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ALBATROSS

THE MOST EFFICIENT FLYING BIRD

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Abstract

The ALBATROSS project conducted eight groups of demonstrations of several concepts bringing a reduction of the carbon footprint of aviation, in particular ATC/ATM. This report describes the activities conducted and the results obtained. Some of the activities had to be carried out differently than planned, due to the effects of the last relapses of the covid crisis, and then due to sudden reprise of traffic. However, the overall results are extremely satisfying: specific real world improvements have been researched or deployed, always in large-scale real-world operational contexts, with many results remaining as part of operations after the end of the project.

This project can be considered a visible sign of the concrete and long-lasting reduction of the carbon footprint of European aviation, taking advantage of available air- and ground-technology and of collaborative processes. Further steps are still required and possible, and ALBATROSS also paves the way for further progress.

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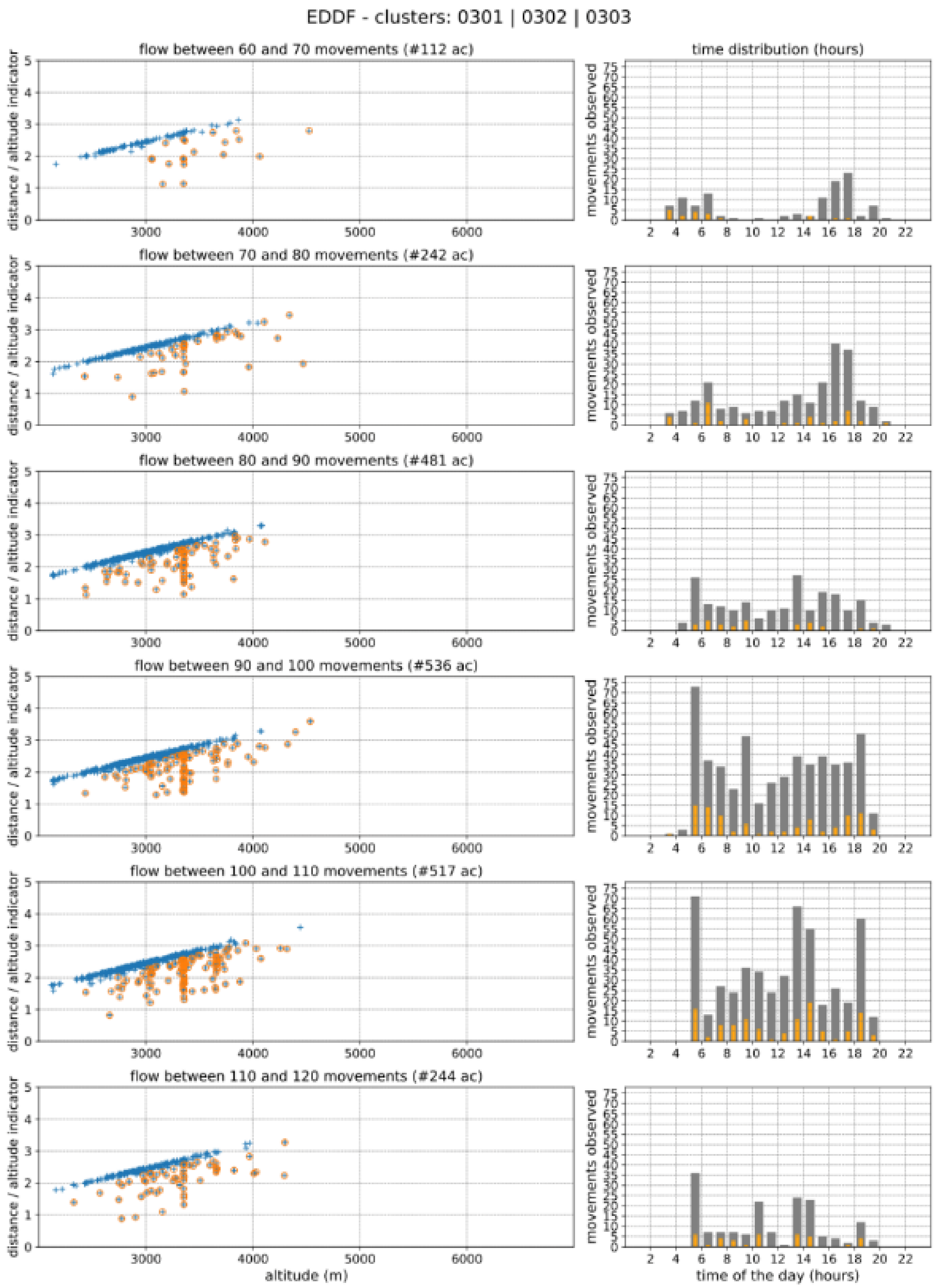

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1 Executive summary

The objective of the ALBATROSS project was to demonstrate ATM operations mitigating aviation's environmental footprint and contributing to the reduction CO2 emissions. The project explored various possibilities for ATC and airlines to facilitate flights with "Zero waste of fuel and CO2 emissions". A series of exercises, including live trials, have demonstrated to what extent such flights, called "Greener Flights", can be defined and executed in various operating environments.

The project conducted eight groups of demonstrations of several concepts. This report describes the activities conducted and the results obtained.

The key ideas of the project revolve around the notion of "smart innovation" in ATM/ATC/flight operations, to complement CO2 reductions enabled by larger investment (new aircraft, advanced ATM tools). Smart innovation means: Executing known processes with more fine-tuned flight parameters; Coordinating all actors, to relax airspace constraints when they are not necessary; Exploiting the increasingly available advanced aircraft capabilities, such as precision navigation and data sharing; Exploiting the tools of modern data science. ALBATROSS has shown how these approaches, sometimes combined, bring improvements that might seem small, individually, but that are repeatable on very many flights.

ALBATROSS defined and calculated the "flight with zero-waste of CO2". Used as a reference, this calculation allows to size ATM inefficiency for a specific route/airspace and aircraft type; on the Paris-Stockholm route taken as an example, excess emissions of about 10% were evaluated for the A320 a/c family. Most ALBATROSS exercises (not only on CDG-ARN) could show that thanks to the applied improvements, excess emissions were routinely reduced by one-third to one-half, sometimes more, on the concerned segment of flight (i.e. a gain of 3-5% on the baseline of "current operations").

The concepts demonstrated in the exercises, with their main objectives, method of demonstration and outcomes, are listed below. The Arrivals segment (especially the vertical profile) received particular attention, having the biggest margin of improvement. However the activities also covered: the departure and the en-route segments; the taxiing segment, object of two activities; and last but not least, additional decarbonation initiatives from "SAF dematerialization" and "hydrogen generators".

- A "Gate-to-Gate" exercise had the ambition to apply multiple of the concepts of all other exercises at the same time, with additional improvements in the en-route segment. Planning difficulties (calendars) resulted in a smaller-than-hoped-for scope of execution, but nevertheless more than 100 flights could be evaluated on two to four improvements. Particularly successful was the evaluation of "Dynamic-RAD" mechanisms.

- The "LNAS: energy-optimised descent profiles" exercise demonstrated a novel combination of closed-path PBN-to-ILS procedure in Zürich, with and without an energy-management pilot-assistance system (LNAS) used by Swiss International Airlines. The demonstrated benefits, were significantly more predictable vertical and airspeed profiles, lower average thrust settings, lower use of speed brakes, and overall lower fuel burn from the last 30 NM.

- Two exercises conducted precise post-ops evaluations of the inefficiencies of arrival procedures in the TMA, analyzing thousands of real trajectories: the DUS/CGN TMA, using advanced Machine

Learning/Artificial Intelligence; The Stockholm-Arlanda TMA, comparing real fuel burn to a calculated "perfect flight".

- Two exercises on "PBN-to-Final": one procedure deployment in Vienna; and in Paris-CDG, an advanced analysis method was devised to assess the PBN-to-ILS live trials conducted by DSNA

- During several incremental iterations, optimized descents were implemented in the peculiar airspace structure of CDG arrivals. Multiple possibilities of altitude relaxations were investigated, at three "scales": Final approach / STARs / Full descent ToD-to-landing. These improvements, collectively designated as "Green Descents", benefited more than 5000 flights during the project, and some STARs will be permanently adapted.

- Two exercises demonstrated flight optimization solutions that consider parameters variation of individual aircraft or flights, and propose fine-tuned vertical profiles (executed by the FMS or by the crew).
For the descent phases, the "DPO" and "IFO" solutions provided by NAVBLUE / AIRBUS have been used in real operations by Novair. These tools act on each individual aircraft's FMS parameters, allowing reduced engine thrust margins and a fine-tuned IDLE factor, resulting in optimal descent profile / TOD position. With DPO/IFO on A321 NEO (362 flights), a reduction of 160kg of CO_2 per descent was estimated.
For the climb phases, OptiClimb calculates a climb profile that is unique per aircraft/flight, based on a machine-learning model for the specific aircraft serial number, flight load, and the latest weather parameters. Applied on several dozens long-haul Air France departures, a reduction of 300kg of CO_2 per departure was measured.

- The taxiing segment was the subject of two exercises:
The "Taxi-Bot at Schiphol" exercise aimed to create a better understanding of Sustainable Taxiing based on trials using TaxiBot vehicles to taxi aircraft from Runway-to-Gate and Gate-to-Runway. While the trials scope was reduced, partners made meaningful progress on some of the main hypotheses, gained some of the envisioned learnings and further progressed on the CONOPS.
The planned exercise by AF on Single-Engine Taxiing at Departure had to be descoped to a feasibility study for implementation of "go-nogo" decision-support to be continued in future projects.

- Two "additional decarbonization initiatives" not directly applied to operations, were the study of the "Book and Claim" mechanism for dematerialized usage of Sustainable Aviation Fuels, as a way to solve SAF limited physical availability and the deployment of hydrogen-based backup power supplies by DSNA, testing the prerequisites of large-scale operational deployment.

In conclusion, the overall results are extremely satisfactory. All demonstrations applied their concepts in real-world very-large-scale contexts. Detailed quantitative analysis confirmed the benefits. At least six concepts resulted in permanent deployment or use solutions that are already operationally available. Lessons learned resulted in a "Concept of Operations" (a dedicated project deliverable) to inspire the ATM/aviation community about deployable concepts that reduce the carbon footprint.

The project contributed two SESAR Solutions: "Dynamic-RAD" and "Engines-off Sustainable Taxiing through use of a Sustainable Taxiing Vehicle".

ALBATROSS is a visible sign of the concrete long-lasting reduction of the carbon footprint of European aviation, taking advantage of available air- and ground-technology and of collaborative processes. Further steps are still required and possible, and this project paves the way for further progress.

2 Introduction

2.1 Purpose of the document

This document is the Demonstration Report of project ALBATROSS. It consolidates the results obtained in the different demonstration exercises carried out in the project.

2.2 Scope

This is the DEMO Report for the VLD ALBATROSS.

2.3 Intended readership

The intended readership for this document is the SESAR Community at large. The project participants, the SESAR Joint Undertaking itself and any member, affiliate or associate having access right to this document might be interested to understand, up to a significant level of detail, the who, why, when, where and how the demonstration took place.

2.4 Background

The ALBATROSS project responds to the "Open VLD 2" call for projects issued by the SESAR2020 Programme (SESAR 2020 Open VLD2 Call H2020-SESAR-2020-1), and specifically to Topic 4 "Environmental sustainability".

The high level *raison-d'être* of the project can be described quoting from the text of the call: " This VLD aims at demonstrating ATM operations mitigating aviation's environmental footprint and significantly contributing to the reduction CO2 emissions. Applicants are invited to promote and demonstrate "zero CO2 waste" trajectories. Projects are encouraged to explore the possibilities for protecting green flights and environmentally optimised trajectories from unnecessary deviations or other constraints. "

Of the three known approaches for aviation to reach its carbon neutrality, the main focus of ALBATROSS is the optimization of operations (the two others being (i) new more efficient aircraft and engine technology and (ii) the usage of alternative fuel – notice however that an activity linked with SAF has also been carried out).

The ALBATROSS project was set up and executed in the midst of the covid crisis. The absence of income forced all actors to limit investment to the minimum, but the low traffic gave the opportunity to experiment new ways to perform known processes.

Seven "local" exercises concentrated on various concepts, while one "gate-to-gate" exercise had the ambition to bring multiple of them together. For the size and ambition, it has been a complex project, actually a set of multiple parallel projects. See section 3 for a high level description of the content, then Appendices A to H for the details.

2.5 Structure of the document

According to the template, the document contains the following parts :

Chapter 2 is an introduction and high level overview.

Chapter 3 describes the concepts concerned and summarizes the Demo Plan [19].

Chapter 4 describes at high level the results from the demonstrations.

Chapter 5 summarizes the high level conclusions from the project.

It must be kept in mind that ALBATROSS is a collection of many exercises, with more or less tight links amongst them. The individual exercises are described in detail in dedicated Appendices A to H.

2.6 Glossary of terms

Term	Definition	Source of the definition
4DTM	"4D Trajectory Management" is the name of SESAR Project PJ18 during the SESAR2020 wave 1, that hosted in particular the Solution 18-06 focussed to the enhancement of Trajectory Prediction computation based on information extracted from the ADS-C flight data (notably EPP).	Summary based on PJ18 Final Project Report
ADS-C	A means by which the terms of an ADS-C agreement will be exchanged between the ground system and the aircraft, via a data link, specifying under what conditions ADS-C reports would be initiated, and what data would be contained in the reports. ADS-C content includes among others: position, altitude, speed, managed modes, estimation to waypoint, elements of navigational intent and meteorological...	SESAR Concept of Operations Step 1, Edition 2015
Authorization	the security mechanism to determine access levels or user/client privileges related to system resources including files, services, computer programs, data and application features	
EPP	Specifies the aircraft predicted trajectory up to 128 waypoints including for each waypoint, Latitude, Longitude and when available, Fix, Level, ETA,	Baseline 2 ATS Data Communications

	Airspeed, Vertical type(s), Lateral type(s), Level constraint, Time constraint, Speed constraint. When available, provides the relevant data for the trajectory as Current gross mass and EPP trajectory intent status. It indicates the date and time these values were computed.	Standard: ED-228 march 2014 edition
CWP	Controller Working Position, i.e.: the operator (ATCO/AFISO) work station including necessary ATS systems.	06.09.03 – D09 – Contingency TWR trial 1 validation report
FMS	An integrated system, consisting of an airborne sensor, receiver and computer with both navigation and aircraft performance databases, which provides performance and RNAV guidance to a display and automatic flight control system.	ICAO, Technical Committee of the Regional Safety Oversight Cooperation System, ADVISORY CIRCULAR, AC : 91-008

Table 1: Glossary of terms

2.7 List of Acronyms

Acronym	Definition
ACC	Area Control Center
ADS-B/-C	Automatic Dependent Surveillance - Broadcast / -Contract
AFUA	Advanced Flexible Use of Airspace
AGL	Above Ground Level
AI	Artificial Intelligence
AIC	Aeronautical Information Circular
AIP	Aeronautical Information Publication
AIS	Aeronautical Information Service
ANSP	Air Navigation Service Provider
AO	Aircraft Operator
ASM	Air Space Management
ATC	Air Traffic Control
ATFM	Air Traffic Flow Management
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management

AU	Airspace User
AUP	Airspace Usage Plan
EAUP	European Airspace Usage Plan
UUP	Updated (airspace) Usage Plan
CAS	Corrected AirSpeed
CCO	Continuous Climb Operations
CDA	Continuous Descent Approach
CDM	Collaborative Decision Making
CDO	Continuous Descent Operations
CFSP	Computerized Flight-planning Service Providers
CI	Cost Index
CONOPS	Concept of Operations
CR	Change Request
CTOT	Calculated Take Off Time
DAR	Direct Access Recorder
DPO	Descent Profile Optimization
QAR	Quick Access Recorder
DEMOP	Demonstration Plan
DEMOR	Demonstration Report
DMAN	Departure MANager
EATMA	European ATM Architecture
ECAC	European Civil Aviation Conference
EFB	Electronic Flight Bag
EFPL	Extended Flight PLan
EPP	Extended Projected Profile
FDR	Flight Data Recorder
FIR/UIR	Flight Information Region / Upper Information Region
FL	Flight Level
FMS	Flight Management System
FPL	Flight PLan
FRA	Free Route Airspace (NB: also IATA designator for Frankfurt)
GRRT	Group ReRoute Tool

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HMI	Human-Machine Interface
HPAR	Human Performance Assessment Report
IAF	Initial Approach Fix
IFO	Idle Factor Optimization
ILS	Instrument Landing System
INTEROP	Interoperability Requirements
KPA	Key Performance Area
KPI	Key Performance Indicator
LNAS	Low Noise Augmentation System
LOC	LOCalizer
ML	Machine Learning
MSN	Manufacturer Serial Number
NM	Network Manager or Nautical Miles (typically when preceded by a number)
NOP	Network Operations Plan
OI	Operational Improvement
OSED	Operational Service and Environment Definition
PAR	Performance Assessment Report
PBN	Performance-Based Navigation
QAR	Quick Access Recorder
QoS	Quality of Service
RAD	Route Availability Document
RNP	Required Navigation Performance
RNP-AR	Required Navigation Performance - Authorization Required
RRP	ReRoute Proposal
RWY	Runway
SAC	Safety Criteria
SAF	Sustainable Aviation Fuels
SAR	Safety Assessment Report
SESAR	Single European Sky ATM Research Programme
SID	Standard Instrument Departure
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SPR	Safety and Performance Requirements

STAM	Short Term ATFCM Measure
STAR	Standard Terminal Arrival Procedure
TMA	Terminal Manoeuvring Area
TOC/TOD	Top Of CLimb / Top Of Descent
TS	Technical Specification
VLD	Very Large-scale Demonstration
VPA	Variable Profile Area
WP	Work Package

Table 2: List of acronyms

3 Very Large Demonstration (VLD) Scope

This section provides the general background for the Demonstration Report.

3.1 Very Large Demonstration Purpose

The ALBATROSS project should be seen as the collection of many related but autonomous demonstrations.

Eight groups of exercises have been carried out, delivering twelve different exercises (some of which were repeated in two, three, or four instances) taking place in the airspace between six main geographical poles (in brackets the concepts demonstrated and the technology environment):

Sweden / Stockholm ((1) post-ops analysis of TMA operations, especially descent - also extended to other terrains; statistical analysis of actual fuel-bun data, referenced for each flight to the "ideal minimum"; (2) Novair, Aircraft FMS: deployment of Airbus tools for fine-tuned optimization of descents.)

France / Paris (Five exercises: (A) Detailed statistical analysis of flight data collected during the PBN-to-ILS trials in CDG; (B) Inter-ATC coordination to facilitate optimized descents, by raising IAF altitudes; (C) Airline data-oriented tools to calculate flight-specific fine-tuned climb profiles for AF long-haul departures; (D) Feasibility study of the conditions to encourage single-engine taxiing at departure; € Deployment of hydrogen-based backup power supplies for ATC ground equipment.)

Austria / Vienna (Permanent deployment of a PBN-to-ILS arrival procedure using radius-to-fix for runway 27)

Switzerland / Zürich (energy-management pilot-assistance system used with closed-path PBN-to-ILS procedure in Zürich by Swiss International Airlines)

Germany / several TMAS (AI/ML tools for the analysis of real trajectory, to identify opportunities for optimization of TMA airspace)

Schiphol Airport (Taxi-Bot: towing vehicles for engines-off taxiing)

Of particular importance was the so called "Gate-to-Gate Demonstration" that aimed at a combined implementation of multiple concepts in the execution of the flights over some European "city-pairs" (origin-destination).

Not linked to any specific location, was the investigation of Sustainable Aviation Fuels "Book and Claim" mechanism, to spur the usage of SAF despite the limitations in widespread physical availability.

3.2 SESAR Solution(s) addressed by VLD

The initiatives and concepts put in place in the ALBATROSS exercises do not all come from the SESAR Catalogue.

An initial list of possible SESAR Solutions to be used was drafted in the Demo Plan, but actual implementation in the exercises could not achieve that plan.

Two ALBATROSS exercises result in the initialization of new SESAR Solutions:

Instances	Subject	Description
EXE-01 Gate-to-Gate	Dynamic-RAD	The aim is to introduce a process allowing a more dynamic management of restrictions according to traffic evolutions. The daily activation of the restrictions according to the real needs will offer opportunities for the AUs to get benefits in terms of unconstrained trajectories during the relaxation time of the restrictions.
EXE-07 Taxi-Bot at Schiphol	Engines-off Sustainable Taxiing through use of a Sustainable Taxiing Vehicle	Use of an airport-based system (specialized equipment) to allow for sustainable taxi-out and taxi-in of aircraft. By allowing a convoy (equipment and aircraft attached to one another) to taxi using the drivetrain of the specialized taxiing equipment, the aircraft's own engines become superfluous. The use of specialized equipment allows the pilot in control of the aircraft to take over steering operations of the convoy during the main taxiing phase (after loading and/or pushback) using the aircraft's own steering and braking systems, thereby minimizing forces applied to the aircraft structure. This allows for a safe, environmentally friendly and efficient ground operation.

Table 3: SESAR Solution(s) under Demonstration

OptiClimb (EXE-06C) and DPO (EXE-05B) are technical changes that were initially thought to be potential SESAR Solutions or Enablers, but were instead categorized as self-contained optimizations with no ATM impact.

3.2.1 Deviations with respect to the SESAR Solution(s) definition

The ALBATROSS exercises did not use the datapacks of existing SESAR Solutions to conduct their work.

The reasons for this are twofold:

- Some exercises were running known operational processes (deployment of PBN-to-ILS; Dynamic management of RADs; coordination between control centers to decide on altitude relaxations; analysis of flown trajectories to decide on possible airspace redesign; already certified FMS features).
- Some exercises covered concepts that are not yet included in the SESAR catalogue (TaxiBot and Single-engine taxiing;) or that do not concern operations (SAF and hydrogen generators).

The project is anyway willing to include the relevant outcomes of its activities in the relevant SESAR Solution Datapack. The project finally proposed to open 2 new solutions to be integrated in the SESAR Catalogue: "Dynamic-RAD" and "Engines-off Sustainable Taxiing through use of a Sustainable Taxiing Vehicle".

3.3 Summary of Demonstration Plan

3.3.1 Demonstration Plan Purpose

The ALBATROSS project should be seen as the collection of many related but autonomous demonstrations.

Eight groups of exercises have been carried out, delivering twelve different exercises (some of which repeated in two, three, or four instances) taking place in the airspace between six main geographical poles (in brackets the concepts demonstrated):

Sweden / Stockholm (analysis of TMA operations, especially descent - also extended to other terrains)

France / Paris (CDO/CCO, precision approach, relaxed airspace constraints, airline data-oriented tools, single-engine taxiing, hydrogen power supply)

Austria / Vienna (TMA operations, descent, precision approach, airline data-oriented tools)

Switzerland / Zürich (airline data-oriented tools for descent optimization using closed-loop procedures)

Germany / several TMAS (data-oriented tools for the optimization of TMA airspace)

Schiphol Airport (towing vehicles for engines-off taxiing)

Of particular importance was the so called "Gate-to-Gate Demonstration" that aimed at a combined implementation of multiple concepts in the execution of the flights over some European "city-pairs" (origin-destination).

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3.3.2 Operating method description

Different exercises applied different demonstration techniques. However, all activities concerned real-world very-large-scale contexts, either with flight trials on commercial "production" flights in real traffic conditions, or with studies applied to very large volumes of real traffic data.

Two demonstrations were classified as "additional decarbonation initiatives" that did not directly concern ATM/ATC/flight processes: the usage of hydrogen power generators and the usage of sustainable aviation fuels through a dematerialization mechanism. These two activities also focused on actual implementation (real generators being used in real operations for prolonged periods; SAF fuel "credits" to be actually claimed linked to real flights).

The approach followed in the ALBATROSS demonstrations has been described in detail in the dedicated deliverable "*Methodologic Approach Towards Green Flights*" [21]. The operational principles applied in the ALBATROSS demonstrations can be grouped in the following high level categories :

Collaboration of all involved stakeholders, at the right scale

In the Strategic and Planning phases, concrete opportunities for change emerged from analyzing portions of airspace (known inefficiencies and possible mitigations) with the active involvement of all concerned stakeholders, working with the right balance of detailed local operational knowledge and vision of the available innovation possibilities.

In the Execution phases: The increasing availability of Information sharing channels (ground-ground and air-ground) is a crucial leverage towards conducting each flight in the most optimized way, by having the operational stakeholders be aware of each other's "intentions and preferences".

Dynamic Management of ATM constraints

Constraints are of different nature: some have a permanent nature (e.g. orography limiting optimum approach/departure), others are introduced (e.g. RAD restrictions) to enable States/FABs/ANSPs to maximise capacity and reduce complexity. ALBATROSS focused on moving decision making about certain “ATM constraints” from "always sized for the worst case" to "dynamically adapting to the operational circumstances", when the reasons that require those constraints do not materialize in a constant way (as is often the case). Depending on the specific cases, the dynamicity (in space and time) can be more or less fine-grained (ranging from one single waypoint to entire airspaces; and from a few hours per day to permanent restructuring). It must be pointed out that the possibilities of improvement are very specific to local circumstances, depending on the local traffic patterns.

New CNS capabilities that are becoming commodity

The widening installed base of several new Communication, Navigation and Surveillance capabilities enable flights to operate in a more precise and predictable way, allowing more exact performance calculations/optimizations and a reduction of buffers. Air-ground connectivity also facilitates information sharing, so that exact flight conditions are downlinked (both to ATC and AU backoffice) and advanced optimizations, complex clearances or awareness on network conditions can be uplinked. (Toddler-steps towards Trajectory Based Operations).

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New tools and techniques of advanced Data Analytics

The field of data analytics has seen, in recent years, spectacular advances in terms of improved methods and algorithms and cheap access to automation and computing power that allows to collect, store and process very large amounts of data. The environmental optimization of aviation takes advantage of these novelties.

In Post-ops data analytics: The analysis of large bases of historic data (flown trajectories, crossed with the operational circumstances) provide detailed knowledge about inefficiencies existing in a specific location or on a certain process, and can suggest ways to overcome them.

In the "execution loop": calculations driving operational decisions can use models that are more accurate and more specific to the specific circumstances, first and foremost by using the exact parameters of an individual flight on a specific aircraft as opposed to a generic model per aircraft-type and using average values.

Improvements in the "Ground" segment

ALBATROSS has investigated, and partially demonstrated, some "green taxiing" possible improvements, namely TaxiBot vehicles, that allow the aircraft to taxi with the engines off, and single-engine-taxiing, a process already applied, but which may offer margins f further improvement. The attention on these concepts, in the present document, is only partial, because the main focus is put on improvements that concern the airspace and the flight phase, and the techniques used to optimize flight and airspace do not apply to taxiing (for one thing, on the ground the aircraft could stop and wait with engines off!). Nevertheless, improvements in the pre-takeoff phases should not interact with the flight phases in a way that could be detrimental to the reduction of the environmental footprint.

