RC$ Where C_{OCT1} is the calculated cost of the minimum cost trajectory in free flight
CEA_C2	Comparison between calculated costs of actual trajectory and calculated costs of the minimum cost trajectory following horizontally the flight plan	$CEA\_C2 = (\frac{C_{AT}}{C_{OCT2}} - 1)\%$ $C = p_{FUEL} \cdot (\Delta m + CI \cdot \Delta t) + RC$ Where C_{OCT2} is the calculated cost of the minimum cost trajectory following horizontally the flight plan

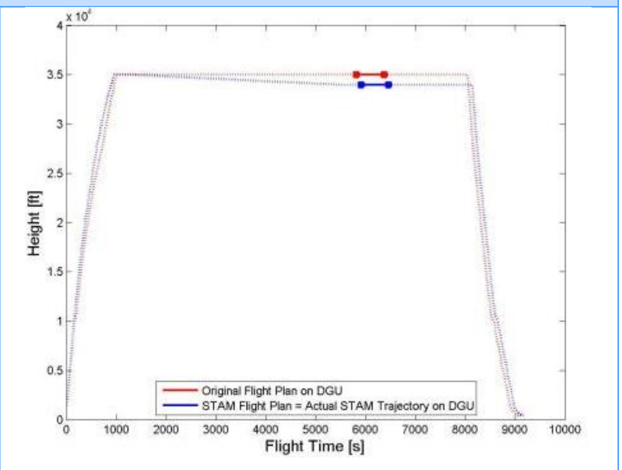
Appendix B Applicable STAM

The following figures show the complete set of applicable STAM to the eligible flights defined in Section 2.3. Each of these flights can apply the two types of STAM considered: Level-Capping and Re-Routing. The following figures show the horizontal and vertical profiles of each of these STAM.