In a few words and in a schematic view, this is how the ALBATROSS exercises put those principles in practice.

		Collaborative process / Strategic	Collaborative process / Tactical	Dynamic constraints mgmt	Advanced CNS	Aircraft- /Flight-specific CDM	Air-Ground info sharing
EXE-01	- Gate-to-gate approach - Dynamic RAD	X	X	X			
EXE-02	Big-Data analysis of ESSA TMA	X					
EXE-03	LNAS-CDA along closed-path PBN-to-ILS		X		X	X	X

EXE-04	Big-Data analysis of German TMAs	X					
EXE-05A	PBN-to-ILS Vienna				X		
EXE-05B	"DPO/IFO" profile optimization tools					X	
EXE-06A	PBN-to-ILS Paris-CDG				X		
EXE-06B	"Green Descents" Paris-CDG	X		X			
EXE-06C	"OptiClimb" climb optimization		X			X	X
EXE-07	TaxiBot at Schiphol	X	X				

Last but not least, the concept of **"Optimum Flight"** (flight with "zero excess of CO2") was used as a detailed investigation tool by compare real flights to their optimums :

- Measure what margin for "improvement of CO2 emissions" exists on a given origin-destination;

- Identify which constraints in the airspace deoptimize the fuel-efficiency of the flight, causing an excess of CO2 emissions.

The concept of "Optimum Flight" looks at the full 4D profile, not just the "shortest ground distance". Following an optimized vertical profile is paramount for CO2-optimization, besides obviously following the shortest horizontal path, also considering the effect of wind (favourable or contrary).

3.3.3 Summary of Demonstration Objectives and success criteria

The ALBATROSS demonstrations established three high level objectives, touching the following aspects:

1. Demonstrate a measurable reduction of CO2 emissions brought by the applied operational concepts

2. Demonstrate that the envisioned operational concepts are sustainable in operational conditions ("can be deployed")

3. Besides the improvements to the core processes of Air Traffic Management and Flight Operations, showcase additional decarbonation initiatives (SAF and alternative power supply).

[OBJ]

Identifier	OBJ-VLD-ALBATROSS-001
Objective	To demonstrate that trajectories closer to the "optimum" can be executed or planned-and-executed. This implies: i. being able to identify potential improvements on flights (any process); ii. designing a concrete solution to materialize those benefits; iii. operating under the improved conditions as part of daily operations.

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Title	Greener trajectories
Category	<performance> (Environmental
Key environment conditions	Nominal conditions, possibly limited to circumstances of low volume and low complexity.

[OBJ Suc]

Identifier	Success Criterion
CRT-VLD-ALBATROSS-001	Over the duration of the project (2021-2022) measure a reduction of CO2 emissions (and optionally other gaseous emission and noise emissions) on one-thousand revenue/production flights (i.e. not "test-flights" set up on purpose).

[OBJ]

Identifier	OBJ-VLD-ALBATROSS-002
Objective	To demonstrate that certain ATM processes can enable greener trajectories, at least when specific conditions are met (typically low density or complexity) : thy should be activated as often as possible and fully used by the operators, thanks to the appropriate information sharing.
Title	Greener collaborative procedures
Category	<operational feasibility>, <human performance>, <acceptability>
Key environment conditions	Nominal conditions, possibly limited to circumstances of low volume and low complexity.

[OBJ Suc]

Identifier	Success Criterion
CRT-VLD-ALBATROSS-002	Reduction in the extent (locations and time windows) when ATM constraints causing inefficient trajectories need to be active.

[OBJ]

Identifier	OBJ-VLD-ALBATROSS-003
Objective	Showcase aviation decarbonisation initiatives
Title	Other decarbonisation initiatives
Category	<performance>, <operational feasibility>, <acceptability>
Key environment conditions	Nominal conditions

[OBJ Suc]

Identifier	Success Criterion
CRT-VLD-ALBATROSS-003	The selected decarbonisation initiatives can be effectively performed (i.e. "do produce an effect") by the relevant Aviation/ATM/ATC actors.

Table 4: Objectives Layout

3.3.4 Demonstration Assumptions

Identifier	Title	Type of Assumption	Description	Justification	Impact on Assessment

Table 5: Demonstration Assumptions overview

No assumptions and prerequisites are identified at overall project level.

Concerning the eight exercises / twelve concepts, those that made specific assumptions are summarized below (full detail is in Annexes A to H).

Exercise EXE-03 ("LNAS-CDA: energy-optimized descent profiles") assumes the existence of a temporary closed-path PBN-to-ILS procedure (for an accurate value of the remaining flight path distance), which was temporarily defined for the exercise.

Exercise EXE-06D ("SEPHER hydrogen-based backup Generators") made assumptions related to the carbon footprint of diesel versus hydrogen generators for its calculation of the benefits.

Exercise EXE-07 ("TaxiBot Schiphol") had a list of over 200 hypotheses, assumptions, and sub-hypotheses and more than 180 research questions. The full report can be obtained on request from Schiphol SNBV. The points that may be raised at general level are the following:

- The right of way for aircraft performing Sustainable Taxiing operations is clear to all involved stakeholders on airside.

- Specific preconditions are formulated on the impact on safety, workload, capacity, fairness and availability of the necessary resources.

3.3.5 Demonstration Exercises List

Id	Title	Execution (§)
EXE-01	Gate to Gate	Aug-Nov 2021 – Dynamic RAD FABEC
		Mar 2022 – Gate-to-Gate Stockholm (Vienna, Zürich)
		Jun 2022 – "Connect Europe Days" optimized flights
		Nov 2022 – Gate-to-Gate "second round"
EXE-02A	Novair/LFV TMA Optimiz. ARN	2022
EXE-02B	Novair Fuel Efficiency measures	2022
EXE-03	LNAS-CDA: energy-optimized descent profiles	Jul-Dec 2022
EXE-04	AI/ML TMA Optimization	2022
EXE-05A	PBN-to-ILS VIE	2021 until Nov 2022
EXE-05B	Airbus DPO/IFO	Mar-Aug 2022 Aug-Oct 2022
EXE-06A	PBN-to-FInal CDG	Jan-Mar 2022 – Live Trials
EXE-06B	"Green Descents" CDG	Jan-Jul 2022
EXE-06C	Optimized Climbs AF	Jun-Dec 2022 – All Boeing long-haul AF departures from CDG enabled (40-60 each day)
EXE-06D	Single-engine Taxi-out AF	(Rescoped to a feasibility study)
EXE-06E	SEPHER Generators DSNA	May-Jun 2022 – Two installations used in real operations during four weeks.
EXE-07	TaxiBot Schiphol	

EXE-08	Sustainable Aviation Fuels	Aug-Oct 2022

Table 6: Demonstration Exercises List

[EXE]

Identifier	EXE-VLD-ALBATROSS-001
Title	Gate-to-gate trials
Description	Demonstrate actual production "Greener Flights" on selected city-pairs, applying multiple improvements on all flight phases and ATM processes. Some concepts demonstrated "individually" in the other ALBATROSS exercises will be applied in EXE-01, besides additional improvements specific to the gate-to-gate trials.
Demonstration Technique	Live trials and detailed analysis by comparison to an "Optimum Flight"
KPA/TA Addressed	Fuel efficiency, as a proxy for CO2 emissions. (Also Operational Efficiency and Capacity will be evaluated, but are not the primary targeted KPAs)
Number of flights	150
Start Date	Preparation : start = July 2021 Implementation : start = February 2022
End Date	Preparation : end = February 2022 Implementation : end = December 2022
Demonstration Coordinator	Eurocontrol
Demonstration Platform	Potential combined usage of the ALBATROSS concepts from all Exercises (in particular EXE-06), with the addition of NM tools for en-route collaborative processes (mainly FUA and Dynamic RAD) and MUAC collaborative portal (ATMP).
Demonstration Location	Airspace around/between France, Sweden, MUAC area.
Status	Finished
Dependencies	All other ALBATROSS Exercises

[EXE Trace]

Linked Element Type	Identifier
<Demo Objective>	OBJ_VLD_ALBATROSS_001 OBJ_VLD_ALBATROSS_002 ~~OBJ_VLD_ALBATROSS_003~~

[EXE]

Identifier	EXE-VLD-ALBATROSS-002
Title	ALBATROSS Swedish Cluster
Description (*Note : The scope of this exercise has changed significantly compared to the Demo Plan*)	**EXE-02A: Novair/LFV TMA Optimization, Stockholm Arlanda Airport (ARN).** Post-ops analysis of TMA operations, especially descent - also extended to other terrains; statistical analysis of actual fuel-bun data, referenced for each flight to the "ideal minimum". **EXE-02B: Novair Fuel Efficiency measures** Analysis of flight efficiency related to ATC constraints and clearances
Demonstration Technique	Flight data analysis
KPA/TA Addressed	Fuel efficiency, as a proxy for CO2 emissions
Number of flights	1000
Start Date	Q1/2022
End Date	Q4/2022
Demonstration Coordinator	Novair
Demonstration Platform	Novair "Delta Fuel Burn".
Demonstration Location	Sweden / Stockholm, Gotheborg
Status	in progress
Dependencies	none

[EXE Trace]

Linked Element Type	Identifier
<Demo Objective>	OBJ_VLD_ALBATROSS_001

[EXE]

Identifier	EXE-VLD-ALBATROSS-003
Title	LNAS: energy-optimised descent profiles
Description	LNAS is a pilot assistance system to help pilots optimise approaches in terms of fuel consumption and noise emissions by predicting the optimal vertical flight path as well as the ideal speed, flap configuration and landing gear sequence

Demonstration Technique	Live trials
KPA/TA Addressed	Primary Fuel efficiency (as a proxy for CO2 emissions) Human performance is also addressed
Number of flights	~100
Start Date	Preparation: start January 2021 Development: start February 2021 Demonstration: start January 2022
End Date	Preparation: end November 2021 Development: end October 2021 Demonstration: end August 2022
Demonstration Coordinator	Swiss
Demonstration Platform	LNAS is a software application which runs on a trial device connected to the avionics. Will be deployed on SWISS A320neo aircraft.
Demonstration Location	Zürich and other destinations flown by Swiss, in particular the ALBATROSS city-pairs
Status	in progress
Dependencies	none

[EXE Trace]

Linked Element Type	Identifier
<Demo Objective>	OBJ_VLD_ALBATROSS_001 OBJ_VLD_ALBATROSS_002

[EXE]

Identifier	EXE-VLD-ALBATROSS-004
Title	German TMA Optimization with Data Analytics
Description	Apply state of the art trajectory analysis based on machine learning and artificial intelligence, in order to systematically implement measures for an operational concept to optimize airspace geometry and flight trajectories, to obtain a reduction of environmental impact
Demonstration Technique	Trajectory analysis based on machine learning and artificial intelligence
KPA/TA Addressed	Fuel efficiency (as a proxy for CO2 emissions), Capacity

Number of flights	none (implementation of the identified improvements is not in scope)
Start Date	Data preparation and analysis: start January 2021 Implementation of the measures: start January 2022
End Date	Data preparation and analysis: end December 2021 Implementation of the measures: end August 2022
Demonstration Coordinator	Lufthansa
Demonstration Platform	
Demonstration Location	TMAs of : Köln/Düsseldorf, and potentially Frankfurt
Status	in progress
Dependencies	none

[EXE Trace]

Linked Element Type	Identifier
<Demo Objective>	OBJ_VLD_ALBATROSS_001

[EXE]

Identifier	EXE-VLD-ALBATROSS-005
Title	ALBATROSS Austrian Cluster
Description	Two instances: EXE-05A : Design and publication of PBN-to-ILS procedures in Vienna EXE-05B: Climb and descent optimization solutions based on tail-centric NAVBLUE / Airbus solutions used in real operations by WizzAir
Demonstration Technique	Live trials + detailed analysis by comparison to an "Optimum Flight" + Feasibility studies
KPA/TA Addressed	EXE-05A: Fuel efficiency (as a proxy for CO2 emissions), Noise impact. (Also Operational Efficiency and Capacity will be evaluated, but are not the primary targeted KPAs) EXE-05B: Fuel efficiency
Number of flights	EXE-05A: (the assessment can use all traffic using the new published PBN-to-ILS procedure, when active)

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	EXE-05B: 100 flights
Start Date	EXE-05A: Preparation = Q4/2021; Procedure published Q1/2022 EXE-05B: January 2022
End Date	EXE-05A: Q1/2023 EXE-05B: December 2022
Demonstration Coordinator	EXE-05A: Austro Control EXE-05B: Airbus
Demonstration Platform	EXE-05A: New published procedures will be assessed based on the recorded flown trajectories. EXE-05B: Pre-departure usage of the "CPO, DPO and IFO" tools. Results assessment based on Airbus analysis tools.
Demonstration Location	Vienna, Austrian Airspace, ALBATROSS city-pairs
Status	in progress
Dependencies	none

[EXE Trace]

Linked Element Type	Identifier
<Demo Objective>	OBJ_VLD_ALBATROSS_001 ~~OBJ_VLD_ALBATROSS_002~~

[EXE]

Identifier	EXE-VLD-ALBATROSS-006
Title	ALBATROSS French Cluster
Description	Six exercise instances : EXE-06-A PBN-to-ILS at CDG EXE-06-B Inter-center coord. to facilitate CDO EXE-06-C Data Analytics Tools for trajectory optimization EXE-06-D Engine-off Taxiing at departure EXE-06-E Renewable power supply for ground equipment ~~*EXE-06-F Continuous Climb*~~ *(cancelled)*
Demonstration Technique	Feasibility studies + Live trials
KPA/TA Addressed	Fuel efficiency (as a proxy for CO_2 emissions); Environmental efficiency.

Number of flights	A total of 500 flights is targeted EXE-06-A: 200 (PBN-to-ILS at CDG) EXE-06-B: 200 (Inter-center coord. to facilitate CDO) EXE-06-C: 50 (Data Analytics Tools for trajectory optimization) EXE-06-D: 50 (Engine-off Taxiing at departure) EXE-06-E: not applicable (power supply for ground equipment) ~~*EXE-06-F: (Exercise to be confirmed)*~~
Start Date	EXE-06-A: start = January 2021 EXE-06-B: start = February 2021 EXE-06-C: start = March 2021 / October 2021 EXE-06-D: start = June 2021 EXE-06-E: start = October 2021 ~~*EXE-06-F: start = March 2022 (to be confirmed)*~~
End Date	EXE-06-A: end = June 2021 EXE-06-B: end = June 2021 EXE-06-C: end = December 2022 EXE-06-D: end = December 2022 EXE-06-E: end = December 2022 ~~*EXE-06-F: end = December 2022 (to be confirmed)*~~
Demonstration Coordinator	Air France
Demonstration Platform	New platforms are involved for: EXE-06A and EXE-06B: New flight data analysis tools at Air France (post-ops usage) EXE-06C, ~~EXE-06F~~: Decision support tools.
Demonstration Location	Paris TMA, French Airspace and selected airports, ALBATROSS city-pairs
Status	In progress
Dependencies	None

[EXE Trace]

Linked Element Type	Identifier
<Demo Objective>	OBJ_VLD_ALBATROSS_001 OBJ_VLD_ALBATROSS_002 OBJ_VLD_ALBATROSS_003

[EXE]

Identifier	EXE-VLD-ALBATROSS-007
Title	TaxiBot at Schiphol Airport
Description	Sustainable taxiing by using TaxiBot vehicles to taxi aircraft from Runway-to-Gate and Gate-to-Runway. Using the TaxiBot ensures that aircraft engines are not used.
Demonstration Technique	Live trials
KPA/TA Addressed	Fuel efficiency and Environment, in the taxiing phase. (Also: interdependency on time performance and ATC procedures)
Number of flights	"several dozens" (likely between 30 and 60)
Start Date	Preparation: start = November 2021 Execution: start = beginning of summer 2022
End Date	Preparation: end = May 2022 Execution: duration = 3 months
Demonstration Coordinator	Schiphol Airport
Demonstration Platform	Schiphol Airport: Two Taxibot vehicles will operate on "production" traffic
Demonstration Location	Schiphol Airport
Status	in progress
Dependencies	none

[EXE Trace]

Linked Element Type	Identifier
<SESAR Solution>	SESAR Solution Identifier 1
<SESAR Solution>	SESAR Solution Identifier 2
<Demo Objective>	OBJ_VLD_ALBATROSS_001 ~~OBJ_VLD_ALBATROSS_002~~

[EXE]

Identifier	EXE-VLD-ALBATROSS-008
Title	Sustainable Aviation Fuels
Description	This exercise targets to make use some SAF on ALBATROSS flights,

	by addressing some of the current obstacles to the deployment of SAFs. It will explore potential chain of custody for SAF integration, via dematerialisation ("Book-and-claim" – explained in Section **Erreur ! Source du renvoi introuvable.**) and supply and logistic challenges for SAF. Ultimately, this exercise aims to contribute to the promotion of SAF, to support the emergence of a mature market.
Demonstration Technique	"Book-and-claim" mechanism applied on some of the flights involved in any of the ALBATROSS exercises.
KPA/TA Addressed	Reduction of CO2 impact (via dematerialized claim)
Number of flights	A portion to be defined of the ~1000 estimated ALBATROSS flights
Start Date	Preparation : start = September 2021 Implementation : start = January 2022
End Date	Preparation : end = February 2022 Implementation : end = December 2022
Demonstration Coordinator	Airbus
Demonstration Platform	"Book and claim" concept and related chain of custody
Demonstration Location	Every ALBATROSS location
Status	in progress
Dependencies	All other ALBATROSS exercises

[EXE Trace]

Linked Element Type	Identifier
<Demo Objective>	OBJ_VLD_ALBATROSS_003

Table 7: Demonstration Exercise layout

3.4 Deviations

3.4.1 Deviations with respect to the S3JU Project Handbook

In line with the open Call and based on the nature of Demonstration Projects (VLD), the Project used several available SESAR Solutions but also utilised other externally available work, to maximise outputs. Most exercises focused on opportunistic real-world deployment of improved processes.

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3.4.2 Deviations with respect to the Demonstration Plan

Deviations with respect to the Demo Plan [19] are to be highlighted concerning the following exercises. The deviations are described in detail in the respective Annexes:

EXE-01 "Gate to Gate" (did not address objective OBJ_VLD_ALBATROSS_003 "Other decarbonation initiatives": the usage of SAF, that was covering this objective, could not be done as part of the exercise).

EXE-02 "Swedish cluster – Novair and LFV TMA Optimization" (no new procedures were designed, the activity focused on post-ops analysis)

EXE-05B (DPO and IFO were implemented on Novair aircraft instead of Wizzair; furthermore, objective OBJ_VLD_ALBATROSS_002 "Large scale implementation" has been removed from the scope, given the size of the concerned fleet)

EXE-06D "SEPHER Hydrogen generators" (the decision support for taxiing was studied but could not be implemented)

EXE-07 "TaxiBot SChiphol" (fewer than planned TaxiBot movements could be executed; for this reason, the objective OBJ_VLD_ALBATROSS_002 "Large scale implementation" has been removed from the scope of the exercise)

EXE-08 "Sustainable Aviation Fuels" (no actual "Book-and-claim" of SAF could be concretely realized)

4 Demonstration Results

4.1 Summary of Demonstration Results

Demonstration Objective ID	Demonstration Objective Title	Success Criterion ID	Success Criterion	Demonstration Results	Demonstration Objective Status
OBJ_VLD_ALBATROSS_001	Greener trajectories	CRT-VLD-ALBATROSS-001	Measure a CO2 reduction (proxy: fuel reduction)	Seven demonstrations implementing more than ten improved operational processes. CO2 reduction systematically confirmed.	OK
OBJ_VLD_ALBATROSS_002	Greener collaborative procedures	CRT-VLD-ALBATROSS-002	Achieve a reduction of ATM constraints	Four demonstrations executed on live operations, sustained during prolonged periods of time or resulting in permanent implementation.	OK
OBJ_VLD_ALBATROSS_003	Other decarbonisation initiatives	CRT-VLD-ALBATROSS-003	Effectively implement other (non-ATM) means of decarbonization	Successful usage of hydrogen-based backup generators. Partial achievement of the objectives for SAF.	Partially OK

Table 8: Summary of Demonstration Exercises Results

4.2 Detailed analysis of Demonstration Results per Demonstration objective

The table below shows the coverage of the high level ALBATROSS objectives per ALBATROSS Exercise. (Cells marked with a red "O" were foreseen in the Demo Plan, but were later removed; please see Section 3.4.2 for an explanation of these deviations.)

Id	OBJ_VLD_ALBATROSS_001	OBJ_VLD_ALBATROSS_002	OBJ_VLD_ALBATROSS_003
	Measure CO2 reduction	Large scale implementation	Non-ATM decarbonation
EXE-01	X	X	O
EXE-02	X		
EXE-03	X	X	
EXE-04	X		

Id	OBJ_VLD_ALBATROSS_001	OBJ_VLD_ALBATROSS_002	OBJ_VLD_ALBATROSS_003
EXE-05	X	O	
EXE-06	X	X	X
EXE-07	X	O	
EXE-08			X

Table 9: Cross Reference of Objectives and Exercises

4.2.1 OBJ_VLD_ALBATROSS_001 Results

The results of the various activities that addressed this objective are summarized below. A more extensive description can be found in the individual Annexes describing each Exercise.

EXE-01 "Gate to Gate"

Within EXE-01, Objective OBJ_VLD_ALBATROSS_001 was particularly covered in the following execution instances :

Instance 1: The quantitative analysis concentrated on 12 RAD measures that were managed dynamically, involving DFS, DSNA, ENAV and skyguide. More than 8400 flights took advantage of the improved routes made available, resulting in an estimated reduction of more than 2 800 tons of CO2 emissions (an average of about 350 kg per flight *) coming from a fuel-burn reduction of about 890 tons (an average of more than 100 kg per flight *).

(*) Note: this overall average should not be read too literally, since the savings are very different, for different relaxed RAD restrictions, depending on the involved flights. It has been calculated to give a high level idea of the effect improvements adding up in time and space.

Instances 2 and 4:

This exercise mainly resulted in prolonged application during several weeks of improvements made possible by the MUAC control center, located centrally in the city-pairs of the consortium members. These improvements were: Pre-tactical relaxation of a RAD constraint; Sevral DCT direct routings allowed tactically; Proposal (tactically to the crews) of the highest possible flight level.

On instance 2 the MUAC improvements could be combined with the optimized descents into CDG, enabled by DSNA.

The measured reductions of CO2 emissions systematically correspond to 2-5% of the emissions generated in the concerned segments of flight (typically lasting 15 to 45 minutes). This unit amount must be multiplied by the high number of flights to which the improvements were offered (discussed in objective n. OBJ_VLD_ALBATROSS_002).

EXE-02 "Novair/LFV TMA Optimization in Stockholm ARN and Novair Fuel Efficiency measures"

The two parts of the exercise, EXE-02A and EXE-02B, were strongly linked, so the results can be described together.

The availability of a very large dataset of flight data, correlated with the specific conditions of the arrival airports, and correlated with the actual ATC clearances given to the flights made it possible to have very specific and detailed quantitative measurements of the impact of various constraints on arrivals (for illustration: for closed-loop arrivals into ESSA the average excess fuel due to vertical inefficiency is reduced by 24kg; the ratio of vertical inefficiency between best-case and worst-case number of clearances can be more than double). The works from the exercise were generalized into the definition of a method that can be used for assessing the efficiency/inefficiency related to the operational environment based on FDR data. This method can practically help to get an idea of what kind of operational challenges are causing vertical inefficiencies, in a specific TMA. The method also estimates the "excess CO2 emissions", from increased fuel-burn, that each inefficiency can cause.

EXE-03 "LNAS-CDA: energy-optimized descent profiles"

EXE-03 has evaluated the benefits of closed-path PBN-to-ILS procedures in a direct comparison between manually-controlled and pilot-assisted aircraft energy management. EXE-03 provides particularly valuable lessons for further widespread deployment of PBN-to-ILS procedures with the goal of maintaining high capacity and utilizing different types of aircraft energy management functions. In the case of EXE-03, the aircraft energy management function LNAS was used.

Flights along the PBN-to-ILS trajectory conducted with LNAS support resulted in significantly more predictable vertical and airspeed profiles, lower average thrust settings, lower use of speed brakes particularly at low altitudes, and overall lower fuel burn from the last 30 NM compared to PBN-to-ILS approaches without a pilot assistance system and compared to approaches using radar vectoring. Optimum flights using LNAS result in a fuel burn of 6.1% lower than the baseline flights

EXE-04 "AI/ML TMA Optimization"

The analysis of airspaces and traffic flows with the help of machine learning (AI) was successful, in that it allows to identify which factors lead to good or less good trajectories, in the specific operational conditions of a TMA: In summary, the solutions that enable more efficient vertical flight profiles include: performing lateral sequencing and separation in a larger airspace, therefore obtaining a better use of the runway resource; and flexible descend windows and raised transfer levels. Notice that this exercise did not directly calculate an amount of CO2 reduction; it concentrated instead on identifying the conditions that determine the best- and worst-performing flights, to derive priorities in the factors to implement.

The work for first carried out for Frankfurt; The findings will then be used to transfer the approach to the DUS/CGN airspace system.

EXE-05

EXE-05A "PBN-to-ILS VIE"

The full process that culminated with the permanent publication of the procedure has been successfully carried out : Coordination with local communities and governmental bodies at and around Vienna airport as part of the institutionalized “mediation”; Procedure design phase (multiple iterations); Safety Assessment including all stakeholders; Procedure evaluation using full-flight simulators and Live-Trail flights in VMC conditions (multiple Aircraft and FMS type); ATC training; Publication of the procedure in the Austrian AIP with AIRAC November 3rd, 2022.

Implemented PBN-to-ILS on RWY 29 will be usable by all flights into Vienna (depending on traffic situation, only used in off-peak periods at the beginning, but active and available H24)

Benefits assessment by Austro Control / Eurocontrol on the noise exposure / reduction, fuel burn and evaluating CO2 reductions from reduced track miles and improved flight efficiency (using AEDT / IMPACT).

EXE-05B "Airbus DPO/IFO"

This exercise demonstrated the benefits of the DPO and IFO solutions : DPO is an improvement of the accuracy of an aircraft type applying at the entry into service of the aircraft. IFO is an improvement of the accuracy by MSN all along the life of this aircraft. The use of IFO allows maintaining the fuel benefits mainly obtained with DPO along the time. These solutions bring an improvement in the management of the energy in descent: reduction of airbrakes usage; increase of Idle thrust usage; encourage the use of the FMS management mode in descent.

In this exercise, IFO was applied on 362 flights. The estimated benefit per flight being of around 16kg of CO2, the total reduction of CO2 obtained in this exercise is at ~5792kg (~6T). The impact of IFO depends on the age of the aircraft, which are quite recent for the exercise: it could be up to ~50kg of fuel and 160kg of CO2 per descent (estimated).

In addition to the values, the demonstration of the capacity to optimize the descent profile computed by the FMS suggests that additional benefits can be expected by the combination of these functions with ATM solutions as for example: Continuous Descent Operations, Controlled Time of Arrival or by the use of the EPP, taking benefit of a potential improvement in terms of predictability.

EXE-06 "French Cluster"

EXE-06A "PBN-to-FInal at CDG": Advanced evaluation methodologies were devised by DSNA and by AF for the Live Trials carried out for the preparation of "PBN-to-Final" procedures at Paris-CDG. These methodologies allowed to quantify the benefits of the PBN to ILS/RNP procedures both in terms of noise and CO2 emissions. The observed benefits were more or less pronounced for different arrival flows and traffic conditions. The sizes of the samples used for the assessment were smaller than hoped for, and therefore the significance of the quantitative results is limited. However, the PBN-to-FInal concept is confirmed as a crucial building block (in the final segment) for achieving an optimized profile along the entire descent.

EXE-06B "Green Descents CDG": In the timeframe of the project, an opportunistic improvement of the altitudes at some IAF points for Paris-CDG arrivals has evolved into permanently available improved arrival procedures. These could be applied on thousands of flights over several months. A clearly measurable reduction of CO_2 from reduced fuel-burn can be detected. This amounts to 300 kg of CO_2 saved (average) for each improved flight in the case of wide-body aircraft and 100 kg of CO_2 for medium-haul aircraft. For the quantitative assessment on this exercise, Air France used the tools and methodology established in EXE-06A.

EXE-06C "Pilot assistance tools for flight profile optimization": Following a successful "study phase" on a limited number of pilots, the OptiClimb tool was rolled out to the entire Boeing long-haul fleet of Air France (40~60 departures from CDG every day). The usage of a finely calculated climb profile (still within the acceptable envelope for ATC) results in an average reduction of more than 300 kg of CO_2 per departure. The rate of application of this process is very high, resulting in a significative cumulative benefit.

<u>EXE-07 "TaxiBot Scchiphol"</u>

For several reasons beyond the influence or control of the Exercise Team, this exercise had to deviate from its original plan (which was to demonstrate TaxiBots on several dozens of live flights).

Given the adjustments, it hasn't been possible to directly measure the fuel consumption improvements within this Exercise.

4.2.2 OBJ_VLD_ALBATROSS_002 Results

The results of the various activities that addressed this objective are summarized below. A more extensive description can be found in the individual Annexes describing each Exercise.

<u>EXE-01 "Gate to Gate"</u>

Within EXE-01, Objective OBJ_VLD_ALBATROSS_002 was particularly covered in the following execution instances :

<u>Instances 2 and 4</u>: NM was in charge of the coordination with different stakeholders of these last trials, run during second half of November and first half of December, with an active contribution of MUAC to prepare the demo flights in their AoRs. These trials, as those run in March (Instance 2), were focused on the possibility to provide benefits to selected consortium flights (e.g. Air France, Lufthansa, Swissair, Novair, Wizzair) whenever possible, without specific treatment but just as result of the coordination between the different stakeholders. The trials took also benefits by other activities running in the same

period, namely the dynamic RAD in Spain and France. MUAC provided great contributions to this last set of demo flights, addressing different improvements identified for a number of city pairs.

Instance 3: During the Connecting European Days event, organised in Lyon, France, on June 28, 2022 five flights have been coordinated among ATM and AUs partners to demonstrate the potentiality of the gate to gate approach. The execution of the flights confirmed the full cooperation of the involved actors, ANSPs and military, as well as the majority of the Aircraft Operators operating routes to Lyon. The primary goal of the demonstrating flights was to show the potential ATM improvements in contributing to the reduction of CO2 emission through optimised trajectories. The special treatment asked for the execution of the flights should not be considered as "solution" per se but as opportunity of improvements through standard coordination.

EXE-03 "LNAS-CDA: energy-optimized descent profiles"

EXE-03 has evaluated the benefits of closed-path PBN-to-ILS procedures in a direct comparison between manually-controlled and pilot-assisted aircraft energy management. EXE-03 provides particularly valuable lessons for further widespread deployment of PBN-to-ILS procedures with the goal of maintaining high capacity and utilizing different types of aircraft energy management functions. In the case of EXE-03, the aircraft energy management function LNAS was used.

EXE-06 French Cluster"

Four out of the five exercises of EXE-06 "French Cluster" were successfully conducted in real operations and for prolonged periods of time (the exception being EXE-06C "Single-engine Taxi-out" whose scope had to be reduced). The exercises systematically spurred close and constructive cooperation between the ANSP and the airlines, which brings fruits beyond the strict scope of the projects. In two cases the outcomes of the activity directly continue into permanent deployment.

EXE-07 "TaxiBot Schiphol"

For several reasons beyond the influence or control of the Exercise Team, this exercise had to deviate from its original plan (which was to demonstrate TaxiBots on several dozens of live flights).

However, the continued collaboration together with the other local sector partners allowed to achieve meaningful progress on some of the main hypotheses and gain some of the envisioned learnings to create and further enrich/validate a draft CONOPS for Sustainable Taxiing operations with TaxiBots at Amsterdam Airport Schiphol. This culminated in the demonstration of operations during a Sustainable Taxiing showcase on airside.

- Furthermore, progress on the following concrete aspects could be achieved: progress on the TaxiBot certification of the B737 MAX; An updated design of the TaxiBot, including relevant subsystems; Actual training of stakeholders and improved training materials; Development and realization of a number of infrastructural modifications to allow for TaxiBotting operations

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to and from the Polderbaan, the investigation of an alternative approach to Sustainable Taxiing at Amsterdam Airport Schiphol with a focus on centralized scale-up to maximize short-term uptake within current operational and procedural boundaries.

These developments all contribute to bringing Sustainable Taxiing operations closer, and lay the groundwork for upcoming trials and possible implementations steps, some of which will take place under the HERON consortium. Furthermore, all these points contribute to the ALBATROSS objective to "progress towards long-term and wide-scale implementation of the operational improvements identified as technically bringing a reduction of CO2 emissions".

4.2.3 OBJ_VLD_ALBATROSS_003 Results

This objective covers the decarbonation initiatives that do not directly come from new ATM operational processes. Some ALBATROSS activities addressed this objective, and their results are summarized below. A more extensive description can be found in the individual Annexes describing each Exercise.

EXE-06E "SEPHER Hydrogen generators"

Two experiments were conducted (in real conditions with an operational ground equipment), with different technology providers of hydrogen technologies, to provide back-up energy to DSNA's Mesnil-Amelot “P+S” radar on the Paris-CDG airport platform, during a period of 4 days (96 hours). The exercise estimated that the carbon footprint from using an electro-hydrogen generator is reduced by more than 85% compared to diesel generator. (Notice that this this is the net CO2 reduction, since the hydrogen used in the installations used was either "green" or had its CO2 impact compensated for, so no CO2 penalty from hydrogen production needs to be counted.)

Additional important results of the exercise are the insights gained into the quality of service of such systems, into the supervision process, and some elements of ROI calculation. These are all key aspects to consider in view of a large deployment in very many DSNA sites.

EXE-08 "Sustainable Aviation Fuel"

While it did not reach the goal initially set, to "make use" of a certain quantity of SAF on the ALBATROSS live-trial flights through the proposed dematerialization mechanism, the initiative to push the Book & Claim through the Albatross project has allowed to explore its feasibility and the needs and expectations for such a concept. The lessons learned include the explanation of the concept to the concerned stakeholders and the identification of some challenges to its wide application.

4.3 Confidence in Results of Demonstration Exercises

4.3.1 Limitations and impact on the level of Significance

This section of the Demo Report addresses two aspects of the exercise results :

1. Extrapolation of the obtained results to other operational environments in Europe

The ALBATROSS approach focuses on a very locally-targeted analysis of constraints causing inefficiencies and of possible solutions thereof. The extent to which standard airspace constraints can be relaxed highly depends on the specific operational circumstances of a portion of airspace. Each restriction is justified by specific objectives, and may be relaxed (or not!) at specific times and in specific traffic conditions.

The CO2 reduction measured in each ALBATROSS exercise cannot simply be multiplied by the number of locations where it might be possible. On the other hand, the observed order of magnitude of the reduction of emissions normally generated during a specific flight segment is very consistently around 3-5%. Although the improved segment might be quite short (usually between 15 and 45 minutes, rarely more) multiple flight segments can be improved independently (taxi-out, climb, en-route, descent, taxi-in).

2. Limitations impacting the significance of the results

All ALBATROSS activities were carried out in real operations, and on long durations or considering large numbers of flights, usually from all operators present in a geographical scope.

The significance of the observations is considered very high.

One single difficulty was observed on one of the four instances of the "Gate-to-gate" flights, the "Paris / Stockholm" city-pair. The overall reduction of CO2 emissions could no be proven, because of a combination of: a route that is relatively optimum to start with; a reduced number of improvements applied together (therefore small benefits); and an available dataset of "actual delta fuel" measurements that turned out to be smaller than expected.

4.3.1.1 Quality of Demonstration Exercises Results

Since the results derive from very large real-operations scope, accuracy and confidence are considered high.

4.3.1.2 Significance of Demonstration Exercises Results

The significance of the results is considered very high.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

5 Conclusions and recommendations

5.1 Conclusions

At project level, the overall results are extremely satisfactory. All demonstrations applied their concepts in real-world very-large-scale contexts. Detailed quantitative analysis confirmed the benefits. At least six concepts resulted in permanent deployment or use solutions that are already operationally available. Lessons learned resulted in a "Methodologic Approach" (a dedicated project deliverable) to inspire the ATM/aviation community about deployable concepts that reduce the carbon footprint.

ALBATROSS is a visible sign of the concrete long-lasting reduction of the carbon footprint of European aviation, taking advantage of available air- and ground-technology and of collaborative processes. Further steps are still required and possible, and this project paves the way for further progress.

Specifically, main conclusions from some of the exercises:

EXE-01 "Gate to Gate"

The main outcomes of this exercise is the demonstration of how the detailed study of a selected set of flights by all involved stakeholders is a way to obtain the most effective implementation.

For Dynamic RAD, the live trials showed the potential benefits in terms of flight efficiency as well as the feasibility of all the different partners to cope with the level of dynamicity offered.

On the other hand, the "Gate-to-gate" trials that aimed to address multiple improvements with a holistic approach on selected "gate-to-gate" routes were only partially successful. The analysis of the concerned airspace, to identify potential improvements, was a very productive exercise. However, the implemented improvements were less than hoped for, and the CO_2 reductions could not be proven in a statistically significant manner.

Despite the different benefits among the different flights, even in those case with limited improvements, the regular coordination of potentially available measures can contribute to the overall reduction of CO_2 emissions, along all segments of the trajectory.

EXE-02 "Novair/LFV TMA Optimization in Stockholm ARN and Novair Fuel Efficiency measures"The Delta Burn method has proven to be valuable methods to analyse flight efficiency in detail.

The exercise used this method to show how vertical efficiency can be improved when flights can follow closed loop procedures, and more in general showed the negative impact of a high number of ATC clearances (heading, altitude, speed).

EXE-03 "LNAS-CDA: energy-optimized descent profiles"

For the first time in the world, a demonstration and study was conducted in EXE-03 to evaluate the benefits of a closed-path PBN-to-ILS procedure with and without an energy management pilot assistance system (LNAS) compared to radar vectoring procedures to the same runway. Flights along the PBN-to-ILS trajectory conducted with LNAS support resulted in significantly more predictable vertical and airspeed profiles, lower average thrust settings, lower use of speed brakes particularly at low altitudes, and overall lower fuel burn from the last 30 NM compared to PBN-to-ILS approaches without a pilot assistance system and compared to approaches using radar vectoring.

EXE-04 "AI/ML TMA Optimization"

The analysis of airspaces and traffic flows with the help of machine learning allows to identify the factors that lead to good or less good trajectories, in the specific operational conditions of a TMA. Applied to the Frankfurt TMA, solutions recognized to enable more efficient vertical flight profiles include: improving lateral sequencing and separation by using a larger airspace; and flexible descend windows and raised transfer levels. The method first carried out for Frankfurt can be used in other airspace systems.

EXE-05

Part A "PBN-to-ILS VIE" was focused on the deployment of PBN-to-ILS in Vienna; The conclusions are that the deployment was successful and the concept beneficial, in particular in the use of curved procedures (radius-to-fix) which allow to avoid noise sensitive / populated areas.

Part B "Airbus DPO/IFO" focused on technical solutions improving the accuracy of the aircraft (FMS) performance model in descent, and demonstrated how these solutions result in a more optimized descent profile, by the FMS aiming at flying more efficient descent.

EXE-06 "French Cluster"

The various outcomes of the five "French" exercises resulted in semi-permanent deployment of two concepts, on Paris-CDG arrivals and departures: 1. Raised altitudes, during several hours every day, of the altitudes at the IAF into Paris-CDG; 2. "OptiClimb" customized climb profiles for Air France Boeing long-haul fleet. Thousands of flights have benefitted daily from these improvements in 2022, and continue to benefit daily.

EXE-07 "Taxibot Schiphol"

Building on previous efforts, Exercise 7 aimed to create a better understanding of various aspects of Sustainable Taxiing operations based on trials using TaxiBot vehicles to taxi aircraft from Runway-to-Gate and Gate-to-Runway without the use of their own engines. Despite challenging operational circumstances, the continued collaboration between key local sector partners allowed for meaningful progress on some of the main hypotheses and the creation and partial validation of a draft Concept of Operations (CONOPS).

Another concrete deliverable of EXE-07 was the "Sustainable Taxiing full-size showcase" performed on December 6th 2022, with an actual use of TaxiBot FG on airside of Amsterdam Airport Schiphol under normal operational conditions (pilot controlling the TaxiBot with B737 aircraft, Outbound and inbound return movement).

Based on these efforts, Sustainable Taxiing will now become a SESAR Solution, which will be further detailed through ongoing efforts at Amsterdam Airport Schiphol, partly under the HERON consortium.

EXE-08 "Sustainable Aviation Fuel"

1. "The main purpose of the exercise was to highlight the current Sustainable Aviation Fuel challenges. Because we have limited Sustainable Aviation Fuel supply in a few physical locations. The access is limited to carriers in a few hubs with limits on offtake levels. Cost and emissions of transporting SAF to customers have to be considered. The complexity for corporate clients to claim GHG emission reductions is demonstrated. Intention through this exercise was to demonstrate the feasibility of a dematerialized concept called “Book & Claim” to use Sustainable Aviation Fuel within the European Union, thus reducing CO2 emissions on the whole life cycle. The “Book & Claim” solution allows SAF purchase without a physical connection to the supply site. No matter where SAF is purchased the net environmental effect is the same. It enables the attribution of GHG emission reductions through SAF use to corporate customers to reduce their scope 3 emissions. Within the projected process the identified partner was able to provide assurance that transactions were credible, traceable and didn’t lead to double counting.

2. A step by step approach was followed. First by arguing the importance of SAF deployment to the Albatross participants. We identified roles and responsibilities of potential stakeholders (Partnering Airlines, Airbus, Roundtable for Sustainable Biomaterials, regulatory bodies). We explained the concept to convince potential contributors at all occasions, through training sessions with different levels of details. The partnership with RSB (Roundtable for Sustainable Biomaterials) was established to develop specifications, using one of their pilot projects. In parallel we proceeded with a risk review of the Legal, Ethics & Compliance aspects. Additional SAF incentives (Schiphol airport proposal) were envisaged to stimulate the proposal. Preliminary assessment was performed by connecting with the European Union. Finally the complete investigation for potential fuel suppliers, airports was made to initiate potential collaboration with identified stakeholders.

3. A very challenging context was experienced all along the duration of this project. Book & Claim was not identified as the key building block on SAF from the start, it was integrated while the project was already running and budget/resources allocation already defined. The Book & Claim concept increases competition risks for key producers, other initiatives could run in parallel. Limited volume (50-100 tons) expected for the exercise was not attractive for suppliers, and required logistics. The RSB Book & Claim registry requires the suppliers to be certified and accredited, reducing the number of eligible stakeholders. A risk of confusing communications could appear for some project’s stakeholders (eg. key Airlines promoting their SAF roadmap) leading to very limited interest in getting involved in the SAF initiative of the Albatross project (referring to the Schiphol incentivisation initiative that was

launched in parallel). It was Impossible to renegotiate some existing contracts either from a Supply or a Demand side, negotiated for months.

4. The main lessons learnt from this experiment are the following. The initiative to push the Book & Claim through the Albatross project was the opportunity to explore its feasibility, the needs and expectations for such a concept and its complexity. It was an opportunity to de-risk different aspects of this solution, test stakeholders' understanding and appetite. As a final result we capitalized lessons learnt from successes and failures and got experience for future similar work.

5.2 Recommendations

5.2.1 Recommendations for industrialization and deployment

At overall project level, no general recommendations are derived.

Recommendations from the individual exercises are described in more detail in Appendices A to H. This section summarizes the main points.

Exercise EXE-01 ("Gate-to-gate trials / Dynamic RAD") provides recommendations with regard to the potential future implementation of the Dynamic RAD process, which proved to be feasible at D-1 (whereas its applicability at D-OPS requires further evaluation). A duly assessment by relevant stakeholders of RAD eligible for a dynamic management is deemed necessary, as well as pre-validation. While the AUP/UUP process as interim solution seems appropriate, long-term solutions should be addressed in the frame of iNM to implement a common platform to promote ASM/TAFCM processes integration, and to support a notification process that maximizes awareness of Aircraft Operators/CFSPs on the opportunity offered.

Exercise EXE-02 " Big-Data analysis of ESSA TMA" did not derive specific recommendations from the assessment method that it has developed.

Exercise EXE-03 ("LNAS-CDA: energy-optimized descent profiles") provides the following summarized recommendations :

- To fully industrialize the LNAS concept into full maturity integrated within the avionics environment.

- To maximise efficient interaction between ATC and aircraft, so that CO2 and noise optimizations can be achieved within the TMA

- To assign more closed-path trajectories in the intermediate to final approach segment and to refrain from tactical radar vectoring (with unknown DTG from the flight deck perspective).

Exercise EXE-04 "AI/ML TMA Optimization" For industrialization and deployment, this exercise provided concrete measures that could b applied to the Frankfurt TMA.

Exercise EXE-05A "PBN-to-ILS in Vienna" was focused on deployment; the recommendations it can provide are to apply the concept in more traffic-intensive situations or at additional runways and airports (in the medium to long term).

Exercise EXE-05A "DPO/IFO" does not result in specific recommendation for industrialization and deployment. (DPO and IFO are already available on board, so can be considered as already deployed.)

Exercise EXE-06D ("SEPHER hydrogen-based backup Generators") recommendations:

For industrialization and deployment, DSNA recommends associating major companies to create a virtuous ecosystem with green hydrogen produced in few different centres, a logistic organization to deliver this hydrogen on the small and isolated sites if necessary, and a technical harmonisation for the hydrogen storage. In terms of regulation and standardisation, the use of hydrogen is tricky and should be considered by ANSPs or aerospace industry in general.

Exercise EXE-07 ("TaxiBot at Schiphol") has provided recommendations that are already slated for follow-up projects (such as HERON and the EUROCONTROL Sustainable Taxiing Taskforce). They can be summarized in the following items :

- Secure ongoing support and collaboration from all partners, in particular ANSPs/ATC;

- Finalize the draft CONOPS, with help and contribution of ATC/ANSP

- Carry out a larger number of full-scale live trials in standard operations;

- Gather actual fuel data to further validate fuel saving predictions;

- Look at the desired ownership/operating model(s) for Sustainable Taxiing operations;

- Address additional aircraft types (including the wide body fleet

- Continue to exchange with other airports.

5.2.2 Recommendations on regulation and standardisation initiatives

The exercises that provided specific recommendations on regulation and standardization are the following (the exercises that do not appear in the list do not issue any recommendation):

Exercise EXE-01 ("Gate-to-gate trials / Dynamic RAD"): While the AUP/UUP process as interim solution seems appropriate, long-term solutions should be addressed in the frame of iNM to implement a common platform to promote ASM/TAFCM processes integration, and to support a notification process that maximizes awareness of Aircraft Operators/CFSPs on the opportunity offered.

Exercise EXE-03 ("LNAS-CDA: energy-optimized descent profiles"): Efficient interaction between ATC and aircraft should be maximised; this may imply updates to standards and regulations (no specific detail has been worked on, howver).

Exercise EXE-06D ("SEPHER hydrogen-based backup Generators"): in terms of regulation and standardisation, the use of hydrogen is tricky and should be considered by ANSPs or aerospace industry in general.

Exercise EXE-07 ("TaxiBot at Schiphol"): Look at the desired ownership/operating model(s) for Sustainable Taxiing operations; Address additional aircraft types (including the wide body fleet

5.2.3 Recommendations for updating ATM Master Plan Level 2

Two new SESAR Solutions are identified (see Section 3.2):

- "Dynamic-RAD"
- "Engines-off Sustainable Taxiing through use of a Sustainable Taxiing Vehicle".

The following concept/technology elements initially worked on in certain ALBATROSS exercises were considered as new Enablers:

- DPO/IFO from EXE-05B (section E.5.1)

- OptiClimb from EXE-06C (section F.11.1)

- Single-Engine Taxi-out at Departure from EXE-06D (section F.16.1)

It was concluded that the works performed in ALBATROSS were limited to a single actor, and therefore not sufficiently significant to constitute SESAR Enablers.

However, some of these elements will be followed on in HERON, in a wider context possibly involving other actors of the ATM system. In that scope, corresponding SESAR Solutions or Enablers may be defined.

Some elements of the LNAS exercise (EXE-03, Appendix C) have been worked on the DYNCAT project and will continue in DYN-MARS.

6 Summary of Communications and Dissemination activities

6.1 Summary of communications and dissemination activities

In the beginning of the project the initial Communication and Dissemination Plan (D5.1) [20] has been created and approved. The project's website *www.sesar-albatross.eu* was launched, several project participants communicated the project on their websites and social media channels. The website is constantly updated and news are published regularly on a dedicated subpage.

Nine SESAR e-News articles have been published so far (including SJU produced material). The first one announced the project start and the project idea and the second focusses on the project leaders' view on objectives and challenges. Further articles contain interviews and background information on project and SESAR activities.

Project experiences from project partner the eg. Shiphol or DSNA were published in articles on the internet or in internal journals.

In February 2021 the project was already awarded as project of the month.

In September 2021 the communications campaign was accelerated by the AIRBUS summit. ALBATROSS was presented as a priority activity to showcase several solutions to reduce the aviation's environmental impact. Decarbonisation of aviation was one of the key messages of the summit. Stakeholders from industry and science and the general public were invited to join the event in place or online. The livestream was worldwide available and might be downloaded as recording.

As special event for the summit a first ALBATROSS flight was organised from Paris CDG to Toulouse TLS. This flight was already optimised according to some of the ALBATROSS criteria and a certain reduction of fuel burn could be reported. The flight to the summit caused a considerable media echo, which increased the public awareness of the ALBATROSS project.

AIRBUS also launched a media campaign for ALBATROSS topics consisting of several publications around the airbus summit. The articles focussed on the possibility to make the most efficient flight within the project ALBATROSS, the optimum 4D-trajectory, the use of sustainable aviation fuels (SAF) and the support of ground-based infrastructure as sustainable towing vehicles.

Those articles were launched each week for a period of 4 weeks. Thanks to the huge visibility and impact factor of the AIRBUS website the publications were broadcasted to a wide audience.

For the World ATM Congress in Madrid 2021 DSNA, Air France and AIRBUS produced a video describing the idea behind ALBATROSS and the methods used. It references the practical example of the first ALBATROSS flight CDG-TLS.

In November 2022 a special press event took place. An A350 flew on an optimized trajectory from Toulouse to Munich using Sustainable Aviation fuels (SAF). Several articles appeared in social media and on the internet.

The project had been present at several international events also in 2022. High visibility was achieved by the attendance of the World ATM Congress in Madrid 2022. ALBATROSS was presented in a dedicated panel discussion on a separate stage. The attendance of a qualified audience was given and the event was framed by several interviews published on the internet. Next to the World ATM Congress ALBATROSS was also present at the Connecting Europe Days the FABEC Vertical Flight Efficiency workshop and the Aircraft Operator ATM Community Workshop.

Several coordination meetings with other projects took place. Those were a meeting with the Dyncat consortium and a meeting with AEON project participants. Project internal workshops were also organized and conducted. Eurocontrol organized an online workshop on the ideas of dynamic RAD on July 1st 2021 and AIRBUS and DLR organized a hybrid meeting Face to Face and online at the Saint Martin site in Toulouse (16th – 17th Nov. 2021). At this meeting Advisory Board Members were informed about the project progress. Three Advisory Board Member joined the meeting physically and six further Advisory Board Member online.

The project had a vital exchange with the AEON project in April 2022 as well as with the project DREAMS in January 2022. In October 2022 the Advisory Board had the opportunity to participate at a dedicated face-to-face meeting in Amsterdam.

During the first year of the project a TV clip on ALBATROSS was produced and broadcasted by France 3 TV. In that clip some ALBATROSS principles are explained and the further way for CO2 reduction is sketched.

For the scientific community some work has been performed. Martin Gerber (SWISS) had a presentation at the ETH Zürich on next generation cockpit functions also presenting the ALBATROSS ideas and combining those topics. DLR submitted a paper to Euro GNC that is related to the DLR work share in ALBATROSS. The title is “Engine Thrust Model Determination from Large Operational Flight Data Base”.

In Summer 2022 the project and the activities to reduce carbon dioxide emissions were presented in Stockholm on the 33rd ICAS (International council of the aeronautical sciences) conference. In addition to this the ALBATROSS approach was also presented in Toulouse at the Towards Sustainable Aviation Summit TSAS 2022. Scientific work on ALBATROSS related topics was also presented at Euro GNC (guidance navigation and control) in Berlin, at DLRK Deutscher Luft- und Raumfahrt Kongress in Dresden as well as in the journal of CEAS (Council of European Aerospace Societies)

Most of the news published by the consortium or partner can be found on the ALBATROSS home page. The links lead to the websites were the are originally published.

Thanks to the contribution of many partners on their social media channels the ALBATROSS e-news and any kind of news could be shared in a way that the reach of the ALBATROSS news could be increased. Thanks to the popularity of distinct partners of the ALBATROSS consortium and of the SJU the impact of such shared articles is comparatively high.