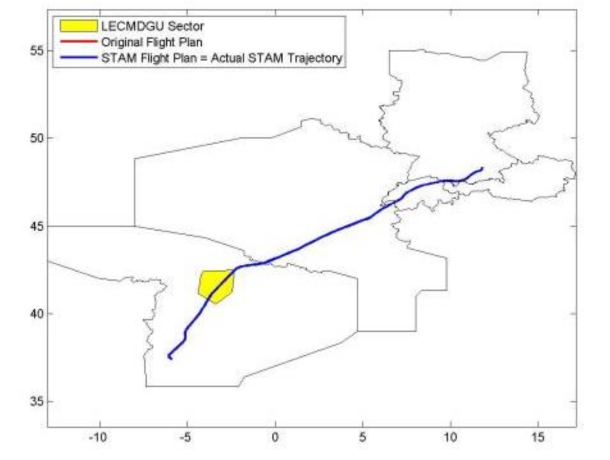
B.1 Level-Capping

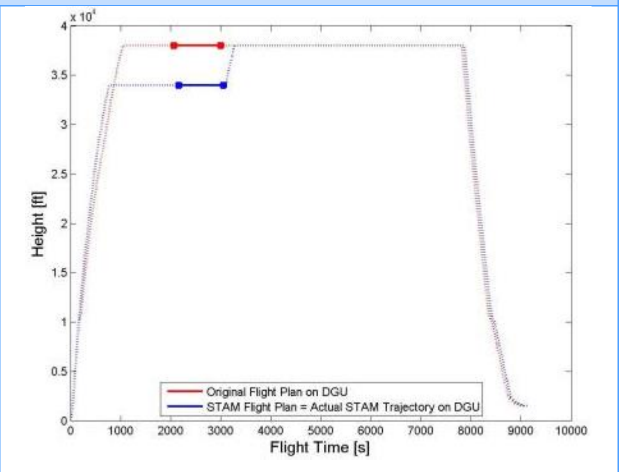
DLH61J, EDDM-LPPT



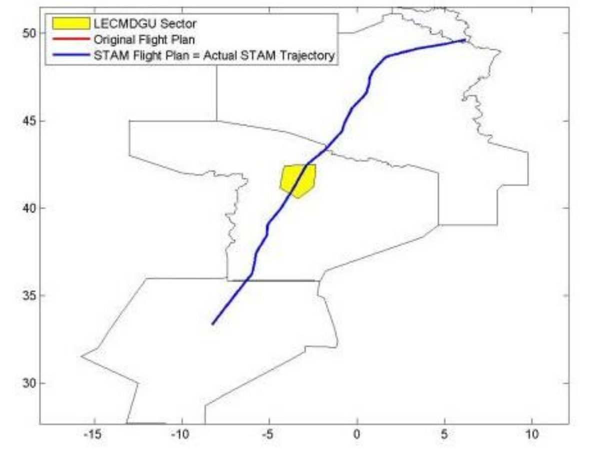


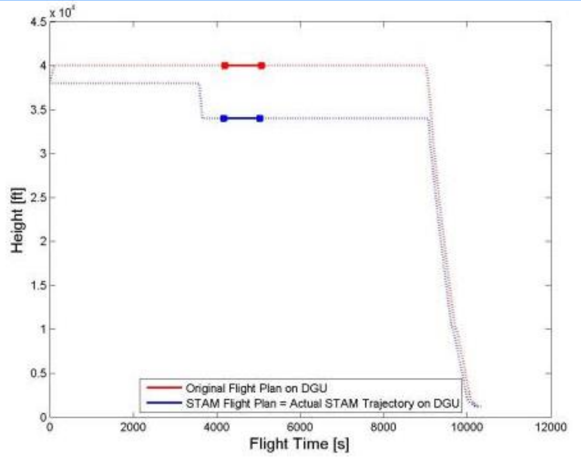
DLH88H, LEZL-EDDM



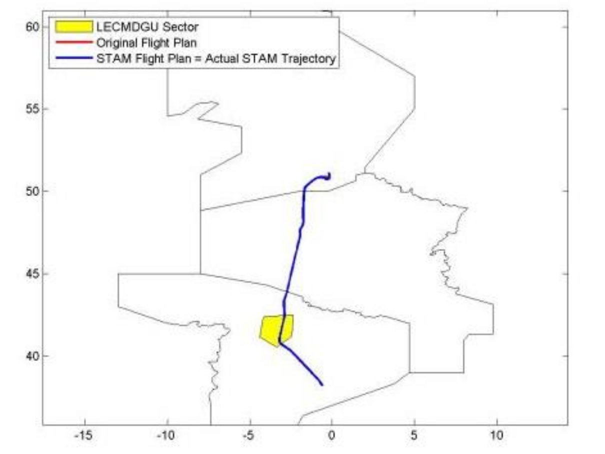


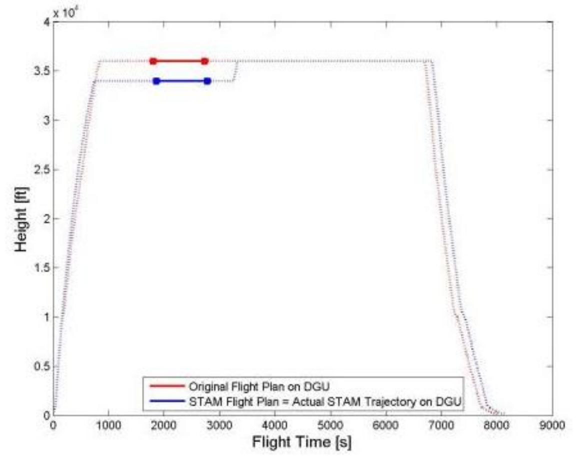
LGL742, GCRR-ELLX