Title	Subject	Date	Place
Kick-off meeting of ALBATROSS project	Presentation of project high-level objectives and key messages; familiarisation with SJU communications	Jan 29th, 2021	Webex hosted by SJU
SESAR project webpage	Presentation of project's objectives in SESAR context	Feb 2021	https://www.sesarju.eu/projects/ albatross
announcement on project start	Information about project's initiation and objectives	Feb 22nd, 2021	SESAR e-news; shared via LinkedIn and Twitter
'new project' presentation	Information about project's initiation and objectives	Mar 5th, 2021	DLR Flight Systems internal magazine ("FlugBlatt")
project webpage	Initial version of official ALBATROSS homepage	June 15th, 2021	https://www.sesar-albatross.eu
e-news#1; general project presentation	Interview with project leader on objectives, challenges and activities of ALBATROSS	Jun 21st, 2021	SESAR e-news; shared via LinkedIn and Twitter
Workshop on dynamic RAD	Workshop with externals from AIRBUS, DSNA, EC and Air France	Jul 1st ,2021	Online - Webex
AIRBUS summit on sustainability and aviation' s decarbonisation	Event at Toulouse, Arrival of a green commercial flight with press and media on board	Sept 21st,22nd 2021	Digital and in situ
AIRBUS summit livestream	Recorded livestream of the online event made available	Sept 21st,22nd 2021	AIRBUS website: https://www.airbus.com/en/newsroom/events/airbus-summit-2021
Press Release	Airbus and Partners target more energy efficient flights	Sept 21st, 2021	AIRBUS website: https://www.airbus.com/en/newsroom/press-releases/2021-09-airbus-and-partners-target-more-energy-efficient-flights

Title	Subject	Date	Place
ALBATROSS SAGA PART I	Online Article	Sept 21st, 2021	AIRBUS website: https://www.airbus.com/en/newsroom/news/2021-09-seeking-the-most-energy-efficient-flight-episode-1-albatross
ALBATROSS SAGA PART II	Online Article	Sept 28th, 2021	AIRBUS website: Seeking the most energy efficient flight - Episode 2 : Flight Trajectory - Innovation - Airbus
ALBATROSS SAGA PART III	Online Article	Oct 06th, 2021	AIRBUS website: Seeking the most efficient flight – Episode 3: Sustainable Aviation Fuels (SAF) - Innovation - Airbus
ALBATROSS SAGA PART IV	Online Article	Oct 12th, 2021	AIRBUS website: Seeking the most efficient flight - Episode 4 : sustainable taxiing on ground - Innovation - Airbus
Increasing the efficiency of airline flight operations with next-generation cockpit functions	Academic Presentation	Oct 26th, 2021	Akademischer Aviatikverein Zürich, ETH Zürich
World ATM Congress	SESAR walking tours and theatre presentations	26.-28.10.2021	Madrid
ALBATROSS Official Videoclip	Information on ALBATROSS Project Idea and the demonstration flight CDG-TLS	Oct 2021	Madrid WAC Online (Youtube) https://www.youtube.com/watch?v=nFsr87aliaM&t=28s
Advisory board workshop	Presentation of current project status to AB – collection of inputs	Nov 16th, 2021	Online and at AIRBUS Saint-Nazaire site in Toulouse
Engine Thrust Model Determination from Large Operational Flight Data Base	Paper Submission	Nov , 2021	EURO GNC (Conference on Guidance Navigation and Control)
LFPG ESSA G2G Preparation Workshop	Workshop of Stakeholder in the area of Air Navigation and Airspace Control	Jan 19th, 2021	Online and at Eurocontrol Site at Brussels

Title	Subject	Date	Place
Results and Findings DYNCAT	Workshop of linked project with participation of ALBATROSS project partners	Jan 26th, 2022	Online
Results and Findings DREAMS and DYNCAT	Workshop of linked project with participation of ALBATROSS project partners	Jan 26th, 2022	Online
Schiphol invests in vehicles to taxi aircraft sustainably	Schiphol e-news	Feb 18th, 2022	Schiphol newsroom
e-news Behind the scenes: measuring the environmental performance of SESAR Solutions	KPI's (Key Performance Indicators)	Feb 24th, 2022	SESAR e-news; SESAR Homepage
Inter project coordination ALBATROSS AEON	Presentation of progresses and findings	Apr 13th, 2022	Online meeting
Engine Thrust Model Determination from Large Operational Flight Data Base	Publication and Conference Presentation	May 3rd – 5th, 2022	Euro GNC, Berlin
WAC 2022	Panel Discussion	21st-23rd June, 2022	Madrid
Video	Interviews from WAC 2022	21st-23rd June, 2022	SESAR Joint Undertaking | ALBATROSS - The most energy-efficient flying bird (sesarju.eu)
Connecting Europe Days	ALBATROSS participation	28th-30th June	Lyon
THE ALBATROSS PROJECT – A EUROPEAN INITIATIVE TO REDUCE AVIATION'S CARBON DIOXIDE EMISSIONS IN LARGE SCALE	Publication and Conference Presentation	Sept 04th-9th, 2022	33rd International Council of Aerospace Sciences (ICAS), Stockholm

Title	Subject	Date	Place
Aerodynamic Model Adjustment for an Accurate Flight Performance Representation Using a Large Operational Flight Data Base	Publication and Conference Presentation	Sept 27th-29th, 2022	Deutscher Luft und Raumfahrt Kongress (DLRK), Dresden
THE ALBATROSS PROJECT – A EUROPEAN INITIATIVE FOR MORE ENVIRONMENT-FRIENDLY FLIGHT OPERATIONS	Publication and Conference Presentation	Oct 18th-20th, 2022	Towards Sustainable Aviation Summit, Toulouse
e-news How to create optimal eco-efficient flights	CONOPS (Concept of Operations)	Oct 19th, 2022	SESAR e-news; SESAR Homepage
Advisory Board Meeting	Project advances and actual status presentation	Oct 25th- 26th	Amsterdam Airport
ATM – A/C Optimization for Idle Thrust ApproachesSESAR Projects DYNCAT and ALBATROSS	Presentation at Aircraft Operator ATM Community Workshop	Nov 28th, 2022	Frankfurt
ALBATROSS FLIGHT Using SAF	Demonstrational Flight with Press Participation	Nov 30th	Toulouse-Munich
e-news En route to greener air traffic management	Project Overview SESAR activities containing ALBATROSS Information	Dec 3rd, 2022	SESAR e-news; SESAR Homepage
Optimum Management of Aircraft Energy Stateduring Descent and Approach	Presentation at 3rd FABEC Vertical Flight Efficiency workshop	Dec 7th, 2022	Nice
AI based analytics of Frankfurt TMA leading to an airspace geometry change	Presentation at 3rd FABEC Vertical Flight Efficiency workshop	Dec 7th, 2022	Nice
Aviation sector starts follow-up sustainable taxiing tests at Schiphol	Status of Polderbaan preparations and sustainable taxiing	Dec 7th, 2022	Schiphol online newsroom

Title	Subject	Date	Place
e-news SESAR partners move ahead with sustainable taxiing tests at Schiphol	Sustainable Taxi in Schiphol	Dec 20th, 2022	SESAR e-news; SESAR Homepage
ALBATROSS, À LA RECHERCHE DE LA PERFORMANCE ENVIRONNEMENTALE DES VOLS	Publication on ALBATROSS related work	Dec 2022	DSNA Internal Journal Quoi de neuf sur les grand programmes.
Engine thrust model determination and analysis using a large operational flight database.	Journal Publication	Dec 2022	CEAS Journal

Table 10: Communication and Dissemination Activities

6.2 Target Audience Identification

Target	How can they benefit from the project	Objectives and expected feedback
General Public	Get information on activities. Reduce environmental input for everyone.	Public awareness. Especially in groups dealing with pollution or noise issues.
Interested Public	Find out more aviation related implications touched by Albatross.	Spread information in own communities. (Students, online networks,…)
Airline Costumers	Increase consciousness.	Conscious choice of airlines.
World wide auditory	Get to know more about European initiatives.	Start similar activities.

Table 11: Target Audience Identification

6.3 Project High Level Messages

ALBATROSS is a visible sign of the concrete and long-lasting reduction of the carbon footprint of European aviation, taking advantage of available air- and ground-technology and of collaborative processes.

Smart innovation based on:

- Executing known processes with more fine-tuned flight parameters;

- Coordinating all actors, to relax airspace constraints when they are not necessary;

- Exploiting the increasingly available advanced aircraft capabilities, such as precision navigation and data sharing;

- Exploiting the tools of modern data science;

- Using the "flight with zero-waste of CO_2" as a reference for analysis and measurement;

brought improvements that although small individually (CO_2 reduction of 3-5% to the baseline of "current operations", on selected flight segments), can accumulate and sum up on very many flights.

Further steps are still required and possible. The lessons learned are collected in a dedicated project deliverable that can inspire the ATM/aviation community about deployable concepts that reduce the carbon footprint, in complement of larger investment in SAF, new aircraft and new ATC tools.

7 References

Content Integration

[1]

Content Development

[2]

System and Service Development

[3]

Performance Management

[4]

Validation

[5]

System Engineering

[6]

Safety

[7]

Human Performance

[8]

Environment Assessment

[9] .

Security

[10]

Communication and dissemination

[11]

Programme management

For what concerns the general collaboration between all the members of the programme:

[12] SESAR3 Membership Agreement

[13] SESAR3 Programme Management Plan

For what concerns the definition of the solutions being addressed by the project, their initial maturity levels and the target maturity dates aimed for:

[14] ATM Master Plan

[15] SESAR Maturity Report

[16] SESAR Release Strategy

For what concerns the specific scope of work covered by this project and the general way of working expected from all projects in the SESAR3 programme:

[17] 101017678 ALBATROSS Grant Agreement, [dd/mm/yyyy]

[18] SESAR3 Project Handbook

7.1 Reference Documents

[19] ALBATROSS Demo Plan (Deliverable D3.2)

[20] ALBATROSS Deliverable D5.1: Initial Communication and Dissemination Plan

[21] ALBATROSS Deliverable D2.4 - Methodologic Approach Towards "Green Flights" [*formerly known as "ALBATROSS Concept of operations*"]

[22] ALBATROSS Deliverable D4.3 – Flights Assessment

[23] SESAR Environment Assessment Process (https://www.sesarju.eu/sites/default/files/documents/transversal/SESAR%202020%20-%20Environment%20Impact%20Assessment%20Guidance.pdf)

[24] DSNA Study report (Environmental performance) – Arrivals on track 27 during the LT PBN to ILS (LFPG) evaluation (https://www.ecologie.gouv.fr/sites/default/files/rapport_etude_evaluation_PBN-to-ILS.pdf)

Appendix A Demonstration Exercise #01 Report

A.1 Summary of the Demonstration Exercise #01 Plan

The key ambition of the ALBATROSS VLD is to deliver "Greener gate-to-gate flights" for selected European city-pairs. The term "Gate-to-gate" refers to the fact that the execution of a flight and the possibilities to minimize its environmental impact are considered in a holistic way:

- Looking at all phases of execution, from departure stand until arrival stand;
- Looking at how the flight has been planned
- Looking at the flight as part of the Network and its interactions with other traffic.

In the scope of EXE-01, the first work has been dedicated to the identification opportunities for improvements, in particular those that could be deployed, under specific conditions, in the selected areas, thanks to the availability of all involved stakeholders. Besides the solutions demonstrated in the various "local" demonstrations (the other exercises described in the other sections of this Report) specific concepts have been put in place in the gate-to-gate exercises, to analyse benefits when combining multiple relevant technical solution.

A.1.1 Exercise description and scope

In the scope of ALBATROSS EXE-01, the following demonstration instances have been carried out (Ctrl-click on the titles below to jump to the detailed description) :

- *Instance 1: Dynamic RAD*
- *Instance 2: Stockholm (and Vienna, Zürich) G2G*
- *Instance 3: Flights for the "Connecting Europe Days" event (Lyon, 28 June 2022)*
- *Instance 4: Second round of G2G*

1. Instance 1: Dynamic RAD

a. Background

In October 2020, DSNA proposed in one of the NM working arrangement the introduction of the dynamic RAD management concept, including the possible application via AUP/UUP process. The aim was to get rid of permanent RAD restrictions and to introduce a process allowing a more dynamic management of restrictions according to traffic evolutions.

The group discussed the proposal and supported the idea to introduce a more dynamic management of the RAD, possibly automated, avoiding waste of capacity with unnecessary application of permanent RAD restrictions.

The proposal was discussed by different NM working arrangements, showing a general interest in the concept. To support its possible implementation, the different stakeholders agreed to launch live trials for its validation in 2021.

b. Dynamic RAD Concept

Currently, RAD measures are static and fixed in advance compared with operations. They are implemented for various reasons, which include rejection of dangerous flight plans, traffic organisation, enforcement of letters of agreement at the interface with foreign ANSP, technical systems limitations, or capacity management. In the case of capacity management, RAD experts create RAD rules to redirect flows from crowded sectors, towards other sectors where their presence is more manageable, relying on their expertise of the flows in their ACC, and the usual loads and typology of traffic.

Since these measures are tailored to handle difficult traffic situations, they may prove unnecessary in case of low traffic.

The recent COVID crisis exacerbated the need of Aircraft Operators and CFSPs to ease flight planning, since staff needed to find flight planning solutions has been lacking. Thus, RAD relaxation measures have been applied with concrete benefits in terms of flight efficiency as well as simplification for flight planning.

Considering the temporary nature of this solution, subject to the traffic growth after COVID, ATM stakeholders deemed worth to have a new approach, by assessing which RAD measures could be temporarily withdrawn, depending on conditions, e.g. specific levels of traffic, system evolutions, etc; in other words, to introduce a “dynamic RAD” approach.

This approach is obviously fully in line with the ALBATROSS concept of "minimising the impact of ATM/ATC constraints that are necessary, but de-optimize the planning and execution of some flights": by reducing the spatial or temporal scope of activation of constraints to the strict minimum necessary, a reduction of the de-optimization is obtained.

Putting in place a dynamic management of RAD restrictions has required the identification of a process and procedures to allow relevant actors to evaluate, coordinate and agree which restrictions are available for a dynamic management (ON/OFF), which time frame can be considered reasonable for this CDM process and which are the responsibility of the different partners.

Key element to address is the notification to airspace users that should be transparent and easy for managing, possibly through an automated process. This brings to the last element linked with the system support. Any solution adopted should facilitate the automation of the process, from the initial proposal on the status of the identified RAD restriction (ON/OFF), to the final notification to the airspace users.

To prove the feasibility of the concept, the involved stakeholders agreed to launch a set of live trials to address all the elements above mentioned.

c. Dynamic RAD Live trials - Objectives

The main objective of the live trials was to validate the concept of dynamic RAD, in other words to demonstrate the feasibility to manage the RAD in a flexible way, with a mechanism that daily allowed to notify its status active/de-active (ON/OFF).

Besides the main objectives, the trials also aimed to evaluate additional objectives:

- Limits of dynamicity;
- Readiness of Aircraft Operators;
- Performance achievements;
- Feasibility of AUP/UUP mechanism;
- Improvements required.

The objective of evaluating the limits of dynamicity was two-folds: (i.) identify which RAD restrictions were more suitable for a dynamic management and (ii.) what was the time limit to propose a daily status ON/OFF to Aircraft Operators/CFSPs to allow them to process the information for flight plan purposes.

With regards to the types of eligible restrictions, the ANSPs involved offered a variety of restrictions, currently published in different RAD appendixes (Appendix 3, Appendix 4, Appendix 5, Pan European Annex). However, the vast majority of them referred to level capping, some to the DCTs availability.

For the time limit, there was a common agreement of the ANSPs, supported by Aircraft Operators and CFSPs, to fix the status of the restrictions (ON/OFF), at D-1, with the AUP publication. The UUP process, in theory available, was deemed too “dynamic” for the initial validation of the concept. The decision on the time limit for the notification of the RAD status (ON/OFF) was also influenced by the capability of the Aircraft Operators to process the information for flight plan purposes. Indeed, the readiness of the Aircraft Operators to capture the opportunities and file accordingly is a key factor. In this respect, providing the information at D-1 offered enough time ahead to allow Aircraft Operators to get and process the information for the preparation of flight plans.

The decision to use the AUP/UUP process for the management of dynamic RAD was driven by different factors: the level of automation, the availability of the process with limited technical improvements, the possibility to use B2B services. Although not necessarily the final solution, the trials offered a good opportunity to assess its feasibility.

The trials provided as well the chance to understand which kind of improvements could be required to grant an effective process in place, allowing all the actors to manage the information, possibly with high level of automation.

d. Live Trials preparation

The members of the different groups involved in the discussion unanimously supported the proposal to launch live trials for the validation of the concept and facilitate an earlier implementation.

The ANSPs that expressed their willingness to be involved in the live trials are the following:

DSNA ; ENAV ; ENAIRE ; NATS ; IAA ; SKYGUIDE. After the initial consultation, NATS and IAA decided to postpone the trials at a later stage.

To support the preparation of the live trials, NM drafted a common framework document that provided a sort of check-list for the execution of the trials. It covered the identification of the selected RAD restrictions, , responsibility of the single ANSPs, procedures that will be used during the trials, notifications/publications required to ensure an appropriate awareness among the interested stakeholders. All this information were published on the NOP Portal, in a dedicated home page (dynamic RAD). An internal Operational Instructions (OIs) was prepared for NMOC staff. An AIM was published on the NOP portal with the start of the trials

The coordination with the selected ANSPs facilitated the set-up of the required data to be loaded in the NM system to allow their management via AUP/UUP.

The involvement of AUs and CFSPs, was essential in the preparation of the live trials. One of key requirements was the need to ensure the capability of CFSPs to process the data properly. In this respect, a dry run was organised in June, with the support of ENAV and ENAIRE to test the technical solutions identified for managing the dynamic RAD The possibility to have a dry run helped, with the feedback of some CFSPs, to identify some technical issues that were fixed before the start of the trials planned for the 12th of August, according to the AIRAC cycle, with DSNA. .

The involvement of the selected ANSPs, especially DSNA, facilitate the identification of synergies with the ALBATROSS projects and the operational partners of the consortium. In this respect, a dedicated awareness campaign was organised with the Aircraft Operators involved in Albatross consortium, potentially interested by the opportunities that the selected RADs could offer. Due to the DSNA involvement, the potential main beneficiary of the trials was AF.

e. Live Trial execution

The involved ANSPs run the live trials with different schedules, each of them identifying the suitable RAD restrictions to be managed dynamically during the trial periods.

DSNA started the 12th of August and concluded the trial the 5th of November. They proposed the majority of the RAD restrictions tested; most of them related to level capping.

ENAIRE started the 12th of August and ended the 2nd of December, de facto the longest trial. They proposed few RAD restrictions, including DCTs.

ENAV and SKYGUIDE started together the 8th of October and terminated the 2nd of December. They run the trials using selected RAD restrictions varying from level capping to DCTs.

f. Live Trial outcomes and feedback

To get enough information to evaluate the objectives described above (page 73), NM, in coordination with the partners involved, agreed to collect a number of data, during the trials and after its conclusion. The data collected includes the analysis of AUP and traffic data as well as feedbacks provided by the relevant stakeholders through a dedicated survey.

Section A.3 below provides the analysis of the data, and the outcomes are described further in this section. Due to complexity and also to the measurable benefits, which are more illustrative for level capping restrictions, the analysis of the trial outcome was done only for this category of RAD restrictions.

Two categories of data were collected for further processing and trial analysis:

- Daily AUP publication of the RAD restrictions activation
- Trajectories based on the last filed flight plans of flights concerned by Dynamic RAD restrictions

After the conclusion of the trials, flight plan data has been processed to filter out the flights concerned by each RAD restriction, considering the active period published in AUP, as well as the geographical scope for each restriction.

In this way, there appear two groups of flights for each restriction:

- eligible flights – those that comply with the scope of the restriction and the time of restriction relaxation;
- acceptor flights – flights that took benefit of the relaxation of the restriction and file FPL accordingly

To measure the potential and actual benefits, two indicators were defined, applicable to each restriction:

- Rate of Availability (**RoA**): duration of RAD restriction suspension within 24 h. It can be calculated daily or for the AIRAC
- Rate of Uptake (**RoU**): portion of the eligible flights that have accepted the restriction relaxation according to the FPL information

The average values are calculated considering the number of days each RAD restriction was scheduled for Dynamic RAD trials.

RAD restriction active time is defined as a duration (in hours) of a period during which RAD relaxation was not available.

For each restriction, the number of flights eligible and accepting the RAD relaxation are the sum of flights for all days the dynamic RAD trial was scheduled. The same applies to fuel burned and CO2 emission values.

To estimate fuel savings, each acceptor flight was compared with a simulated reference pair, which is capped at the highest FL available in the case of active RAD rule.

For fuel burned and CO2 emissions, the BADA model for the type of aircraft was used.

In synthesis, the analysis of the results provides interesting outcomes, demonstrating the interest of ANSPs in managing the restrictions dynamically, offering a very good level of flexibility, in some cases with availability around 90% of the time. In terms of utilisation by Aircraft Operators of the proposed RAD relaxation, the data show different level of efficiency, according to the RAD restriction analysed. Indeed, some of them indicated a very high rate of uptake, while others indicate a very low level, also in comparison of the level of availability provided.

The reasons of these apparent discrepancies could be different. As overall conclusion, it seems appropriate for any future implementation to ensure a preventive coordination between ANSPs, NM and Aircraft Operators, to get a good selection of RAD restrictions to be managed dynamically and to improve the awareness with the AUs.

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In principle, each category of actors supported the feasibility of the dynamic RAD process. Different opinions were expressed about the dynamicity of the process; D-1 seems more reasonable for Aircraft Operators although ANSPs seems interesting to evaluate the extension of the process at D-OPS. No major concerns about the AUP process, although some technical changes would be useful to facilitate the management of dynamic RAD and a better involvement of FMPs.

g. Conclusions

The live trials proved to be a useful platform to validate the concept. The results shows the potential benefits in terms of flight efficiency as well as the feasibility of all the different partners to cope with the level of dynamicity offered. In this respect, D-1 should be considered the target for the initial operations.

The usage of AUP process proved to be suitable enough, although some technical changes are necessary and are planned for NM release 27.0 (April 2023). More advanced solution will be considered in the frame of iNM to support the integration of ASM/ATFCM processes.

The applicability of the dynamic RAD concept will remain a decision of the single ANSPs as well as the selection of the eligible RAD restrictions. However, the trials demonstrate the need to ensure a close coordination with NM to identify any possible constrain that could sterilise the potential benefits. NM and Aircraft Operators/CFSPs could also play an active role in proposing relevant restrictions with high potential improvements in terms of flight efficiency. The coordination with ANSPs will facilitate their analysis and the final decision.

Looking at the comments received by the Aircraft Operators, there are expectations to anticipate the application of the concept to achieve tangible benefits, as demonstrated by the trials. At this stage, the only option is to “replicate” the live trials, focusing on a limited number of restrictions and interested ANSPs. If the partners agreed, NM can still play the role of focal points and facilitate the preparation of new live trials. The target time could be next summer.

2. Instance 2: Stockholm (and Vienna, Zürich) G2G

While the Dynamic RAD trials were focused on a specific improvement, mainly at en-route level, the following set of demo flights aimed to address improvements with an holistic approach on selected "gate-to-gate" (shortened as G2G) routes. In this case, the active contribution of all stakeholders has been proved to be essential. For this reason, the selection of the city pairs has been heavily influenced by the involvement of the ALBATROSS operational partners (ANSPs, NM and Aircraft Operators) and those, mainly ANSPs that offered collaboration for the preparation of the G2G demo flights

a. Analysis phase

- Work on this instance started in June 2021.

- Initial list of city-pairs : about 20, the full mesh of important "bases" for the airlines in the consortium.

- Sorted by highest traffic, but also by coverage by the consortium members, especially ANSPs.

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- "Local" solutions implemented by other ALBATROSS exercises are very concentrated on TMAs, and especially arrivals; also several PBN-to-ILS implementations were planned or demonstrated, but ended up not being active at the time when the exercise could be executed.

The NM team worked on possible improvements to the en-route segment between the city pairs, and in particular on two aspects :

(i) ASM analysis, but the most impacting spaces were in airspace whose ANSPs are not in the consortium. These ANSPs have been approached to verify their availability to participate ; but they couldn't.

(ii) Introduced the opportunity to use Dynamic-RAD;

The usage of AUP + UUP and also of NM's GRRT tool was discussed.

A short list of three city pairs was finally selected: LFPG<->ESSA, LFPG<->LOWW, LFPG<->LSZH (Paris, Stockholm, Vienna, Zürich).

As a reminder: "city-pair A<->B" means that improvements are sought for flights from A to B and also, in fact independently, for flights from B to A.

With this short list decided, the specific opportunities for improvements could now be discussed by the operational experts from the selected airspaces.

b. Preparation Phase

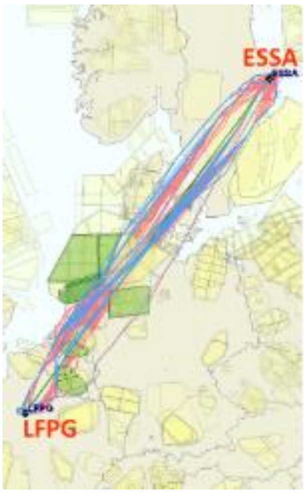
Several workshops and discussions, in January and February, involving Eurocontrol, LFV, Swedavia, Novair, Naviair Denmark, MUAC, NMOC, DSNA, Air France, Airbus.

- A hard constraint on the planning of the exercises is imposed by a very important system upgrade planned at the Reims-ACC in early April: demonstration activities must obviously not interfere, and a "grace period" between the end of the demo/trails and the beginning of the upgrade must be reserved. Therefore end of March is the very latest possible date for the end of trial/demo activities. Because the switch to the Summer season, and the activation of summer-savings time take place on Saturday March 26, it is decided that March 25 will be the last day of demonstration for this instance.

- It is quickly apparent that the ESSA<->LFPG city pair is not very de-optimized because of ATM: the flight plans do not deviate much from a direct path, apart from the SIDs and STARs segments. Furthermore, there isn't much dispersion in the planned and flown trajectories.

Some other points of focus during the discussions:

- Stockholm : RNP-AR arrivals are already published; but AF A320 fleet is not RNP-AR able.



- Some opportunities are found at the interface between MUAC and the French ACCs. Many of them refer to ATC improvements (tactically) while other constraints set in the various LoAs are a possible concept as well.

- AF flight planning settings for this city-pair (in LIDO) calculate minimum fuel or minimum distance routes; no "company catalog" routes are applied on this route.

- Dynamic-RAD: if this process is used, AF prefers not to use the AUP/UUP solution (and use GRRT instead) because the EAUP process is not fully automated (hence not sufficiently reactive/reliable) in LIDO backoffice.

- Military areas do not have much impact on the flights between ESSA and LFPG (in both directions)

- Free Route airspaces in the Scandinavian countries; mandatory entry points/transition points;

- DSNA concerned ACCs (Paris and Reims) as well as Air France are users of MUAC's ATM Portal, which was the tool used by MUAC to support the demonstration.

At the end of February 2022 Air France issues a "Company NOTAM" to inform the concerned pilots of the demonstrations.

None of the candidate improvements is outside the standard operating procedures.

Briefing is performed to AF dispatch, already familiar with the ATMP tool.

By mid-February, MUAC also briefed their OPS room on the agreed procedures to support the candidate ALBATROSS flights. MUAC also informed on their decision to serve all the flights in the selected city-pairs, based on a fairness and transparent principle.

As an outcome of the discussions, the improvements listed below could be confirmed for implementation, for a duration of three weeks (from Monday March 7 until Friday March 25, 2022).