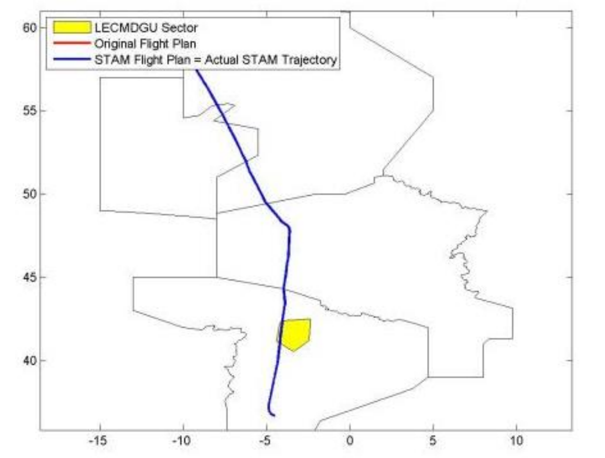


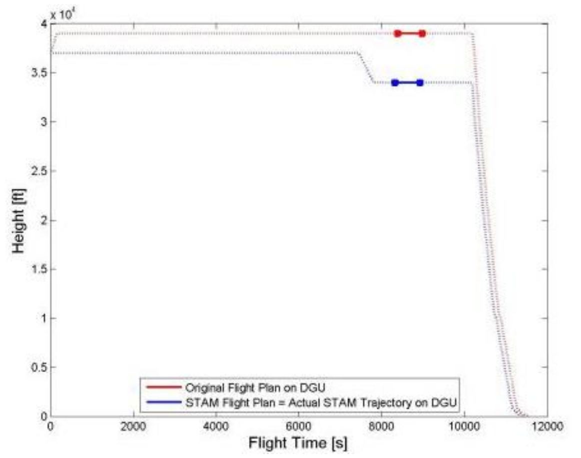
MON35MK, LEAL-EGKK



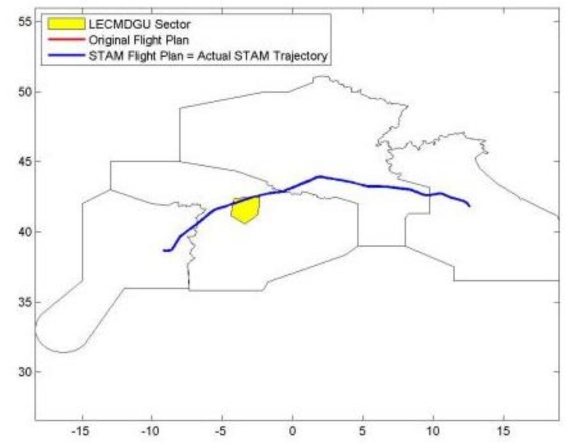


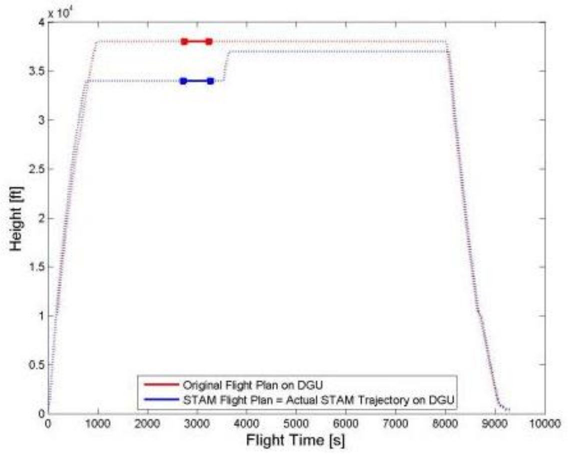
PRW111, BIKF-LEMG



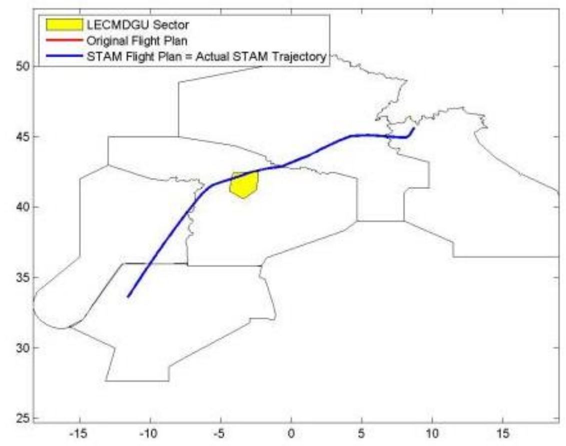


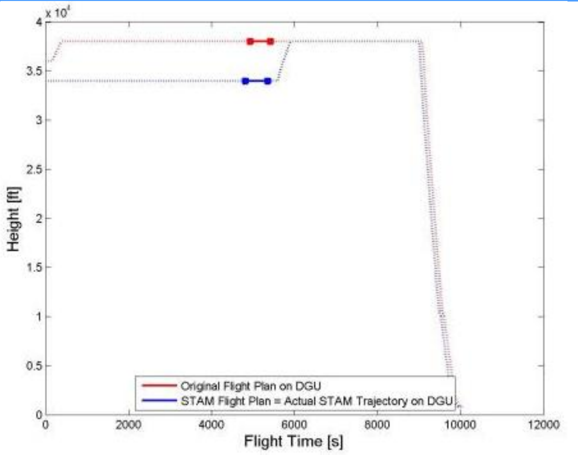
RYR6LV, LPPT-LIRA



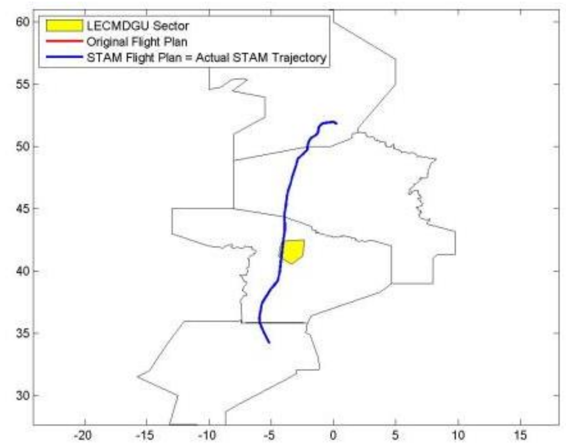