Unfortunately several other candidate improvements could not be implemented, for various operational reasons (mainly: planning incompatibility; or AF flights operated by the Hop subsidiary (not involved in ALBATROSS); or unavailability of ANSPs not part of the ALBATROSS project).

c. The improvements

1. For LFPG Arrivals ESSA->LFPG and LOWW->LFPG

1.1. Via MOPIL coordination point:

Paris ACC would allow DCT DEVIM tactically. Not for flight planning purposes.

No other changes foreseen.

1.2. Via RAPOR coordination point:

MUAC to Paris-ACC interface raised to FL310.

MUAC FMP will check if the PTR restriction that caps flights at FL270 (EDYY9002A) can be removed. (If not possible or not enough time in advance, FMP could skip it manually during the trial.)

MUAC FMP can identify greener trajectories and will send the re-route proposal (RRP) to the Aircraft Operators, via ATM-Portal (see below).

Paris ACC and MUAC agree to propose the possibility to allow IDOSA DCT VEDUS during the trial, only on "ALBATROSS Flights". (This DCT is given ONLY tactically, not to be used for flight planning purposes.)

(Rationale : ALBATROSS trial is a good opportunity to test this "Cross-border FRA" permanent DCT which could benefit all arrivals to LFPG via RAPOR H24 if the trial is successful for all parts. Next steps to follow depending on the outcome of the trial.)

(Note: Some possible improvements were also identified for the DINAN STAR. However this STAR is never filed by Air France, apparently because of a vertical constraint at point FF101 which results in less optimal trajectories than the other available STARs. Therefore, no improvements were implemented on DINAN arrivals.)

1.3. In case of high traffic, it was agreed that LFPG arrivals will be hold higher with regards to departures EDDF.

1.4. During the timeframe of the exercises, the improvement implemented by DSNA as part of EXE-06B was also active. This consists allowing, under specific circumstances, a less constraining altitude (FL170 instead of FL150) on the IAF point "LORNI".

A detailed description of this concept can be found in the chapter for EXE-06B of the ALBATROSS Demo Report.

2. For LFPG Departures

<u>2.1. LFPG -> ESSA</u>

MUAC offers to alleviate the mandatory waypoint VICOT, allowing an earlier turn to the north-east at FERDI.

For flight planning purposes and ONLY during the ALBATROSS demo :

- ADUTO DCT FERDI DCT TUSKA
- ADUTO DCT HELEN DCT MIKNA/DETSO/ALASA

Tactically, ADUTO DCT DETSO/MIKNA is a possibility.

This overrides the RAD restriction "YXLF1001" .

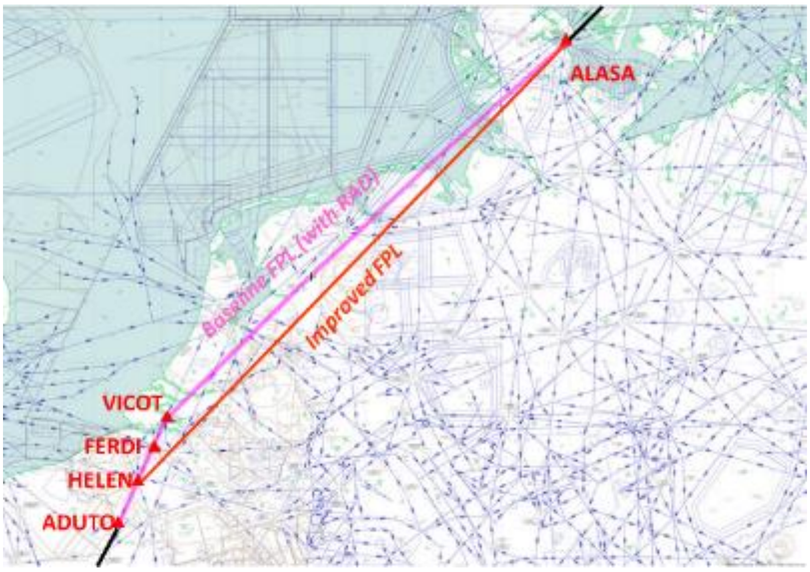


Figure 2: Effect of the relaxed RAD

2.2. LFPG -> LOWW and LFPG -> LSZH

No changes on this city-pair could be applied by Reims-ACC in the March demo.

However, for the northerly route through MUAC Luxemburg Sector in this city-pair, Reims-ACC agreed to coordinate tactical improvements (request higher FL).

The ALBATROSS demonstration on this route during the March iteration will be limited to "existing" improvements that do not require additional coordination.

d. Operating Procedures

MUAC's ATM-Portal Tool

"ATM-Portal" ("ATMP") is MUACs collaborative portal, used with other ANSPs and with Airspace Users.

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ATMP is foreseen as a good coordination tool between the involved partners: All of them have already an ATMP user, and although not every operational agent is trained on the tool, or aware of it, uptake of this collaborative portal should be easy.

Procedure: MUAC FMP confirms the availability of an alternative improved routing on the ATMP tool, in which case Aircraft Operators can chose to use the improvement in FPLs, if at least 2 hours before a flight's EOBT. An additional e-mail notification is sent, to help the dispatchers detect the proposal also when not looking directly on the ATMP. Upon detection/reception of the improvement opportunity, the Aircraft Operators evaluate the associated RRPs and decide if they would like to refile accordingly.

Flight Plans

It is agreed that the indication "ALBATROSS Flight" will be inserted in Field-18 for all

This marker has only the purpose to trace the candidate flights. It is not expected that these flight receive special treatment or priority, apart from the stipulations agreed for the demon, that would improve their trajectory while deteriorating other flights.

For the structural constraints that are relaxed pre-tactically (points above "LFPG Arrival 3." and "LFPG Departures 1.2") on airline dispatch side, these flight plans must be produced manually, to remove the constraint that will still be present in the LIDO database.

Since the RAD was not actually deactivated, the refiled flight plan received from the RRP /ATM-Portal would not be valid in IFPS. Therefore it was agreed to have recourse to the RTECOORATC indicator in FPL Item 18, which gives "immunity" from IFPS checks.

e. Execution Phase

The process described above was active from March 7 until March 25, 2022.

The first week (March 7 – 13) was considered a ramp-up week.

513 flights in total were operated during this period by the following airlines: AFR (all city-pairs), AUA (Vienna), SAS (Stockholm), SWR (Zürich)

(additional cargo flights took place, but were not considered part of the exercise).

As a confirmation and for preparation, every day around 18:00 (Paris Time), the exercise coordination team would send an e-mail to all exercise participants with the updated list of flights scheduled for D+1.

The detailed quantitative analysis of the demonstration flights was the task of Work Package 4. The flights operated by Air France were analyzed in detail (Austrian and SAS not being in the ALBATROSS consortium, and Swiss International being only marginally concerned by the available improvements). However, the improvement opportunities that could actually be uptaken applied mostly to the LFPG<-

>ESSA city pair. As a result, the sample used by WP4 is constituted of 96 flights operated by Air France on the LFPG<->ESSA city pair.

Focusing on the improvements offered by MUAC, during the length of the demo the following were produced:

- 60 Re-routing proposals pre-tactical and 47% of them were taken up by the AOs

- 143 ALBATROSS flights received tactical shortcuts from MUAC ATCOS

Figure 3: Tactical Shortcuts on ALBATROSS flights split per City-Pair

Those tactical shortcuts generate big length savings, which for the cases where a RRPs was accepted are on top of the savings granted in the pre-tactical phase. Graph below shows the actual benefits (expressed in NM) of those tactical shortcuts. Results are split per city-pair.

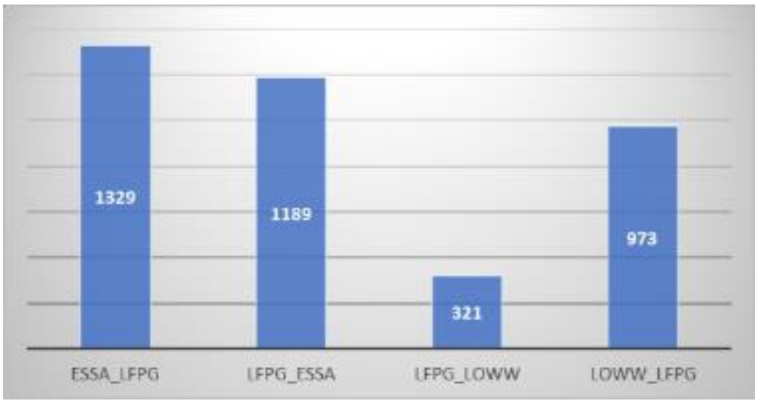

Figure 4: Length savings (NM) thanks to the tactical shortcuts offered by MUAC to ALBATROSS flights.

- 20 ALBATROSS flights got higher cruising levels than the ones in the FPL

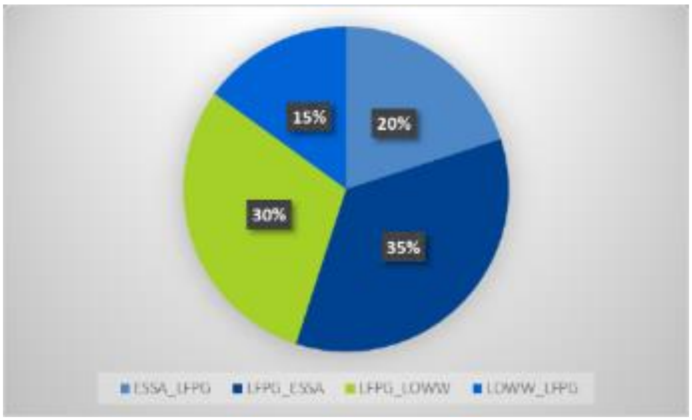

Figure 5: Tactical (higher) Cruising Levels offered by MUAC to ALBATROSS flights.

- 3 ALBATROSS Extra flights were taken in MUAC airspace when not initially planned.

From that amount:

151 offerings were specific for Air France (Mar 14 – Mar 25)

- 39 Pretactical (26 on ESSA city-pair and 13 on LOWW city-pair)

- 8 higher cruising levels (4 on ESSA city-pair and 4 on LOWW city-pair)

- 104 tactical shortcuts (63 on ESSA city-pair and 41 on LOWW city-pair)

Notice that some flights received multiple proposals for improvements (for example a RRP pre-tactically, and then shortcuts or higher FL); on 107 "unique" flights that received proposals (AFR), 5 flights received three or more, 42 flights received two, 60 flights received one single proposal.

Concerning improvement 1.4 above, "Green descents at CDG", applied from EXE-06B:

The improved altitudes at the IAFs for LFPG arrivals are designed to be active during four hours every afternoon, if the runway configuration was east-facing (the improvement only applies to the transitions including a downwind leg; for arrivals from the East, which is the case for ESSA, the concerned IAF is LORNI and the improvement was active when the LFPG runways are used east-facing, ie. 08/09 runways.)

The improvement was active for 19 ESSA-LFPG arrivals of the exercise. Of these, 13 actually took advantage of the improvement, for an uptake rate of 68%, considered very satisfactory.

A comparison of the vertical trajectory (from ADS-B data) for typical "baseline" and "greener" flights for this improvement is shown in the illustration below.

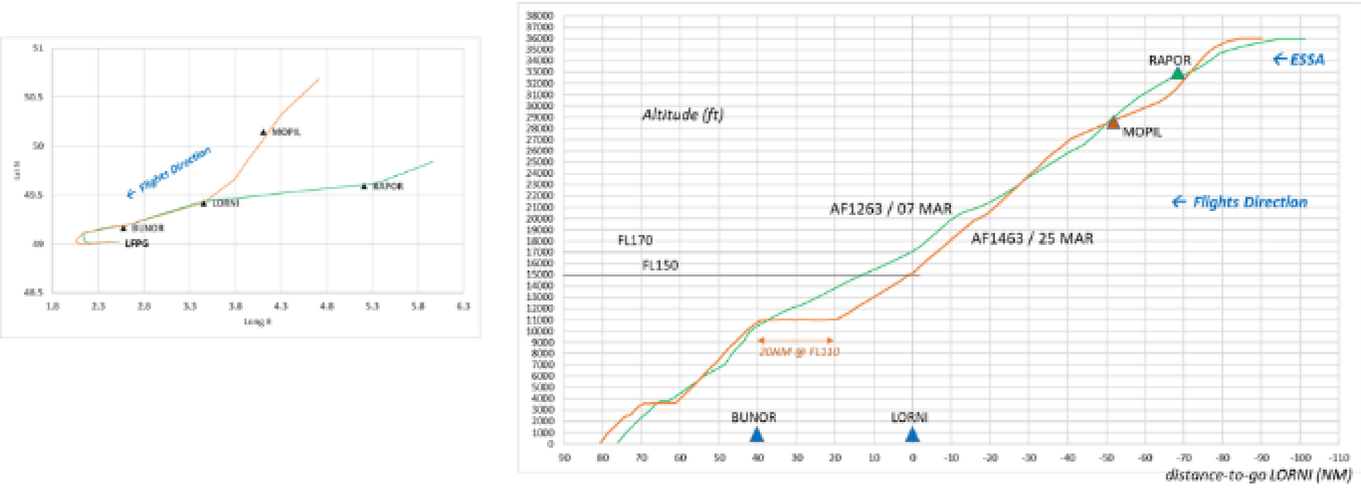

Figure 6: Improved vertical profile from "CDG GReen Descents"

f. Results

(The detailed analysis is the object of deliverable D4)

The overall outcome of the exercise is that out of 96 flights, 23 could be classified as "Greener Flights": a flight is classified as "Greener" when the analysis of the flown trajectory confirms that one of the available improvements was applied. The set of "Greener Flights" constitutes the "Solution sample".

Any flight not classified as "Greener Flight" is considered a "Baseline Flight" and belongs to the "Reference sample".

The quantitative analysis of the CO2 reduction was performed using the ALBATROSS "delta fuel" methodology.

For each flight:

- determine the quantity of fuel actually used, as measured by the flight data recorders;

- determine the minimum quantity of fuel theoretically required to perform the same flight in "optimum conditions ("OF": same aircraft characteristics, same takeoff weight, same weather conditions; no restrictions in the 4D trajectory, ie. lat/long/altitude/speed profiles);

- calculate the difference ("delta-fuel"), in percentage of the "OF";

- compare the statistical distributions of delta-fuels calculated for the "Greener Flights" ("Solution") sample with the distribution for the "Baseline Flights" ("Reference") sample.

The set of 96 "OF" fuel consumption has been calculated using three alternative methods, by Airbus, by Thales and by Eurocontrol.

The "GF versus BF" statistical comparison has been performed on the delta-fuel quantities for the entire flight, from takeoff until landing. The result is that it is not possible to show a statistically significant reduction of fuel burn (and therefore CO2 reduction) in the GF sample as compared to the BF sample.

This could be due to the fact that the applied improvements are concentrated in a relatively small portion of the flights; the impact of the remaining portion (typically, a "GF" that could not perform very well outside the "green" portion) is suspected as the source of this result.

Lessons Learned

- AO/ANSP working together more closely will yield more result
- 'Burden' of AO Re-filing could be relieved by an improvement in network procedures for Flight plan handling
- Accurate measurement of benefits requires more data-sharing

3. Instance 3: Flights for the "Connecting Europe Days" event (Lyon, 28 June 2022)

In the month of June 2022 Albatross was involved in the "Connecting Europe" Days, organised in Lyon, France. During the event, namely the 28th of June, a number of flights have been coordinated among ATM and AUs partners to demonstrate the potentiality of the gate to gate approach.

Considering the interest of the Aircraft Operators, NM analysed a number of city pairs connecting different airports with Lyon. Looking at potential improvements, a proposed optimised route was identified for each of them (attachment 1), selecting specific flights schedule for the 28th of June as following:

Airline	Flight	Departure	Arrival (Lyon St Exupéry)
KLM	KL1415	11:45 (LT) Amsterdam Schiphol Airport	13:20 (LT)
WizzAir	WZZ3061	11:30 (LT) Bucharest Airport (OTP)	13:25 (LT)
Vueling	VY1220	12:05 (LT) Barcelona	13:30 (LT)
Lufthansa	LH1076	12:50 (LT) Frankfurt Airport	14:05 (LT)
EasyJet	EJU4434	14:50 (LT) Lisbon	18:10 (LT)

Table 12: Flights improved in EXE-01 Instance 3

Due to the late coordination for the identified flights, it was impossible to consider specific solutions, such as dynamic RAD, for the management of the constraints identified. Therefore, for each of them, to ensure the acceptance of the proposed FPL by IFPS, based on a preliminary coordination with relevant ANSPs, It was decided to use the indicator RTECOORATC in item 18 RMK/ of the FPL to allow the NM system to accept the optimized routes unconstrained by existing restrictions. The attachment 2 describes in details the ANSPs where constraints relaxation have been coordinated.

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To respect the schedule, coinciding with other activities planned during the event, the Aircraft Operators asked exemption from ATFM measures, using the STS/ATFMX indicator in the FPLs Item 18. To facilitate their identification, the Aircraft Operators inserted the word ALBATROSS in Item 18 RMK/ for the selected flights.

Wherever the proposed routing was interacting with reserved/restricted areas, NM has performed a preliminary coordination with relevant military authorities to seek for the availability of the identified areas according to the scheduled flights.

Where it was NOT possible to find an agreement with the relevant military authority, in reality few cases, the Aircraft Operators filed a trajectory circumnavigating the allocated areas.

Tactical coordination provided additional improvements for the en-route as well as at TMA and airports level whenever possible.

The coordination with ANSPs was triggered by a letter to the Director of Operations of the relevant ANSPs, as done in the past for similar events. The same approach was used to speed up the coordination with relevant military authorities involving members of dedicated NM working arrangements. In this respect, despite the late information provided, their was essential for the successful preparation of the flights.

The execution of the flights confirmed the full cooperation of the involved actors, ANSPs and military, as well as the majority of the Aircraft Operators involved in the demonstrative flights, as described by the Attachment 3. Looking at the details of each flight, namely proposed optimised route, filed FPLs and executed flights, a number of considerations are possible:

- The proposed trajectory took into considerations all possible coordinated improvements;
- The Aircraft Operators filed the proposed trajectories, confirming the good coordination in the preparation for the majority of them (just one flight with problems at the D-OPS due to lack of information at Flight dispatch level; solved with support of IFPS staff);
- One of them (Easy Jet from Lisbon to Lyon) could be considered as the “ideal” one, where the three trajectories almost coincide, providing the required predictability;
- The others show differences from planning to tactical, basically with additional improvements, except one flight (Wizzair from Bucarest to Lyon), subject to re-routings due bad weather conditions.
- For the three remaining with tactical improvements, different considerations are required:

  - The KLM flight for Amsterdam to Lyon required the involvement of different partners; due to the short time, it was impossible to get the approval by all of them to offer the initial improved trajectory also for FPL purposes. For this reason, the proposed FPL was reflecting the standard one. Then, tactically and with the support of MUAC, it was possible to offer consistent improvements, de facto allowing KLM to fly the original optimised trajectory;
  - The DLH flight from Frankfurt to Lyon got a proposed trajectory considering the achieved agreement with some of the actors involved but not all, namely a preliminary agreement to cross the EDR305. Crossing that was allowed at tactical level, improving the already optimised trajectory;
  - The third one, VLG from Barcelona to Lyon, flied the proposed optimised trajectory taking benefit from the agreed improvements. The data of the executed trajectory shown that

tactically the flight got even a better routing, not initially considered in the analysis (some discrepancy for the initial climb, likely linked to the runway in use).

The primary goal of the demonstrating flights was to show the potential ATM improvements in contributing to the reduction of CO2 emission through optimised trajectories. The special treatment asked for the execution of the flights should not be considered as "solution" per se but as opportunity of improvements through standard coordination.

4. Instance 4: Second round of G2G

At the end of 2022 the demonstration of Instance 2 described above was repeated by NM and MUAC.

The table below presents the details and scope of EXE-01 Instances 2 and 4 demos, with the new flows in Instance 4 highlighted in bold text:

	Phase 1 : EXE-01 Instance 2	Phase 2 : EXE-01 Instance 4
Dates	14th-25th March	21st Nov – 11th Dec
Flows - Pre-Tactical phase **Main Actor: TCM**	LFPG→ESSA ESSA→LFPG Arrivals to LFPG via RAPOR Arrivals to LFPG via DINAN	LFPG→ESSA ESSA→LFPG Arrivals to LFPG via RAPOR Arrivals to LFPG via DINAN London TMA→EDDF
Flows - Tactical phase **Main Actor: ATCO**	LFPG→ESSA LFPG→LOWW Arrivals to LFPG via RAPOR	LFPG→ESSA LFPG→LOWW Arrivals to LFPG via RAPOR EHAM→EDDS
Beneficiaries	Although a specific group of Airlines are members of the ALBATROSS Consortium, based on the "equity and fairness" principle, MUAC decided to offer greener trajectories to any airline operating in the aforementioned flows during the period of the demos.	

Table 13: Comparison of EXE-01 Instances 2 and 4

A.1.2 Summary of Exercise EXE-01 Demonstration Objectives and success criteria

The gate-to-gate trials had two main objectives:

OBJ_VLD_ALBATROSS_001: Demonstrate the possibility for Aircraft Operators to plan and execute a "greener" trajectory between selected city pairs, taking benefits by coordinated solutions applied for the specific flights.

The success criterion for this objective (identified as CRT_VLD_ALBATROSS_001) is to show, repeatedly, a reduction in CO_2 emissions (proxied by fuel burn) for the flights in the scope of the trial.

OBJ_VLD_ALBATROSS_002: Demonstrate the feasibility of CDM processes among the different stakeholders to exploit any potential benefit in terms of greener trajectory for any flight along any city pair: Develop operational procedures (possibly temporary and on limited airspace) that enable the targeted improvements. If a space- and time-window exists, where the procedures are feasible in real traffic, apply those procedures on as many concerned flights as possible.

The success criterion for this objective in this exercise (identified as CRT_VLD_ALBATROSS_002) is to analyze at least 3 city-pairs and implement improvements in at least two city-pairs.

The following additional objectives had been formulated in the Demo Plan (under identifier OBJ_VLD_ALBATROSS_003), but could not be addressed specifically :

- Assess the impact of constraints not specifically in the “ATM operational” domain, such as route charges, that should be addressed by regulatory authorities to identify solutions to eliminate/mitigate their impacts (e.g. incentives to fly greener trajectory when they are avoided by operators because “more expensive”).

- Airport solutions such as taxi-bot or one-engine taxiing will be considered if available for the selected city-pairs. In these cases, they will be considered both as contribution to the greener trajectory and as sustainability in combination with other ATM solutions in TMA and en-route operations.

A.1.3 Summary of Exercise EXE-01 Demonstration scenarios

<u>Instance 1: Dynamic RAD</u>

Dynamic management of selected RAD restrictions by DSNA, ENAIRE and ENAV. Notification to airspace users through the AUP/UUP process or via NM's "GRRT" mechanism.

<u>Instances 2 and 4: Stockholm "Gate-to-Gate"</u>

Flights on the Paris-CDG / Stockholm Arlanda city-pair (both directions) benefited, when possible, from relaxed pre-tactical constraints in the MUAC airspace (notified via MUAC's ATMP process), from several tactical improvements by MUAC (flight levels and direct routings) and from "Green descents" for Paris-CDG arrivals (EXE-06B).

Instance 3: Flights for the "Connecting Europe Days" event (Lyon, 28 June 2022)

During the "Connecting Europe Days" event on June 28 2022, a number of flights on Lyon, France have been coordinated among ATM and AUs partners.

Instance 4: Second round of "Gate-to-Gate" / MUAC inititatives

Flights in the MUAC airspace benefited, when possible, from relaxed pre-tactical constraints (notified via MUAC's ATMP process) and from several tactical improvements by MUAC (flight levels and direct routings).

A.1.4 Summary of Exercise EXE-01 Assumptions

Identifier	Title	Type of Assumption	Description	Justification	Impact on Assessment

Table 14: Demonstration Assumptions overview

No assumptions were formally tracked.

A.2 Deviation from the planned activities

The initially defined city-pairs (except for CDG-ARN) could not be optimized, because the relevant airlines and ANSPs could not all be involved together.

Furthermore, the objective OBJ_VLD_ALBATROSS_003 "Other decarbonation initiatives" was included for this exercise, consisting in the usage of SAF for some of the flights of the exercise; it turned out that the implementation of the Book & Claim mechanism for SAF by EXE-08 could not be planned to be synchronized with EXE-01, and the objctive was therefore removed.

A.3 Demonstration Exercise EXE-01 Results

A.3.1 Summary of Exercise EXE-01 Demonstration Results

Demonstration Objective ID	Demonstration Objective Title	Success Criterion ID	Success Criterion	Sub-operating environment	Exercise Results	Demonstration Objective Status
OBJ_VLD_ALBATROSS_001		CRT_VLD_ALBATROSS_001			CO2 reduction estimations confirmed	OK
OBJ_VLD_ALBATROSS_002		CRT_VLD_ALBATROSS_002			Analyzed City-pairs: LFPG-ESSA, LFPG-LOWW, LFPG-LSZH, LFLL-xxxx; Analyzed RADs by 3 ANSPs. Implemented four instances of improvements on real operations.	OK

Table 15: Exercise EXE-01 Demonstration Results

1. Results per KPA

The exercise focused on the "Environmental Efficiency" performance area.

Results are available in sections A.1.11.f, A.1.12.f, A.1.13, A.1.14 .

2. Results impacting regulation and standardisation initiatives

The exercise used processes that are already deployed and standard.

However, the management of Dynamic-RAD through the AUP/UUP process is considered a temporary solution. A more general approach will be developed after ALBATROSS, as part of a new SESAR Solution that has been introduced for Dynamic-RAD.

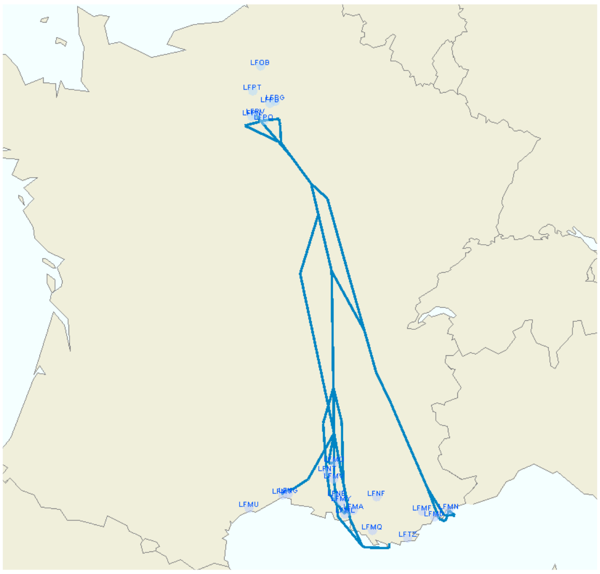
A.3.2 Analysis of Exercises Results per Demonstration objective

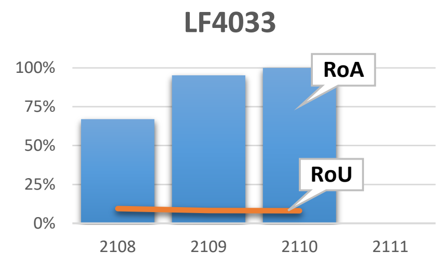
1. Instance 1: Dynamic RAD

Note: images below are used only for illustration and are not showing all assessed flights.

Dynamic RAD restriction: LF4033

From MONTPELLIER_GROUP, NICE_GROUP, PROVENCE_GROUP, RHONE_GROUP, TOULON_GROUP crossing LF to ORLY_GROUP
FL capping: FL345
Applicability: 12-08-2021 until 03-11-2021 (84 days)





Eligible flights: 2149
Acceptor flights: 180
Days RAD active: 14
Actual fuel saved: 0.04 t
Potential fuel savings: 0.44 t
Actual CO2 reduction: 0.14 t
Potential CO2 reduction: 1.39 t
RoA= 87.4%
RoU= 8.6%

Dynamic RAD restriction: LF4132

From MONTPELLIER_GROUP, NICE_GROUP, PROVENCE_GROUP, RHONE_GROUP, TOULON_GROUP crossing LF to LILLE_GROUP, ROISSY_GROUP, LFOB/OP
FL capping: FL345
Applicability: 12-08-2021 until 03-11-2021 (84 days)

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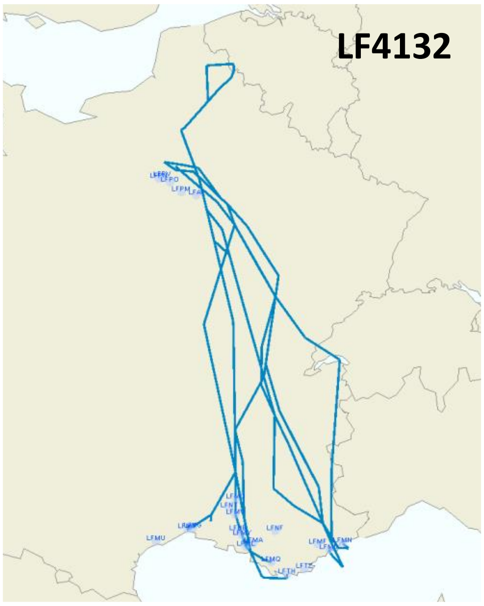
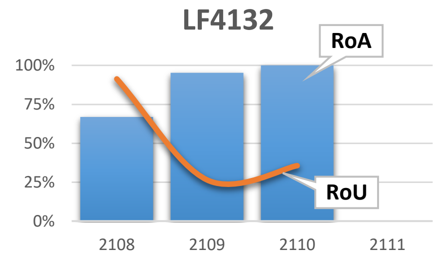
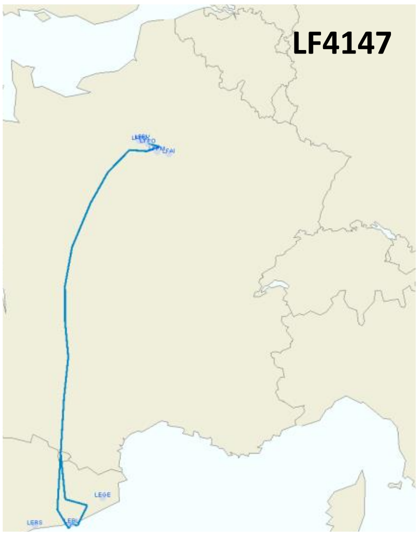


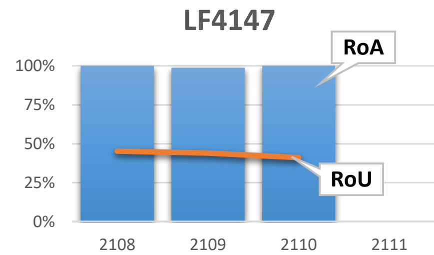


Eligible flights: 2397
Acceptor flights: 1066
Days RAD active: 14
Actual fuel saved: 27.8 t
Potential fuel savings: 51.0 t
Actual CO2 reduction: 87.6 t
Potential CO2 reduction: 185.9 t
RoA= 87.4%
RoU= 51.2%

Dynamic RAD restriction: LF4147

From LEBL/RS/GE crossing LF to ORLY_GROUP
FL capping: FL365
Applicability: 12-08-2021 until 03-11-2021 (84 days)



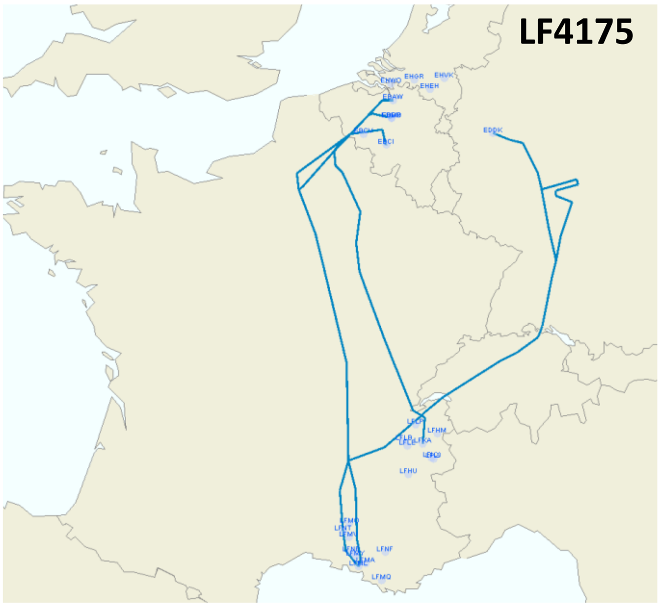


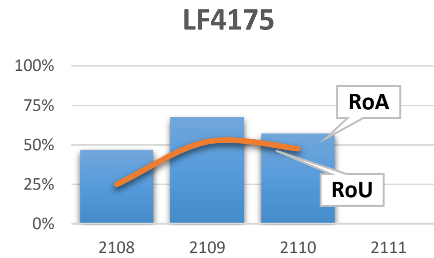
Eligible flights: 448
Acceptor flights: 196
Days RAD active: 1
Actual fuel saved: 2.6 t
Potential fuel savings: 6.0 t
Actual CO2 reduction: 8.3 t
Potential CO2 reduction: 19.0 t
RoA= 99.6%
RoU= 43.5%

Dynamic RAD restriction: LF4175

From CHAMBERY_GROUP, LYON_GROUP crossing ED/ED/EH/LF to EBAW/BR/CI/KT/MB/ZW, EDDF/DG/DK/DL/FE/FM/FZ/LA/LE/LM/LP/LV/LS/LW/VK/WO, EHBD/EH/GR/VK/WO, ETNG/NN/OU via PENDU
FL capping: FL325

Applicability: 12-08-2021 until 03-11-2021 (84 days)

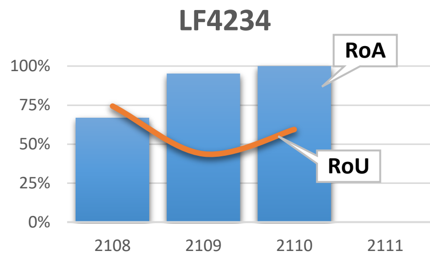




Eligible flights: 70
Acceptor flights: 29
Days RAD active: 45
Actual fuel saved: 0.37 t
Potential fuel savings: 0.83 t
Actual CO2 reduction: 1.17 t
Potential CO2 reduction: 2.61 t
RoA= 57.2%
RoU= 41.5%

Dynamic RAD restriction: LF4234

From BASTIA_GROUP, LFKO crossing LF to ROISSY_GROUP, LFOB
FL capping: FL365
Applicability: 12-08-2021 until 03-11-2021 (84 days)

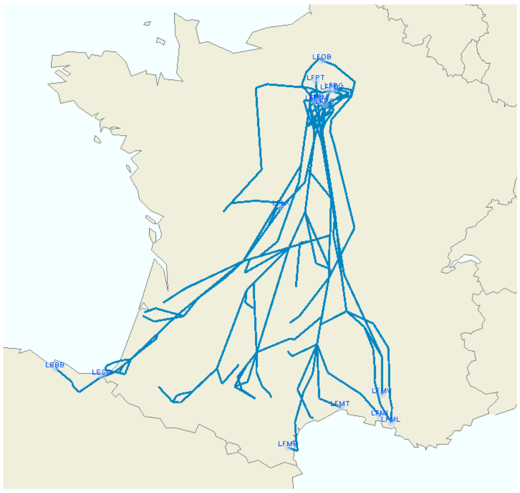


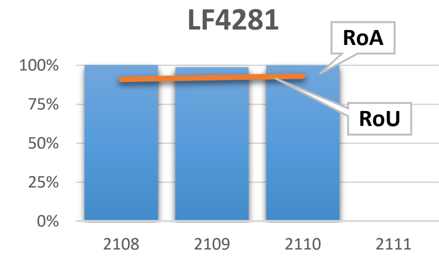
Eligible flights: 103
Acceptor flights: 62
Days RAD active: 14
Actual fuel saved: 1.85 t
Potential fuel savings: 3.10 t
Actual CO2 reduction: 5.84 t
Potential CO2 reduction: 9.75 t
RoA= 87.4%
RoU= 59.2%

Dynamic RAD restriction: LF4281

From PARIS_GROUP, LFOB/LX crossing LF to LFBBFIR, LFMP/MT/ML/MI/MV/MU, LEBB/SO via LFBBCTA

FL capping: FL295
Applicability: 12-08-2021 until 03-11-2021 (84 days)



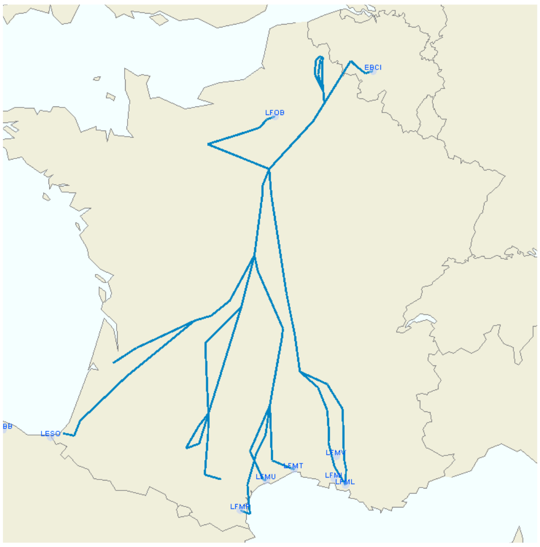


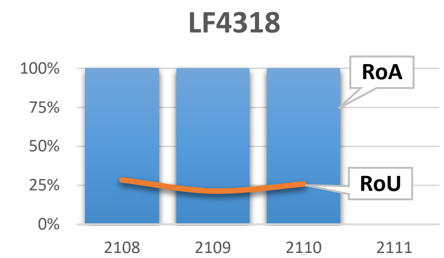
Eligible flights:	6288
Acceptor flights:	5797
Days RAD active:	1
Actual fuel saved:	388.8 t
Potential fuel savings:	421.8 t
Actual CO2 reduction:	1224.8 t
Potential CO2 reduction:	1328.7 t

RoA= 99.6%
RoU= 92.1%

Dynamic RAD restriction: LF4318

From EBCI, LILLE_GROUP, LFOB crossing EB, LE, LF to LFBBFIR, LFMP/MT/ML/MI/MV/MU, LEBB/SO via RESMI
FL capping: FL345
Applicability: 12-08-2021 until 03-11-2021 (84 days)





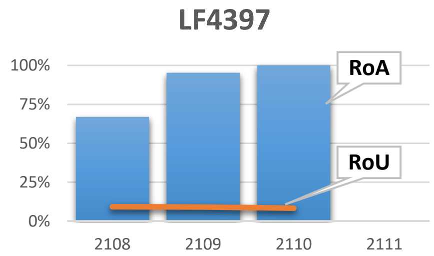
Eligible flights:	1123
Acceptor flights:	283
Days RAD active:	0
Actual fuel saved:	8.9 t
Potential fuel savings:	35.3 t
Actual CO2 reduction:	28.2 t
Potential CO2 reduction:	111.1 t

RoA= 100%
RoU= 25.3%

Dynamic RAD restriction: LF4397

From AJACCIO_GROUP, BASTIA_GROUP crossing LF to ORLY_GROUP, LILLE_GROUP

FL capping: FL345
Applicability: 12-08-2021 until 03-11-2021 (84 days)

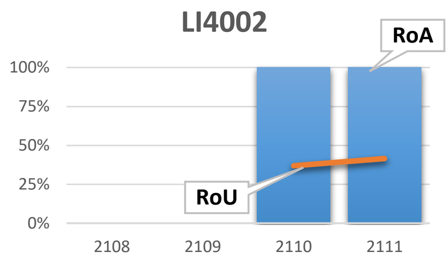


Eligible flights:	1289
Acceptor flights:	115
Days RAD active:	14
Actual fuel saved:	3.6 t
Potential fuel savings:	40.0 t
Actual CO2 reduction:	11.3 t
Potential CO2 reduction:	125.9 t

RoA= 87.4%
RoU= 8.8%

Dynamic RAD restriction: LI4002

From LIBD crossing LI to LIR* except LIRQ/RP
FL capping: FL335
Applicability: 07-10-2021 until 01-12-2021 (56 days)

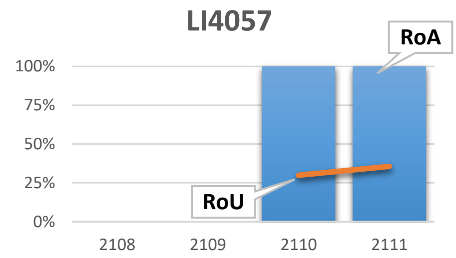


Eligible flights:	218
Acceptor flights:	80
Days RAD active:	0
Actual fuel saved:	2.6 t
Potential fuel savings:	6.5 t
Actual CO2 reduction:	8.1 t
Potential CO2 reduction:	20.6 t

RoA= 100%
RoU= 39.3%

Dynamic RAD restriction: LI4057

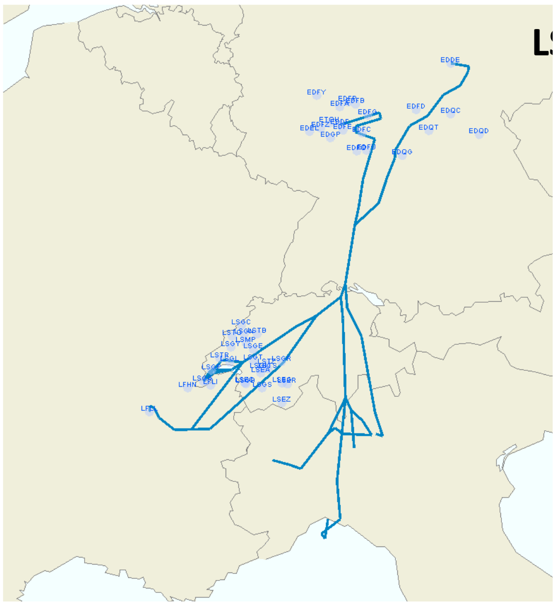
From LIR* except LIRQ/RP crossing LI to LIBD
FL capping: FL335
Applicability: 07-10-2021 until 01-12-2021 (56 days)

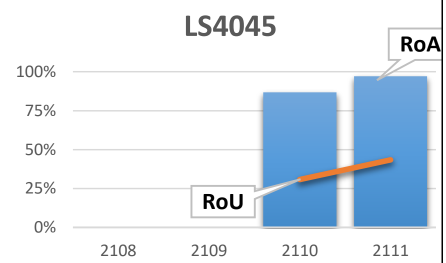


Eligible flights: 249
Acceptor flights: 82
Days RAD active: 0
Actual fuel saved: 3.1 t
Potential fuel savings: 9.3 t
Actual CO2 reduction: 29.2 t
Potential CO2 reduction: 33.2 t
RoA= 100%
RoU= 32.7%

Dynamic RAD restriction: LS4045

From LIM*, LFLL, GENEVA_AREA, GENEVA_GROUP crossing ED, LSEGUTA to EDDE/DF/FE/QC/QD/QG/QM/QT, ETOU, FRANKFURT_YZ_GROUP via LSAZUTA
FL capping: FL335
Applicability: 07-10-2021 until 01-12-2021 (56 days)

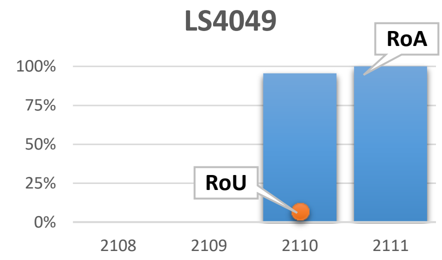




Eligible flights: 887
Acceptor flights: 342
Days RAD active: 13
Actual fuel saved: 6.7 t
Potential fuel savings: 17.9 t
Actual CO2 reduction: 21.6 t
Potential CO2 reduction: 56.5 t
RoA= 92.0%
RoU= 37.1%

Dynamic RAD restriction: LS4049

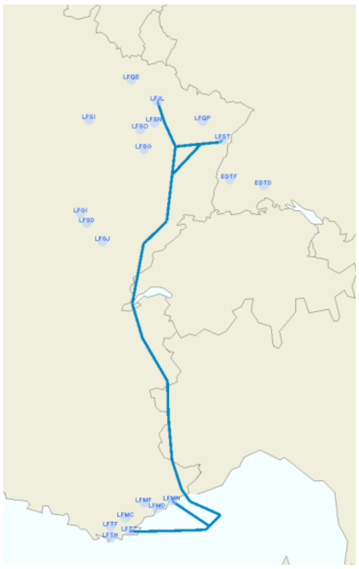
From BASEL_GROUP, LSZH crossing LF, LI, LS to EDDE/DF/FE/QC/QD/QG/QM/QT, ETOU, FRANKFURT_YZ_GROUP via VEVAR
FL capping: FL335
Applicability: 07-10-2021 until 01-12-2021 (56 days)

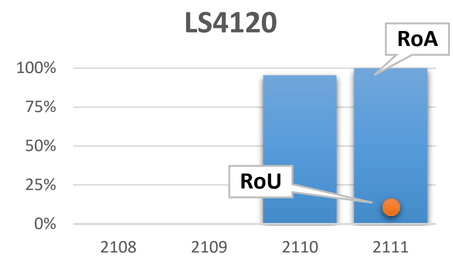


Eligible flights: 30
Acceptor flights: 1
Days RAD active: 2
Actual fuel saved: 0 t
Potential fuel savings: 0.03 t
Actual CO2 reduction: 0.01 t
Potential CO2 reduction: 0.09 t
RoA= 97.8%
RoU= 3.6%

Dynamic RAD restriction: LS4120

From LFGJ/QE/QP/JL/SD/SG/SI/SN/SO/ST/EDTD/TF crossing LF, LI, LS to LFMD, LFMN/TH/TZ via VEVAR, LURAG
FL capping: FL335
Applicability: 07-10-2021 until 01-12-2021 (56 days)





Eligible flights: 32
Acceptor flights: 2
Days RAD active: 2
Actual fuel saved: 0.07 t
Potential fuel savings: 0.59 t
Actual CO2 reduction: 0.21 t
Potential CO2 reduction: 1.87 t
RoA= 97.8%
RoU= 5.6%

Findings and Conclusions

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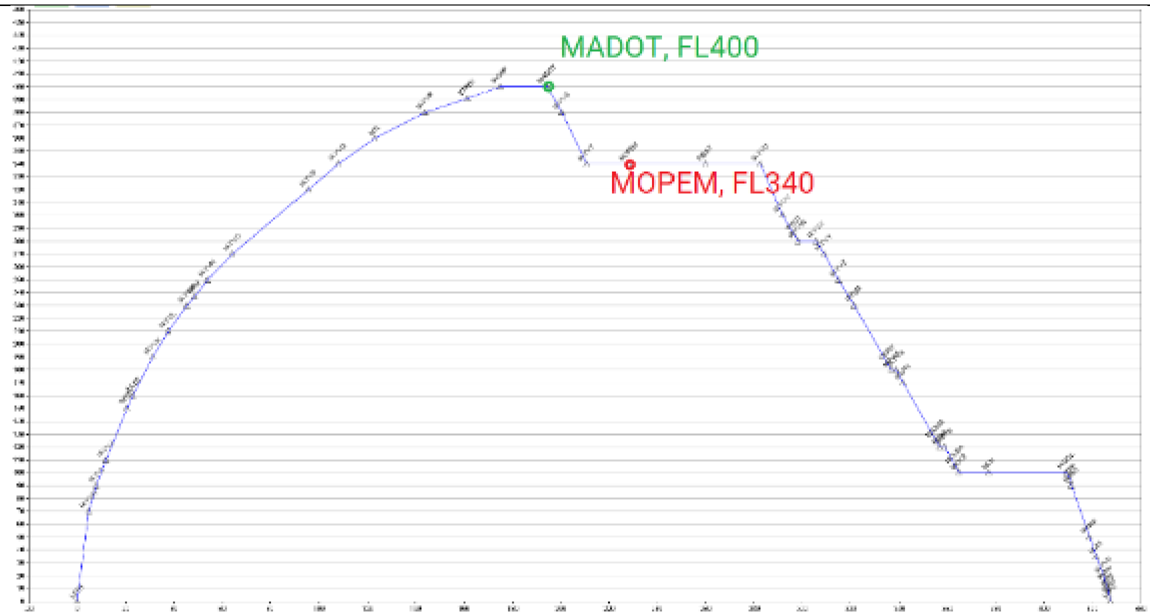
There is not a direct relation between the number of flights and the savings for different RAD restrictions. This is because the cruise portion of the trajectory, when the level capping is relaxed, is different for different city pairs; consequently, the values for fuel saved are not the same.

It has been noticed for a few flights an increase in the fuel when they climbed to higher cruise level. Checking the vertical profile in the flight plan showed an early descend than the calculated TOD point. That profile selection can be put in relation to another restriction not linked to dynamic RAD trial, forcing the flight to stay below a certain flight level at a specific location (sector protection). This conclusion indicates that comprehensive analysis of the candidates for the dynamic RADs regime is essential.

Example:

Relaxed dynamic RAD restriction LF4033 and RAD restriction LF3006 combined effect
LF4033: From (MONTPELLIER_GROUP, NICE_GROUP, PROVENCE_GROUP, RHONE_GROUP, TOULON_GROUP) to (ORLY_GROUP) crossing LF, Not above FL345 *LF3006*: UM976 from MADOT to MOPEM, Not available for traffic ARR ORLY_GROUP above FL345 at MOPEM Comment: Although LF4033 was not active, the flight had to descend below FL345 before MOPEM to fulfil LF3006 condition


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2. Instance 2: Gate-to-Gate Demonstrations (March 2022)

For the detailed analysis of the Air France flights of the Gate-to-gate Instance 2, please refer to the deliverable of Work Package 4 [22].

The analysis of the 96 LFPG<->ESSA flights was conducted using the ALBATROS " statistical delta fuel" method. The high level conclusion is that in the specific case of this city-pair it was not possible to prove a clear quantitative improvement with sufficient statistical confidence.

This is explained by a combination of these main factors:

- A city-pair operated with relatively small penalization from ATM constraints, which implies that the applied improvements could certainly reduce CO_2 emissions, but by a comparatively small amount (the flights being already "close to the optimum")

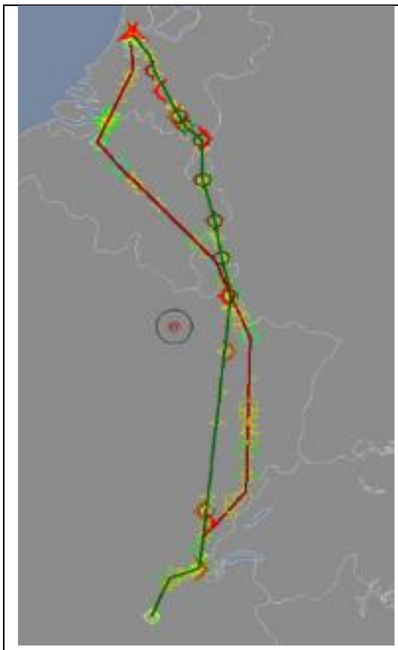
- Some limitations in actual flight data : in particular the unavailability of the exact aircraft mass at takeoff (the information from the flight plan was used, but it can change to some degree on the actual flight) and of the weather conditions recorded by the aircraft (historic weather was used instead, but this is available at a coarse spatio-temporal grain).