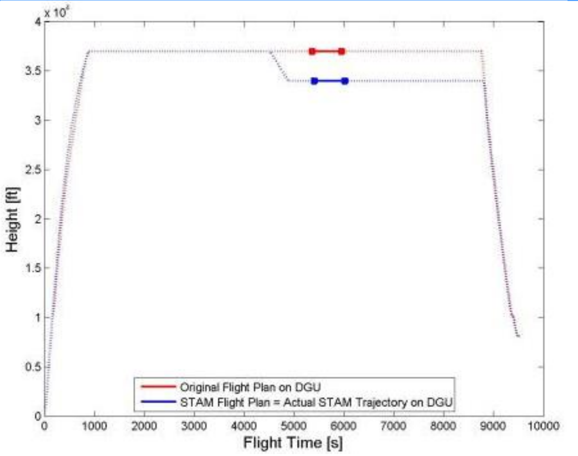
RYR7UC, GCLP-LIMC



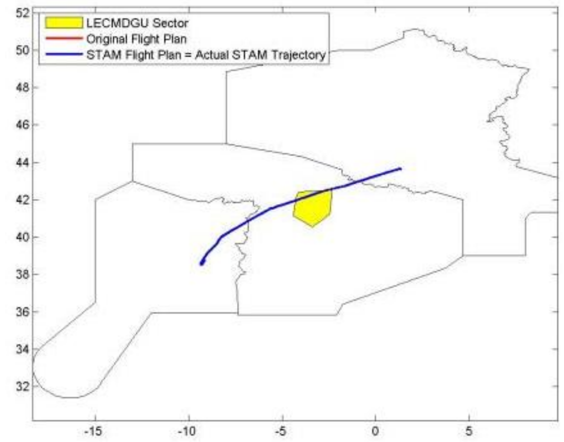


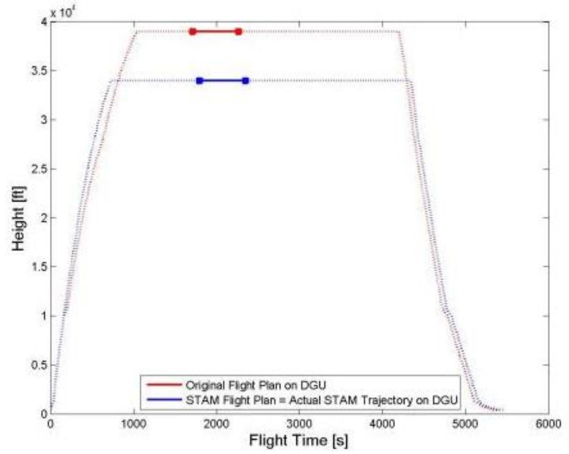
RYR9XU, EGSS-GMFF



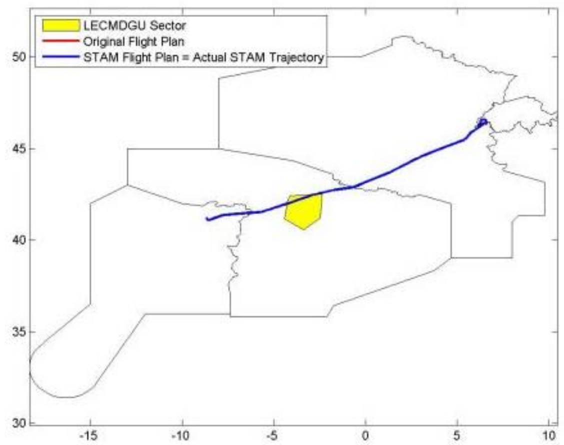


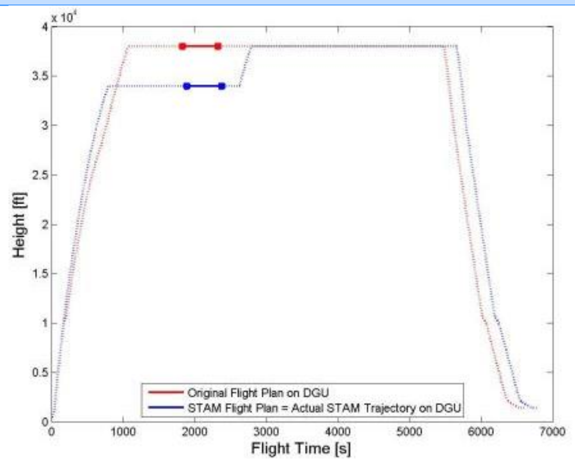
TAP491M, LFBO-LPPT



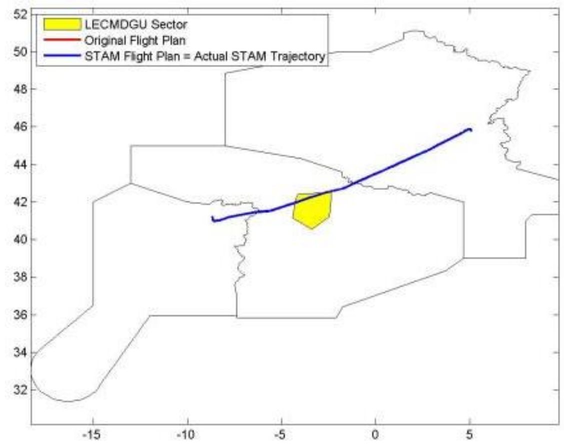


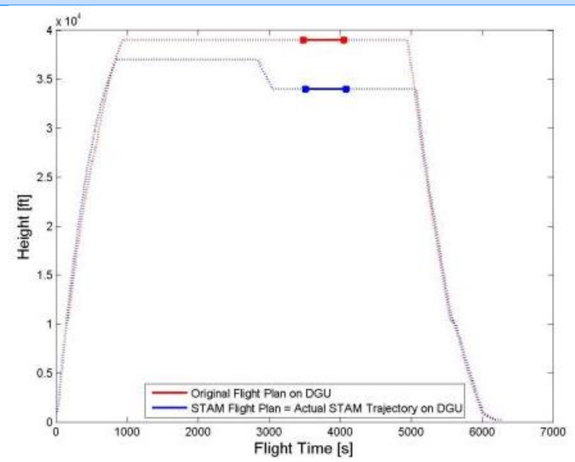
TAP938L, LPPR-LSGG



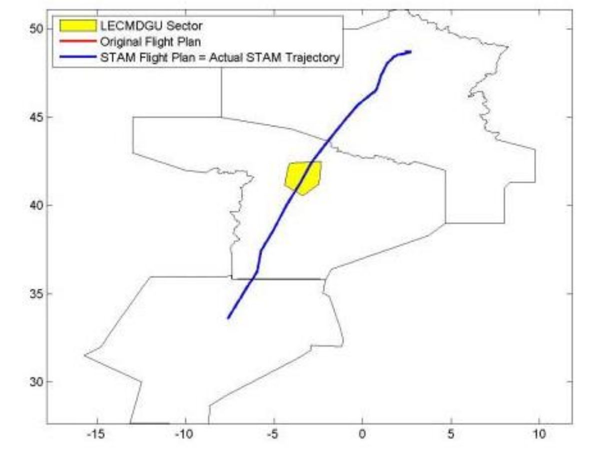


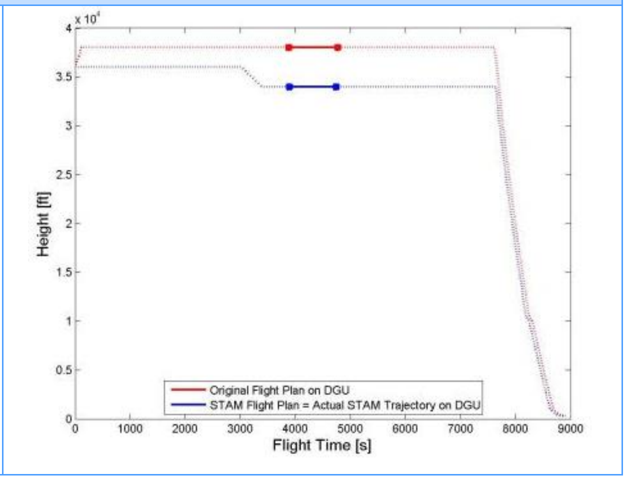
TVF09HR, LFLL-LPPR





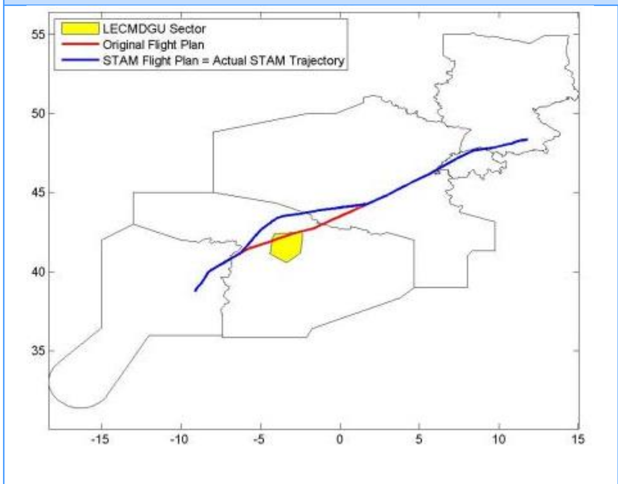
TVF09KA, GMMX-LFPO

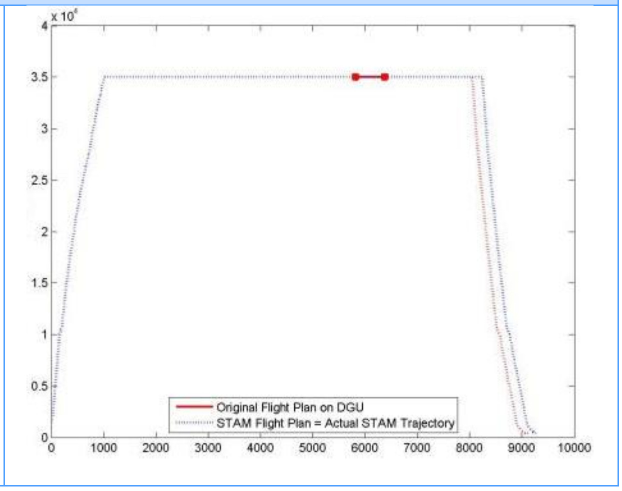




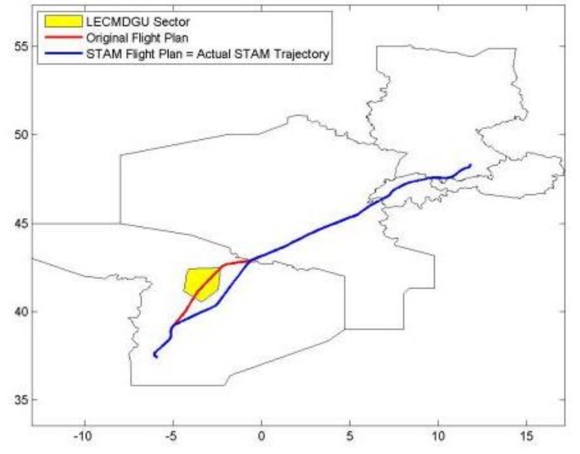
B.2 Re-Routing

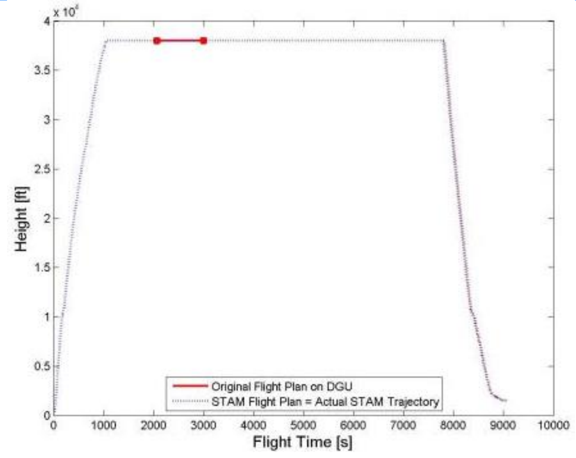