3. Instance 3: Connecting Europe Days

CED events – Selected Flights

EHAM-LFLL; KLM

	Test FPL (RED) N0437F350 LARAS2X WOODY N872 NIK M624 DIK N852 SUTAL UN852 MOROK Z24 BOLGI UN852 MILPA MILPA5N

<table>
<tr><td>
Difference length: 35NM</td><td>FPL with violations (GREEN) – different SID

N0437F350 LOPIK2N LOPIK DCT SOMEM DCT OSGOS DCT ULPEN DCT ARCKY DCT NISIV DCT SUTAL DCT TUROM T14 MILPA MILPA5N

IFPS err

RSA - EHTRA12Z

Restrictions: YX2112A, LF5190A, LS2924A, YX100A</td></tr>
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LPPT- LFLL; EZY

<table>
<tr><td rowspan="2">
Difference length: 8NM</td><td>Test FPL (RED)

N0440F380 IXIDA4N IXIDA DCT TOSDI UN745 ZMR UN976 DGO UT429 TOPTU DCT TOU/N0384F260 DCT GAI DCT MEN DCT NINUN UN871 MEZIN MEZIN5E</td></tr>
<tr><td>FPL with violations (GREEN) – Same SID

N0440F380 IXIDA4N IXIDA DCT TOSDI UN745 ZMR UN976 PPN UN995 LATEK DCT NINUN UN871 MEZIN MEZIN5N</td></tr>
</table>

	IFPS err Restrictions: LELF1016A, LELF1010A, LELF1010B, LF3597A, LF3597B, LF3778A, LF2326B

LROP-LFLL; WZZ

Difference length: 13NM

Test FPL (RED)	FPL with violations (GREEN) – Same SID/STAR
N0432F360 POLUN1K POLUN DCT ANASA DCT SOMUN DCT OKSIG/N0435F380 DCT ROTAR/N0433F370 DCT CHI DCT TOP/N0408F280 P860 RONOP UP860 GIGUS UZ40 AMVAR AMVAR5S	N0432F360 POLUN1K POLUN DCT DIRER DCT TUVAR/N0435F380 DCT ROTAR/N0433F370 DCT IXUSA P860 RONOP UP860 GIGUS Z40 AMVAR AMVAR5S IFPS err Restrictions: LS2427A

EDDF-LFLL; DLH

<table>
<tr><td rowspan="2">
Difference length: 4NM</td><td>Test FPL (RED)

N0413F330 ANEKI1L ANEKI Y163 HERBI Y164 OLBEN N869 MILPA MILPA5N</td></tr>
<tr><td>FPL with violations (GREEN) – same SID/STAR

N0431F330 ANEKI1L ANEKI DCT VABEN DCT OBORN DCT MOROK UN852 MILPA MILPA5N

IFPS err

RSA – EDR205CZ, LFT22AZ, EUC25FC/FE/FW,

Restrictions: ED51425A, EDLF5043B, LF50173B, LS2365A, LS5075C</td></tr>
</table>

LEBL-LFLL; VLG

	Test FPL (RED) N0425F300 DALIN3R DALIN UN870 SOSUR UM976 MTL MTL5N

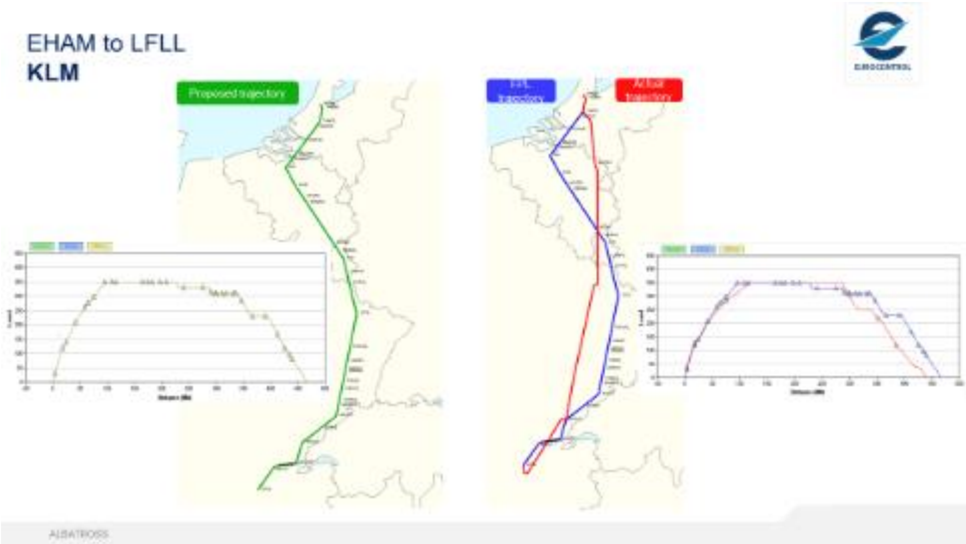
 Difference length: 39NM	FPL with violations (GREEN) – different SID/STAR N0425F300 DCT SLL DCT MAMUK DCT GEANT DCT NINUN UN871 MEZIN MEZIN5N IFPS err RSA – LFRZ1, LFR108HN/RT/AU/HS/HW/RM/RT, LFRQ5T, LFR169, LRF42S, LFRT8/9/10, LFT46S/N, LFT40, LFTAR Restrictions: LE5614A, LE2786AA, LF3625A, LFLE1041B, LF3778B, LF2326B, LE2A

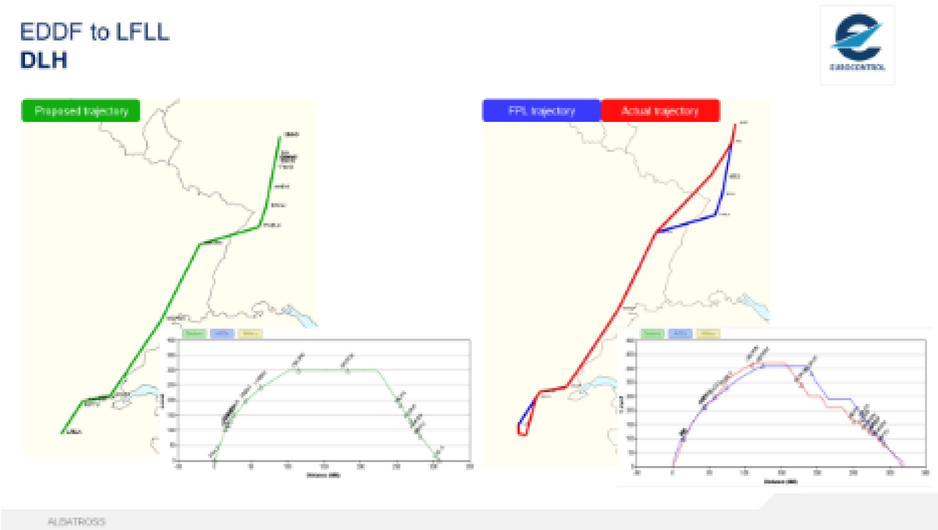
Involved stakeholders

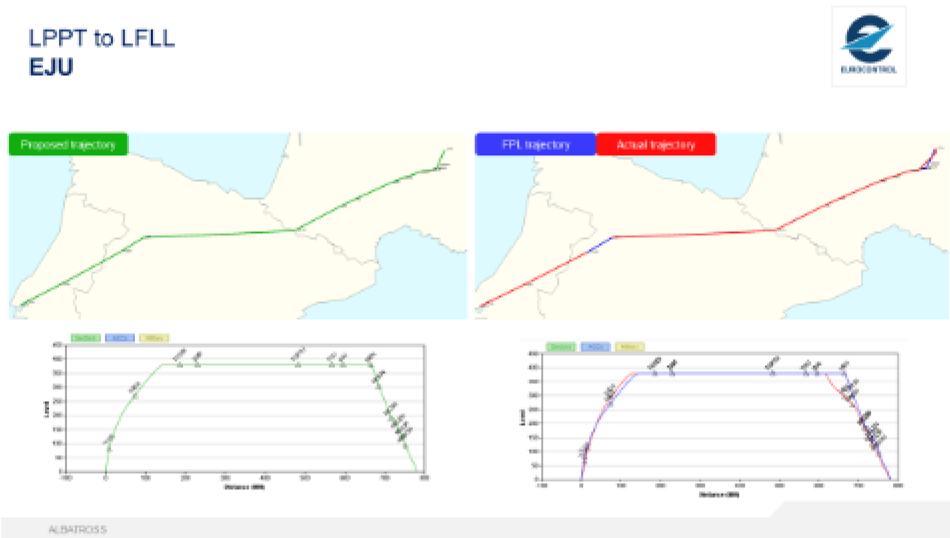
	City Pair	Flight Callsign	ANSPs for ATS constraints coordination	ANSPs for general ATS support	ASM Coordination	RSA	TIME (UTC)
Green route	EHAM_LFLL	KLM1415	LVNL	MUAC, DSNA	Dutch MIL	EHTRA12(Z)	1020-1030
					Belgium MIL	EBTRAN	1025-1030
					French MIL	LFT200(Z)	1040-1055
	EDDF_LFLL	DLH1076	DFS, DSNA, Skyguide		Germany MIL	EDR205,305(Z)	1120-1130
					French MIL	LFT22(Z)	1125-1140
	LPPT_LFLL	EJU4434	ENAIRE, DSNA	NAV PORTUGAL	Spanish MIL	LED47(Z)	1520-1525
					French MIL	LFT42(Z)	1550-1555
	LROP_LFLL	WZZ10CA	Skyguide	ROMATSA, SMATSA, CROCONTROL, ENAV, DSNA	Romanian MIL	LRTRA51,52,59	0925-0935
					Serbian MIL	LYTSA05,11,C1	0940-0955
						LYTR101	
					Italy MIL	LITSA78	1030-1040
						LITSA73	1040-1055
	LEBL_LFLL	VLG1220	ENAIRE, DSNA		French MIL	LFR108(Z)	1055-1110
						LFT40(Z)	1050-1100
						LFT42(Z)	1105-1115

Table 16: Stakeholders Involved in the Dynamic RAD exercise

EUROPEAN PARTNERSHIP
Co-funded by the European Union







Co-funded by the European Union

4. Instance 4: Gate-to-Gate Demonstrations (Nove-Dec 2022)

A quantitative analysis was carried out by MUAC with the outcome described in the following sections.

a. Total Benefits Offered by MUAC for RRP

Summary of the scope of MUAC participation:

	Phase 1 : EXE-01 Instance 2	Phase 2 : EXE-01 Instance 4
Dates	14th-25th March	21st Nov – 11th Dec
Flows - Pre-Tactical phase **Main Actor: TCM**	LFPG→ESSA ESSA→LFPG Arrivals to LFPG via RAPOR Arrivals to LFPG via DINAN	LFPG→ESSA ESSA→LFPG Arrivals to LFPG via RAPOR Arrivals to LFPG via DINAN London TMA→EDDF
Flows - Tactical phase **Main Actor: ATCO**	LFPG→ESSA LFPG→LOWW Arrivals to LFPG via RAPOR	LFPG→ESSA LFPG→LOWW Arrivals to LFPG via RAPOR EHAM→EDDS
Beneficiaries	Although a specific group of Airlines are members of the ALBATROSS Consortium, based on the “equity and fairness” principle, MUAC decided to offer greener trajectories to any airline operating in the aforementioned flows during the period of the demos.	

Table 17: MUAC contribution to EXE-01

Figure below summarises the total benefits offered by MUAC to the 113 ALBATROSS flights on the studied city pairs. It contains the potential benefits of all the actions done by MUAC with the aim to find a “greener” FPL in the pre-tactical phase. Tactical actions are not included.

Major results can be appreciated in three indicators:

- **Fuel** and **CO2 emissions**: as many of the actions result in shortest routes and flights are flying higher for longer periods.
- **Length of the flights**: due to the shortest routes proposed by MUAC FMPs. On top of this figure, there were additional length savings due to the tactical actions.

Minor results in the other two indicators are explained as follow:

- **Route Charges**: slightly negative effect because the RRPs sometimes crossed airspaces with higher route charges.
- **Time Savings**: there were short-haul flights meaning significant savings in time are difficult to get.

(These indicators are calculated mainly from comparing Flight Plans before and after the proposed improvement).

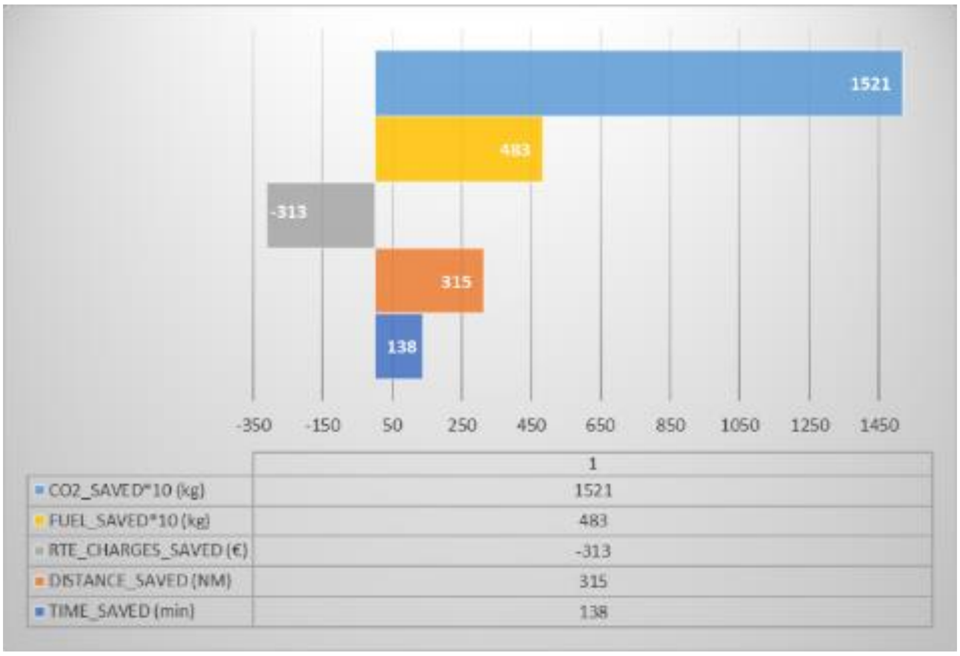


Figure 7: Total Benefits offered by MUAC with RRPs during ALBATROSS demonstration

Sections below provide the expected benefits with regards to all abovementioned indicators.

b. Results derived from Pre-Tactical Re-Route Proposals (RRPs)

There were 113 RRPs submitted to ALBATROSS flights on the city-pairs analysed during the execution of the demonstration (from 21st Nov – 11th Dec). On average, 35% of the RRPs were taken up by the Aircraft Operators.

Total Gains [1]

Graph below shows the gains derived from the RRPs offered (green bars) to the ALBATROSS flights and the actual gains (blue bars) with regards to the following indicators:

- Time Benefit expressed in minutes.
- Length Benefit expressed in NM.
- Route Charges Benefit expressed in €.
- Fuel Benefit expressed in 10*kg
- CO2 Benefit expressed in 10*kg

[1] Offered gains referred to the potential benefits derived from the RRPs submitted to the AOs. Actual gains referred to the benefits of the RRPs accepted by the AOs, meaning they refiled according or slightly different to the RRP submitted.

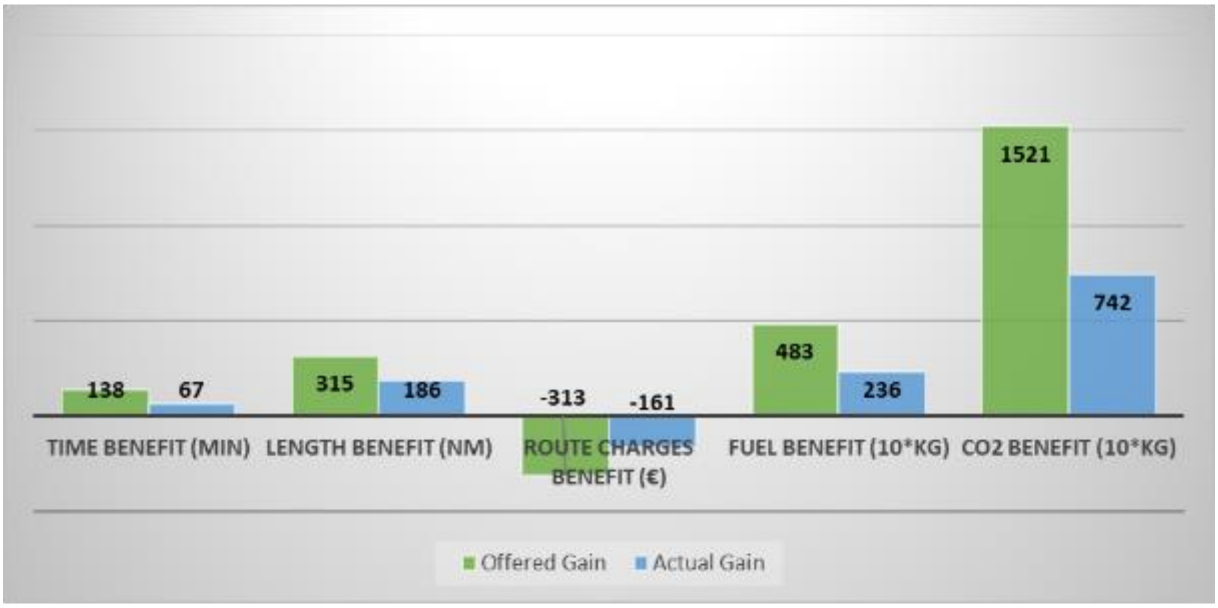


Figure 8: Offered vs. Actual gains on Time, Distance and Route Charges for ALBATROSS flights

Savings per Flow thanks to RRPs offered by MUAC

A more detailed analysis is provided below showing the savings per City-Pair for all the indicators abovementioned.

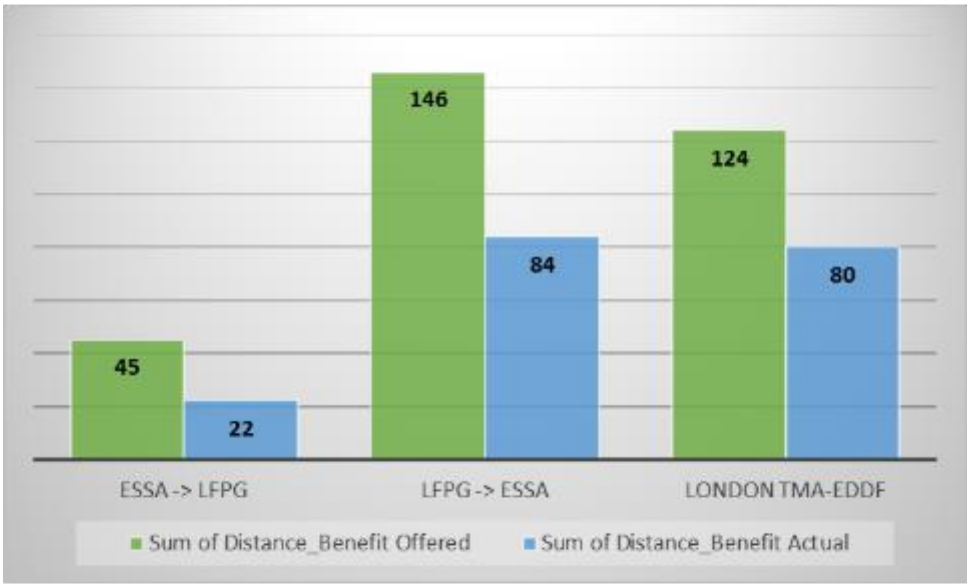


Figure 9: Offered vs. Actual Distance Savings per Flow (NM)

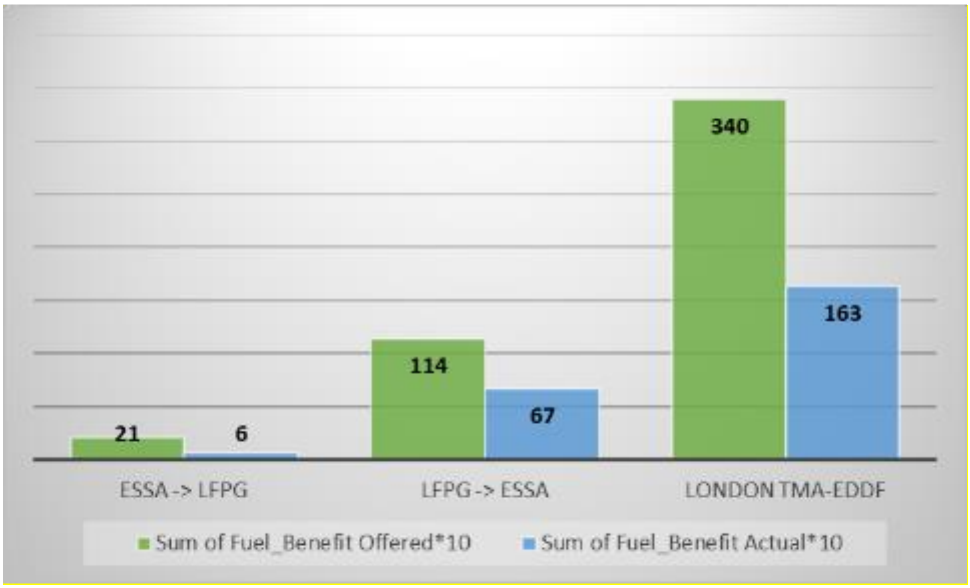


Figure 10: Offered vs. Actual Fuel Savings per Flow (Kg*10)

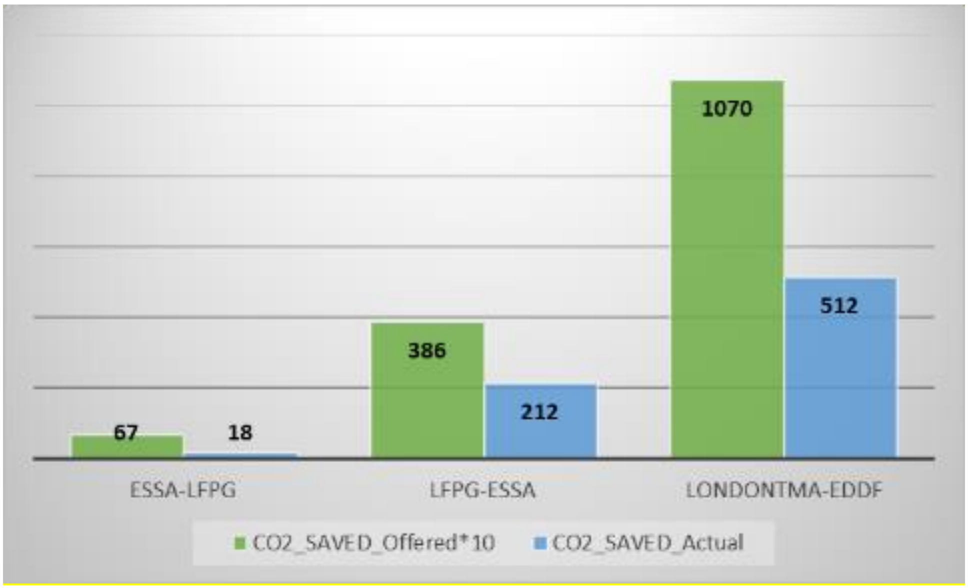


Figure 11: Offered vs. Actual CO_2 Emissions savings per Flow (Kg*10)

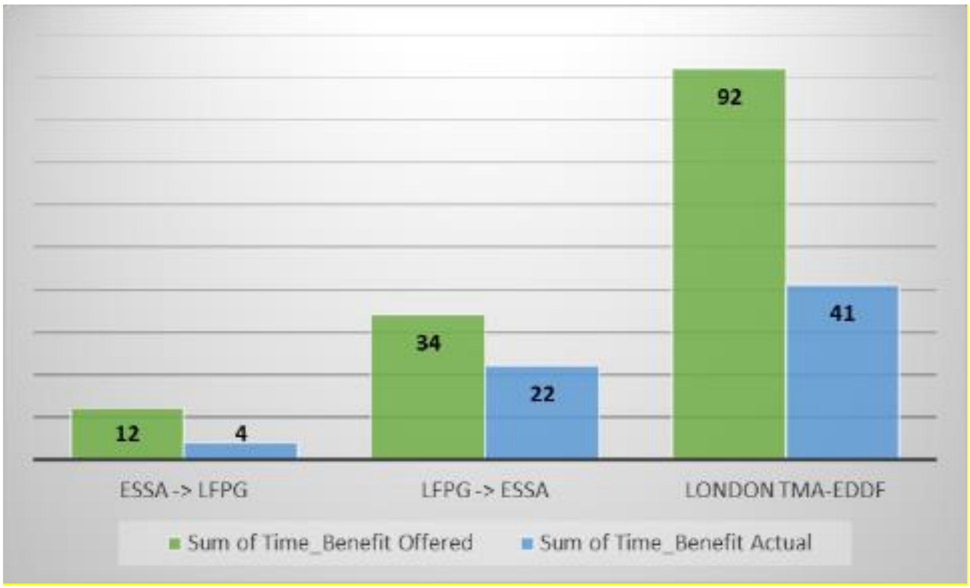


Figure 12: Offered vs. Actual Time savings per Flow (min)

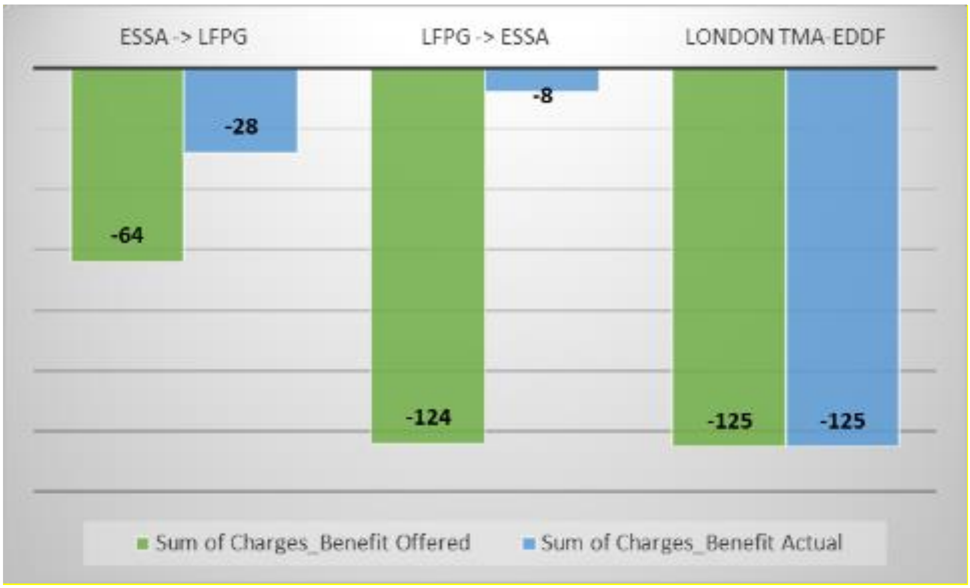


Figure 13: Offered vs. Actual Route Charges savings per Flow (€)

RAD Override Occurrence

During the coordination phase, MUAC agreed to soften RAD YXLF1001 in "LFPG→ESSA" city pair and YX4001 in "London TMA → EDDF" flow during the ALBATROSS demo execution.

RAD ID	#Occurrences (flights)
ED5550	11
ED5555	7
ED5561	1
YX4001	105
YXLF1001	13

Table 18: RAD Override Occurrence during ALBATROSS Demo Execution

c. Results derived from Tactical Actions (ATCOs)

Once the ALBATROSS flights were airborne, MUAC ATCOs were notified on the sector and when possible, they provided the tactical agreements as described in the OPS instruction. Following metrics shows the result of the tactical actions on ALBATROSS flights.

Tactical Shortcuts

In total, **819 ALBATROSS Flights received 1946 tactical shortcuts** from MUAC ATCOs, meaning their routes became shorter (compared to the FPL) tactically. Graphs below shows the split of those tactical shortcuts per City/Pair.