DLH61J, EDDM-LPPT



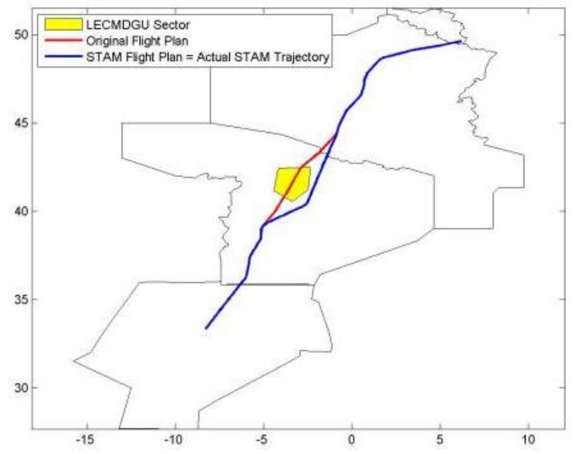


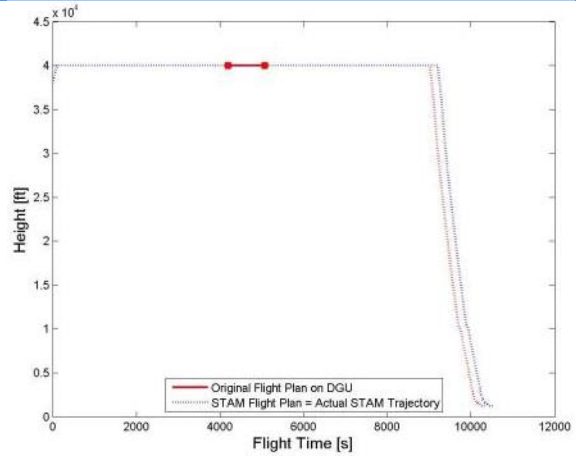
DLH88H, LEZL-EDDM



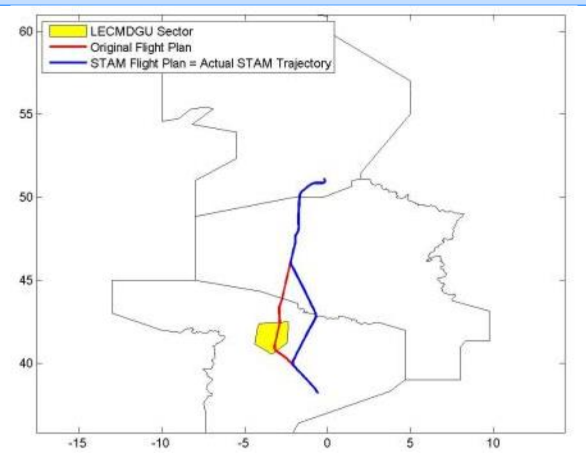


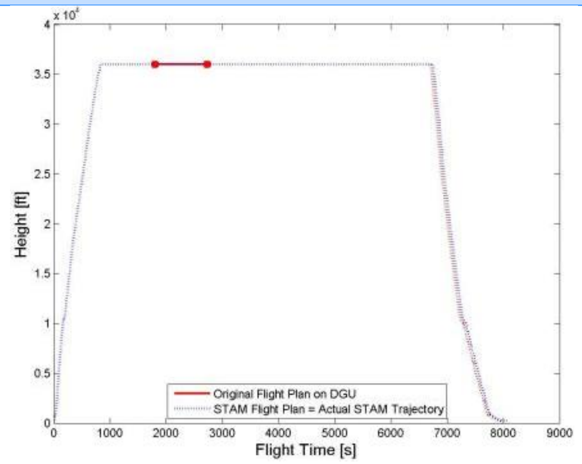
LGL742, GCRR-ELLX



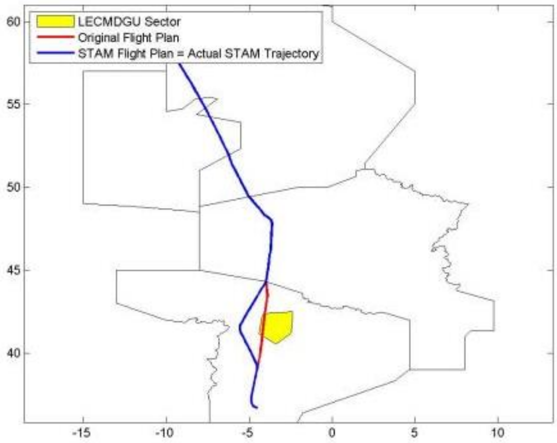


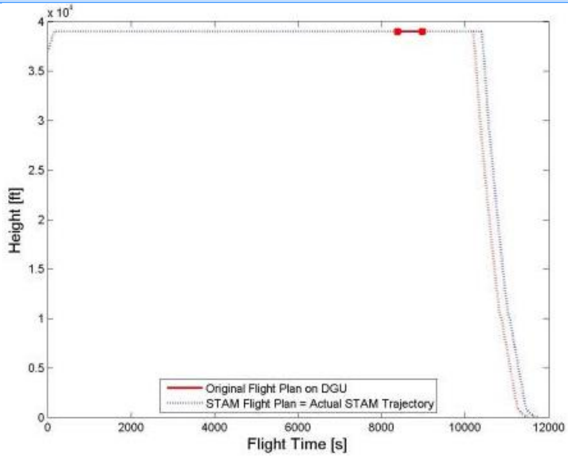
MON35MK, LEAL-EGKK



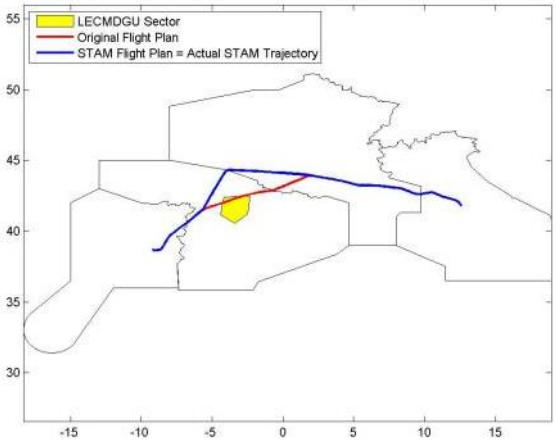


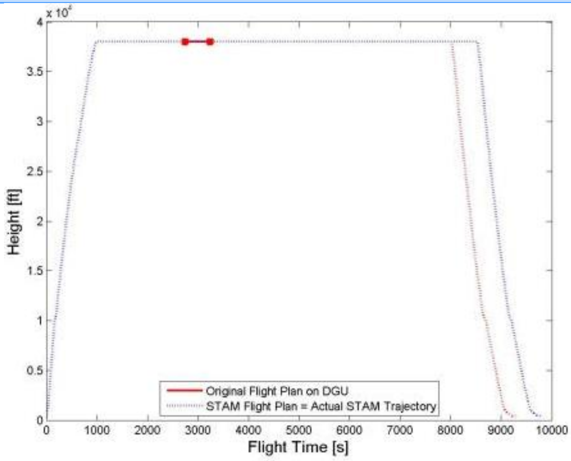
PRW111, BIKF-LEMG



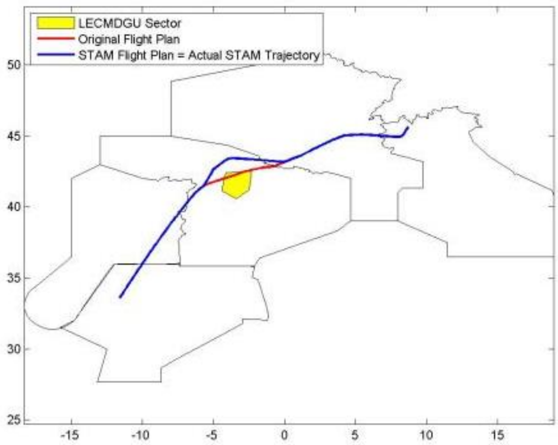


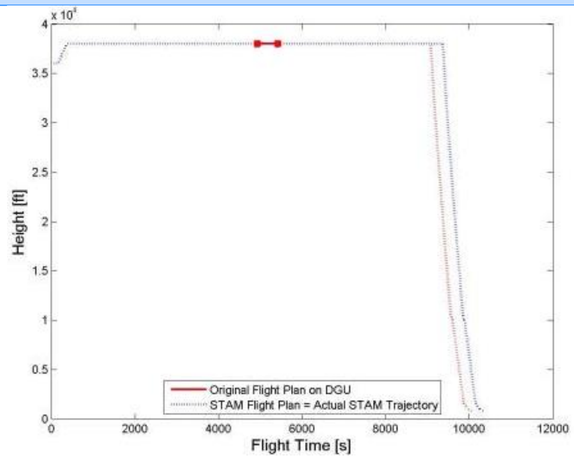
RYR6LV, LPPT-LIRA



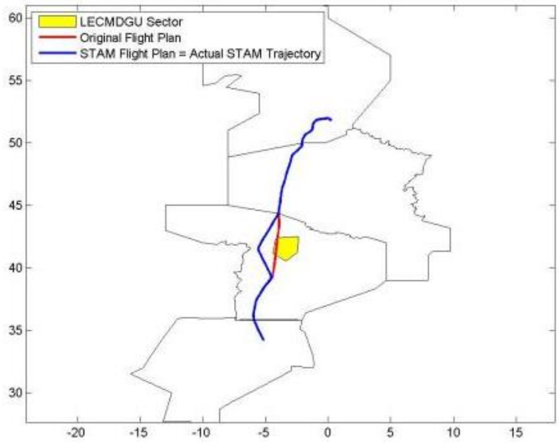


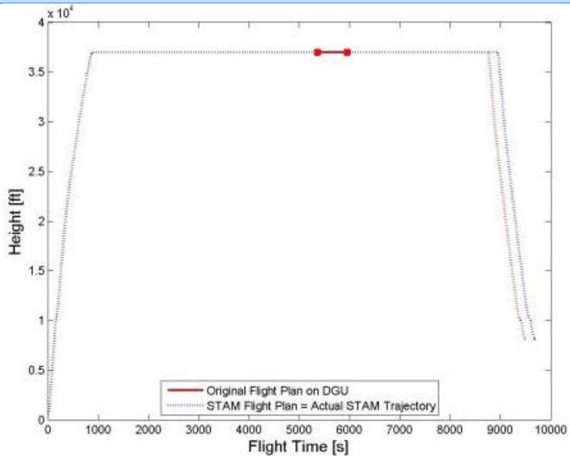
RYR7UC, GCLP-LIMC



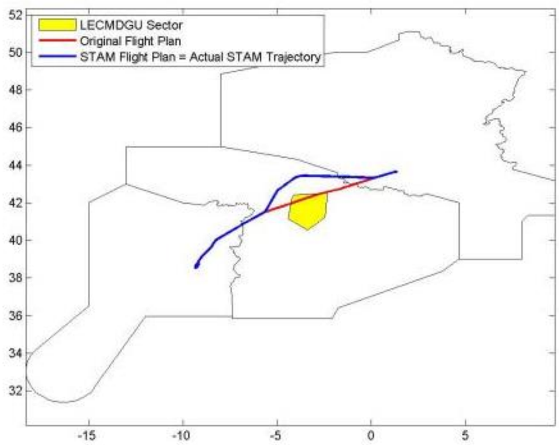


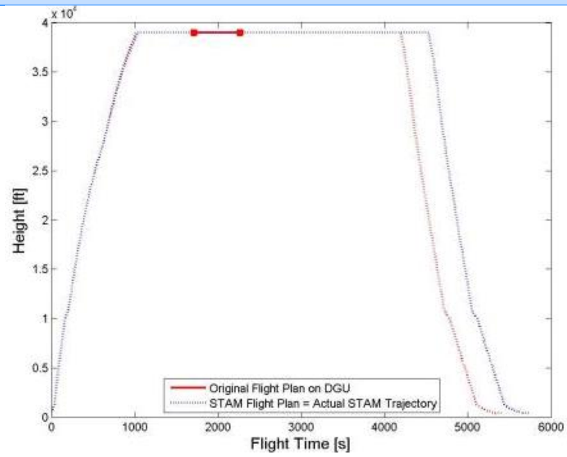
RYR9XU, EGSS-GMFF



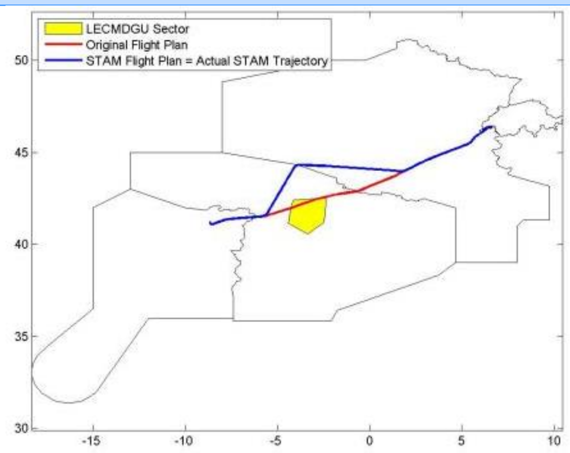


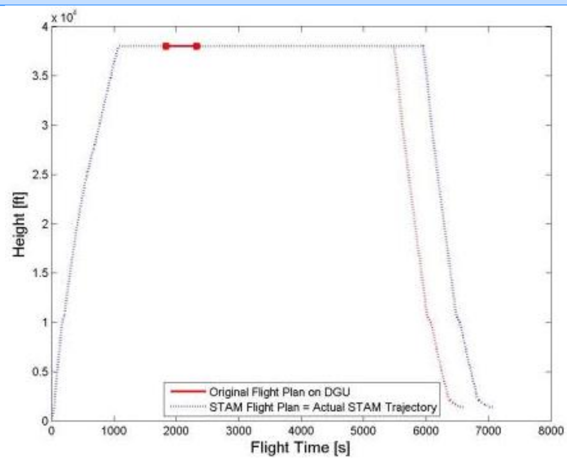
TAP491M, LFBO-LPPT



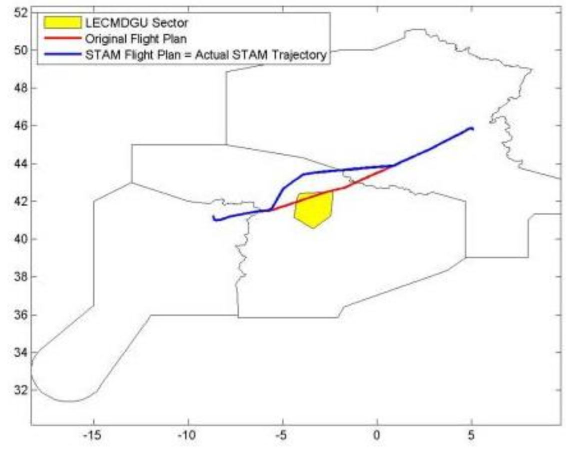


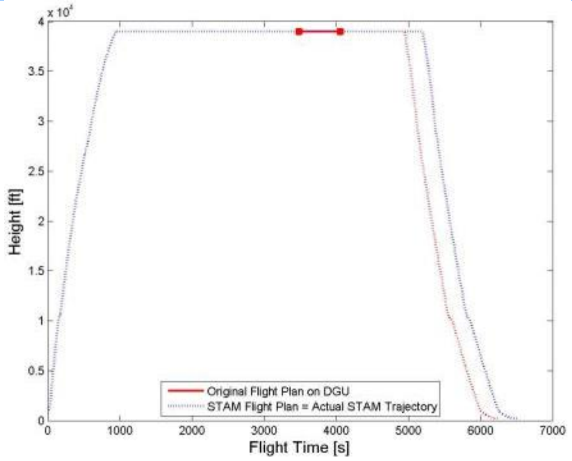
TAP938L, LPPR-LSGG





TVF09HR, LFLL-LPPR





TVF09KA, GMMX-LFPO