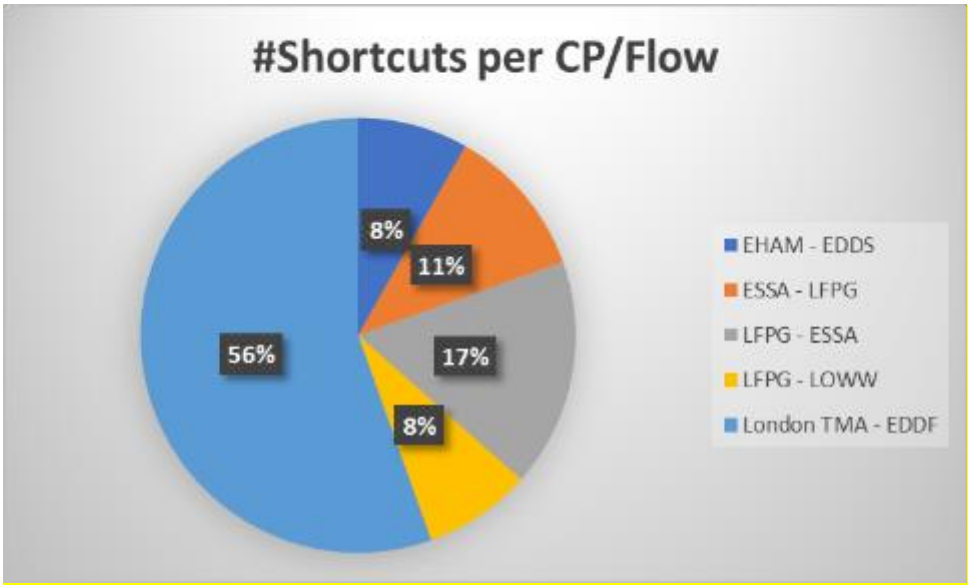


Figure 14: #Tactical Shortcuts on ALBATROSS per City-Pair/Flow

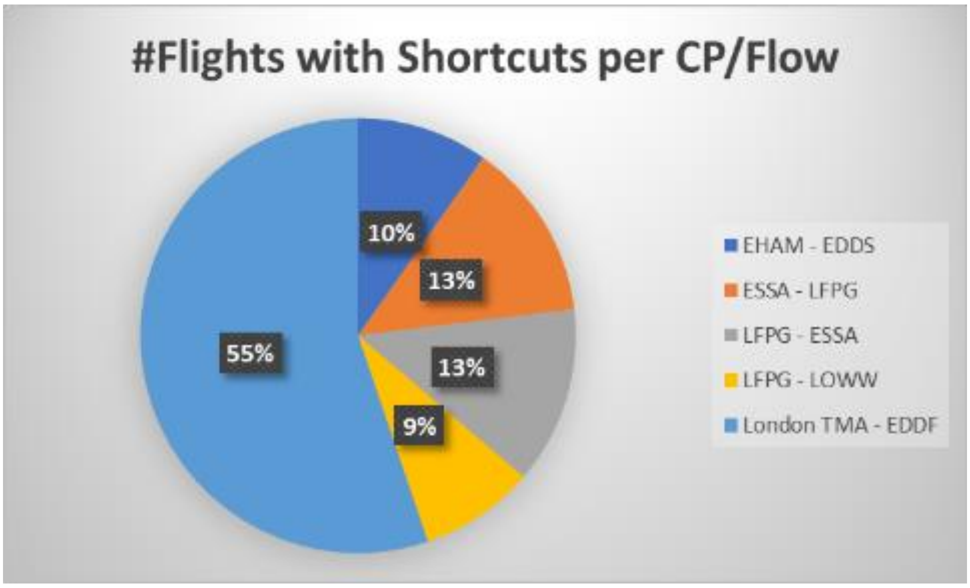


Figure 15: #ALBATROSS Flights with Shortcuts per CP/Flow

Those **tactical shortcuts generate 26.231NM in length savings, which for the cases where a RRPs was accepted are on top of the savings granted in the pre-tactical phase**. Graph below shows the actual benefits (expressed in NM) of those tactical shortcuts. Results are split per city-pair.

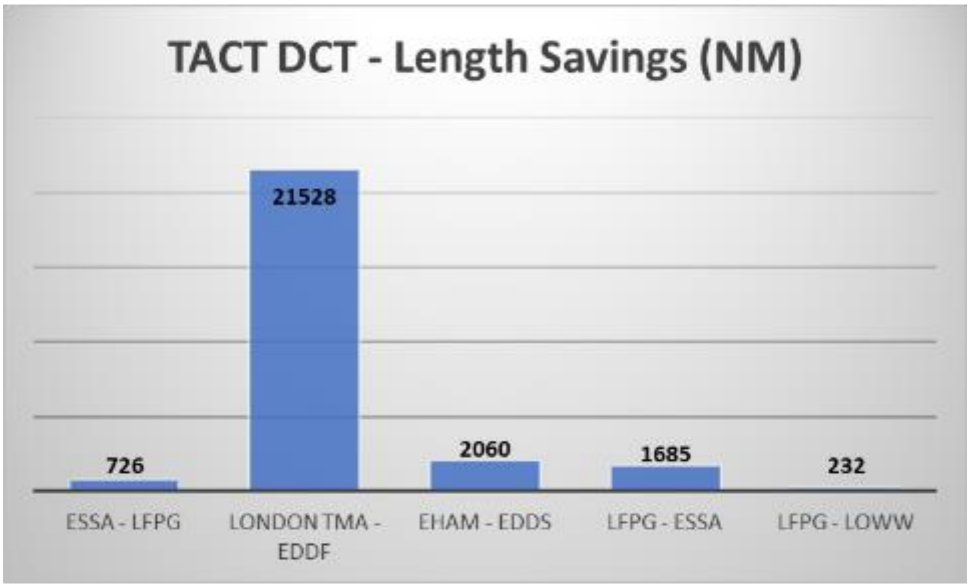


Figure 16: Length savings (NM) thanks to the tactical shortcuts offered by MUAC ATCOs to ALBATROSS flights.

IMPORTANT NOTE

Many of the NM saved in the London TMA→EDDF happened in the arrival phase. The number above is a sum of the MUAC ATCOs shortcuts, and the ATC clearances given in the arrival phase.

Tactical Cruising Levels

In total, **140 ALBATROSS Flights got higher cruising levels** than the ones in their FPL, supporting the green operations. Most of them occurred on the flow London TMA → EDDF (93%) as it can be observed in the graph below.

Tactical Extra Flights

3 Extra ALBATROSS Flights were taken in MUAC airspace during execution of ALBATROSS demo while they had file around or below MUAC.

A.3.3 Unexpected Behaviours/Results

The measurements carried out in EXE-01 Instance 2 ("Stockholm Gate-to-Gate") could, unexpectedly, not show a convincing reduction of "excess CO2/fuel-burn". This exercise instance is the only one where the ALBATROSS assessment methodology is applied on entire flights, from departure to arrival; in such a large scope the method requires data of very high quality (accuracy and number of samples) which, for various reasons, were not available.

A.3.4 Confidence in the Demonstration Results

1. Level of significance/limitations of Demonstration Exercise Results

With the exception of the shortcoming described in section A.3.3, the exercise convincingly demonstrated how the detailed study of a selected airspace / set of flights involving all concerned stakeholders is a way to obtain effective implementation of optimized trajectories.

On limitation that should be mentioned is the fact that the assessment of the benefits from Dynamic-RAD was performed on the basis of flight plan information, whereas it would be preferable to assess the benefits from flown trajectories. This isa known difficulty, not specific to this exercise.

2. Quality of Demonstration Exercise Results

The quantitative results are considered of moderate or high quality.

3. Significance of Demonstration Exercises Results

Like much of the ALBATROSS approach, the works carried out in the exercise cannot be directly extrapolated to other airspaces or city-pairs. On the other hand, the demonstration *approach* is very significant for other "local" initiatives, especially when seeking to combine multiple ones.

A.4 Conclusions

Dynamic RAD

The interest of ANSPs in managing the restrictions dynamically was confirmed; a very good level of flexibility was observed, and the restrictions could be avoided in some cases up to 90% of the time. In terms of utilisation by Aircraft Operators the rate of uptake was variable, probably because of limited awareness about the concept.

In any case, in principle, all actors supported the feasibility of the dynamic RAD process, especially at D-1, while D-OPS may still require adjustments. No major concerns were expressed about the AUP process, although some technical changes would be useful to facilitate the management of dynamic RAD and a better involvement of FMPs.

The results allowed to estimate the potential benefits in terms of flight efficiency as well as the feasibility of all the different partners to cope with the level of dynamicity offered.

While the applicability of the dynamic RAD concept will remain a decision of the single ANSPs, as well as the selection of the eligible RAD restrictions, close coordination with NM is required, to identify circumstances that could undo the potential benefits.

"Gate-to-gate" trials

The trials that aimed to address multiple improvements with a holistic approach on selected "gate-to-gate" routes were only partially successful. Planning constraints reduced the possible improvements to less than hoped for ("only" very few improvements possible on one same flight, and few cases where more than two improvements were actually applied). However, the analysis of the concerned airspace, to identify potential improvements, was a very productive exercise.

Due to the limited number of applied improvements, the quantitative results were disappointing, and the effect of "noise" on the data masked the improvements, which could not be proven in a statistically significant manner.

A.5 Recommendations

A.5.1 Recommendations for industrialization and deployment

The following recommendations are made with regard to the potential future implementation of dynamic RAD process:

- **Dynamic RAD concept proved to be feasible;**
- **The selection of RAD eligible for a dynamic management needs to be duly assessed by relevant stakeholders. In this respect, a pre-validation is deemed necessary to verify their effectiveness in case of relaxation.**
- **The Dynamic RAD process is feasible at D-1. Further evaluation are required to assess its applicability at D-OPS. In this case, full involvement of Aircraft Operators is necessary.**
- **Proper notification process is required, exploiting all the possibility to improve awareness of Aircraft Operators/CFSPs on the opportunity offered.**
- **AUP/UUP process as interim solution seems appropriate. Short-term technical changes should be considered to improve its utilisation.**
- **Long-term solutions should be addressed in the frame of iNM to implement a common platform to promote ASM/TAFCM processes integration.**

A.5.2 Recommendations on regulation and standardisation initiatives

No specific recommendations.

Appendix B Demonstration Exercise #02 Report

B.1 Summary of the Demonstration Exercise #02 Plan

B.1.1 Exercise description and scope

1. Introduction

Within the scope of the SESAR Albatross project, EXE02, an analysis of flight efficiency related to ATC constraints and clearances has been conducted.

The analysis was performed using flight recorder data (FDR data) and ATC clearance data for flights operated by the charter airline Novair. Novair has a fleet of two A321 neo aircraft, operating from Scandinavia to the Canary Islands, Madeira, Egypt and to destinations in the Mediterranean region.

2. Presentation of the data

The analysis within this exercise have been performed using the Novair Fuel Management Information System. It is a SQL Server database containing FDR data for all flights performed by Novair. In addition to the FDR parameters, so called “Delta Burn” values are available for each flight, indicating the vertical, lateral, and total efficiency during the approach phase of the flight. The Delta Burn is presented in the SESAR Environmental documents as one of the preferred methods to analyse flight efficiency [23].

a. Delta Burn

The Delta Burn values are calculated by comparing the actual fuel consumption of each flight with the calculated fuel consumption of a theoretically optimal flight under the same flight conditions. The actual fuel burn is calculated based on the FDR data for the flight and the fuel consumption of the optimal flight is calculated using the Airbus Performance Engineer’s Program (PEP) based on actual conditions for the flight and Cost Index (CI) 0 (minimum fuel usage).

The comparison results in a difference in fuel burn (delta burn) indicating how close to the theoretically optimal flight the actual flight was.

Three different Delta Burn values are calculated for each flight:

- Delta Burn Vertical (DBV), indicating the vertical efficiency of an approach
- Delta Burn Horizontal (DBH), indicating the vertical efficiency of an approach
- Delta Burn Total (DBT), indicating the total fuel efficiency of an approach, included are both lateral and vertical aspects

b. Calculation method

For each flight imported into the Novair Fuel Management Information System, the following is performed:

1. The fuel consumption of a theoretically optimal flight ($FC_{Optimal}$) flown in the same flight conditions as the actual flight is calculated using the PEP. This theoretically optimal flight is defined as a straight in approach from 200 NM with no speed or altitude constraints and flown with CI 0. The following parameters in the PEP calculation are set to the same as for the actual flight: cruise altitude, aircraft mass, winds, temperature, CG, engine anti ice selection and aircraft performance factor. This trajectory is illustrated by the green line in Figure 17 below.
2. The actual fuel consumption for the flight is calculated (based on the FDR data) from the point where the flight trajectory crosses a circle with 200 NM radius centered over the destination airport ($AFC_{200\ NM\ radius}$). This is illustrated by the red line inside the black circle in Figure 17.
3. The actual fuel consumption for the flight is calculated from the point where the flight has 200 NM to touch down ($AFC_{200\ NM\ to\ go}$). This is illustrated by the red line inside the black circle, starting from the marker “200 NM to go” in Figure 17.

The fuel consumption for both the theoretically optimal flight and the actual flight is calculated down to 2000 ft AGL (instead of to touch down) to remove the influence of pilot behaviour and wind during the final approach.

When steps 1-3 have been performed, the Delta Burn Values can be calculated as follows:

- Delta Burn Total = $AFC_{200\ NM\ radius}$ - $FC_{Optimal}$
- Delta Burn Vertical = $AFC_{200\ NM\ to\ go}$ - $FC_{Optimal}$
- Delta Burn Horizontal = Delta Burn Total – Delta Burn Vertical

The PEP descent calculation assumes 250 kt IAS between FL100 and 2000 ft AGL while the real flights reduce speed earlier than that. Because of this, flights with a very high vertical efficiency will have a negative Delta Burn Vertical value.

Figure 17 Trajectories included in the Delta Burn calculations

Descent air distance normalised to FL360

In several of the performed analysis, the descent distance is assessed and compared. Descent winds, aircraft mass and cruise altitude are all parameters that affect the ground distance of an unconstrained descent. In order for the descent distance to be comparable between flights, air distance is used instead of ground distance and the descent distance is normalised for an aircraft leaving the cruise segment at FL360. FL360 is the most common final cruise flight level in the data and therefore it was chosen as the flight level to use for normalisation purposes. The aircraft mass has not been corrected for though, other than excluding all positioning flights (flights without passengers) since they have a significantly lower landing mass than a passenger flight.

Delta Descent Distance

In some of the charts in the document, a parameter called Delta Descent Distance is used instead of Descent air distance normalised to FL360. The Delta Descent Distance is calculated as the difference between the actual descent distance of a flight and the PEP calculated descent distance for the same flight.

Since the PEP calculation is based on the cruise altitude, aircraft mass and descent winds of the actual flight, the Delta Descent Distance value does not suffer from effects of different flight conditions. It could also be used in case of comparing flights performed with different aircraft types (which is not the case with the Novair flights).

As mentioned before, the PEP descent calculation assumes 250 kt IAS between FL100 and 2000 ft AGL while the real flights reduce speed earlier than that. Apart from resulting in negative Delta Burn Vertical values for flights with very high vertical efficiency, this also results in that the descent distance calculated by the PEP is shorter than optimal descent distance for the real flights and hence, the Delta Descent Distance for flights with a close to optimal descent distance is greater than zero.

Delta distance compared to shortest route

To be able to assess if a flight has flown a short or a long route during the approach, a delta distance compared to shortest route has been calculated. It is calculated as the difference between the actual distance flown from passing the 200 NM radius centered over the airport and the shortest flown route among all available flights landing on the same runway and arriving from the same direction. This way, the delta distance compared to shortest route is comparable between flights landing on different runways and arriving from different directions.

Below, a large number of flights landing on RWY 26 at ESSA are shown. The flight path has been plotted from the point where the flight passes the 200 NM radius around ESSA (the red lines). The black circle has a radius of 50 NM and this circle is used to divide the arrivals into different categories depending on in which sector they pass this circle. For RWY 26, three arrival sectors have been defined: 90-150°, 151-220° and 221-350°. Within each of these group of flights, the shortest one is identified and used when calculating the delta distance compared to shortest route for all flights landing on the runway in question and arriving in the given sector.

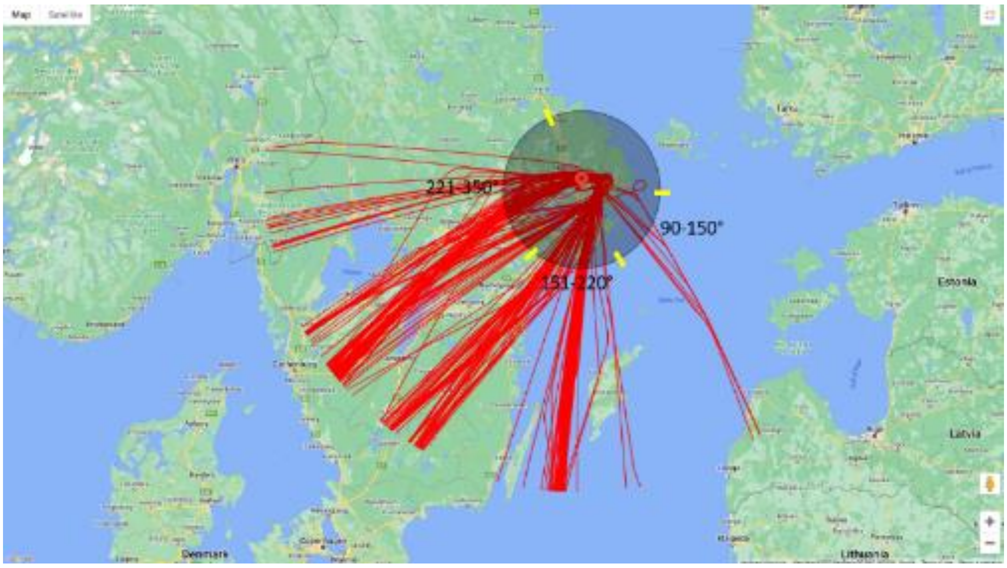


Figure 18 Identifying the shortest route

c. ATC clearance data

For the purpose of performing the EXE02 analysis, ATC clearance data was received from LFV for all Novair flights in the period 2019-2021. The clearance data was imported into the Novair Fuel Management Information System, making it possible to analyse it together with the FDR data and Delta Burn values for the flights.

3. Vertical efficiency in the descent phase

Predictability is a key factor when it comes to vertical efficiency; predictability regarding both distance to go and descent speed. If this information is available when planning the descent, the enroute phase can be left at the optimal Top of Descent (ToD) resulting in optimal use of the available energy.

For closed loop procedures, the distance to go is known in advance. This greatly facilitates the descent planning compared to open loop procedures with radar vectors. In Figure 19

Figure 19 Closed loop procedure (RNP AR) for ESSA RWY 26

below, a closed loop procedure in the form of an RNP AR approach for ESSA RWY 26 is displayed. The lateral track is defined until the runway threshold.

In Figure 20 below, an open loop STAR for ESSA RWY 26 is displayed to the left. The STAR is combined with an ILS approach (displayed to the right). However, the lateral track of the STAR ends at ERKEN and from there the flights are radar vectored until intercepting the localizer of the ILS.

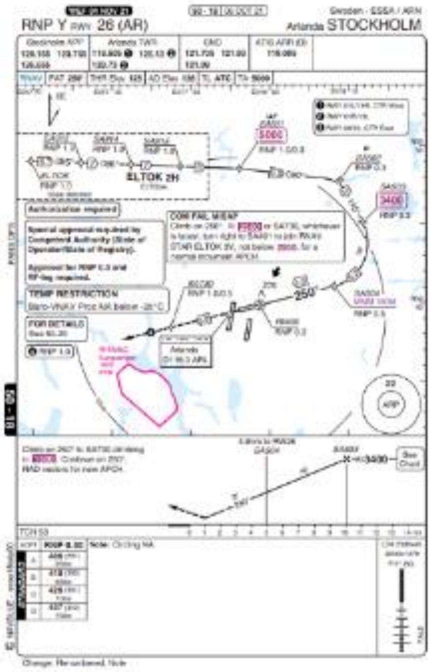


Figure 19 Closed loop procedure (RNP AR) for ESSA RWY 26

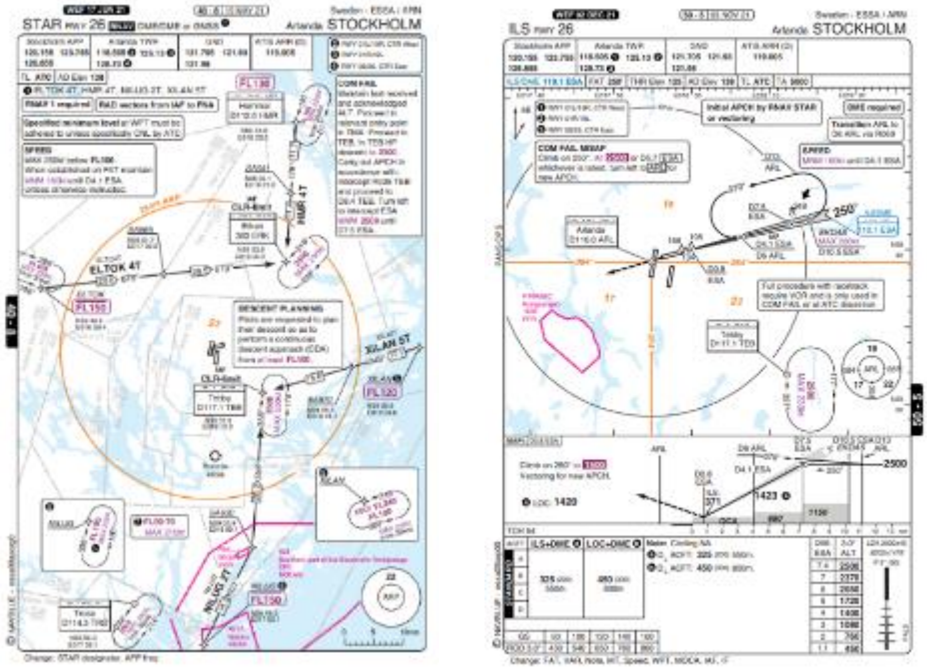


Figure 20 Open loop STAR to the left and ILS approach procedure to the right, for ESSA RWY 26

Below is an example of a flight flying a closed loop procedure, the RNP AR approach for RWY 26 at ESSA that was illustrated in Figure 19

Figure 19 Closed loop procedure (RNP AR) for ESSA RWY 26

. A continuous descent was performed, and the vertical efficiency turned out very high (Delta Burn Vertical -15 kg).

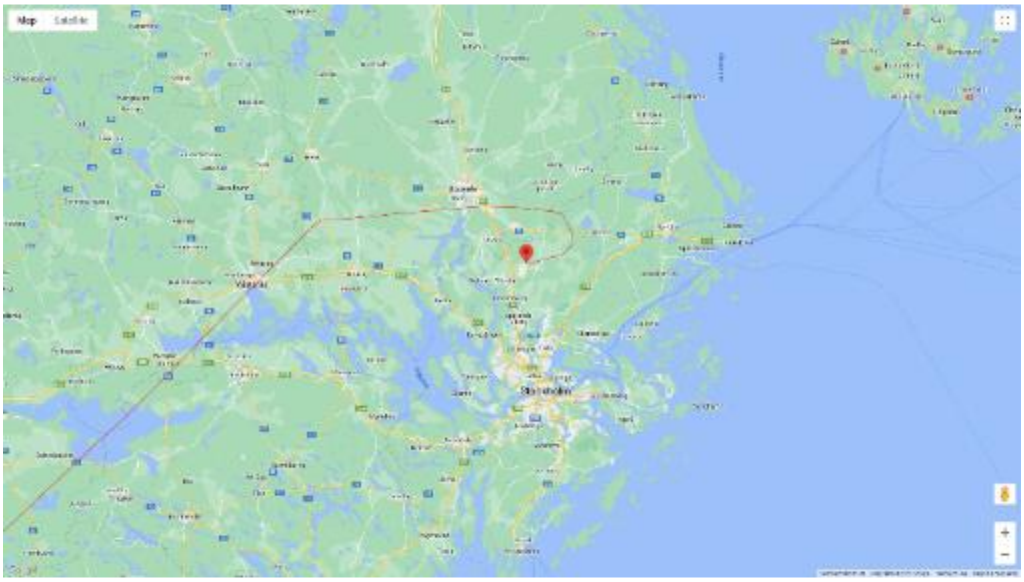


Figure 21 Lateral track of a flight performing an RNP AR approach for ESSA RWY 26

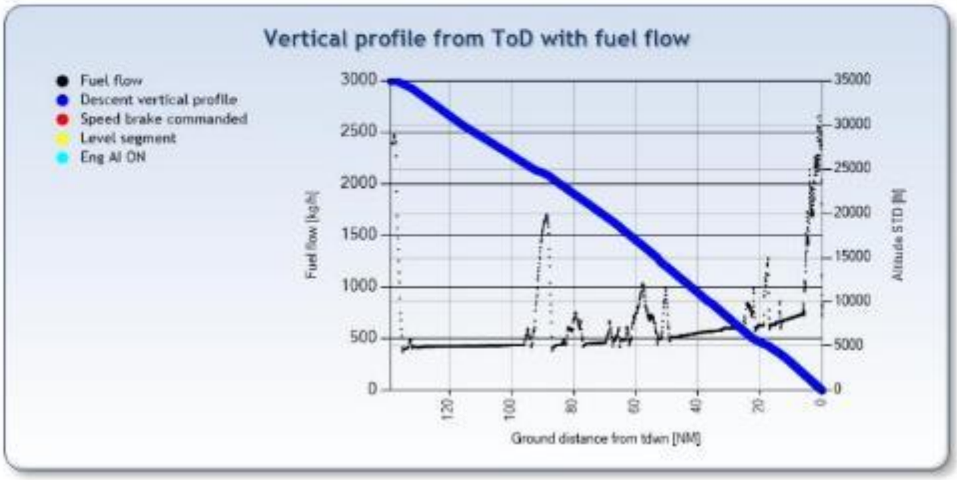


Figure 22 Vertical profile and fuel flow during descent for the flight illustrated in Figure 21

In an open loop procedure with radar vectoring, the distance to go is unknow to the Flight Crew and the location of ToD is based on best estimate. If the route turns out to be longer than estimated, partial thrust to keep a shallower descent angle or level segments will be the result and the vertical efficiency will be negatively affected. Following is such an example, also an approach to RWY 26 at ESSA, flying quite a similar route as the RNP AR approach in the previous example but being radar vectored instead of flying a closed loop procedure. The Delta Burn Vertical value for this flight was 95 kg (i.e., it used 110 kg more fuel for the descent than the RNP AR approach did due to vertical inefficiency).

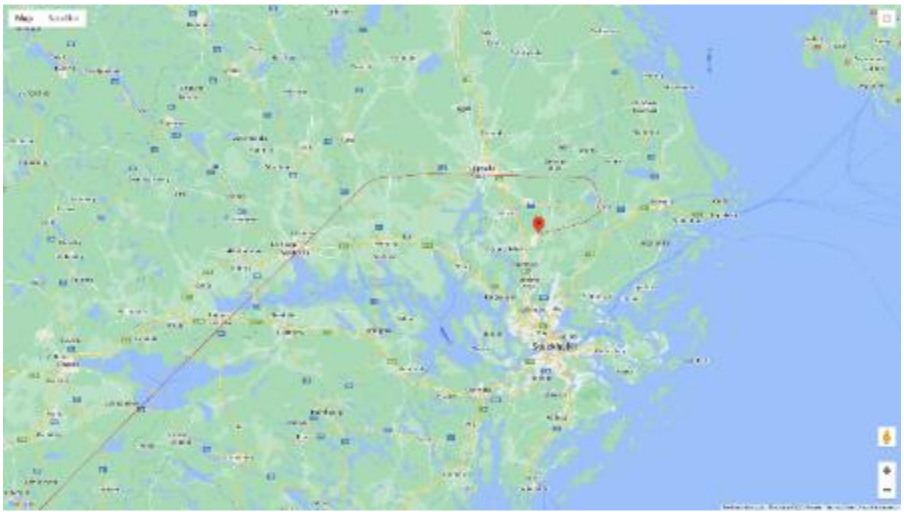


Figure 23 Lateral track of a flight being radar vectored into ESSA RWY 26

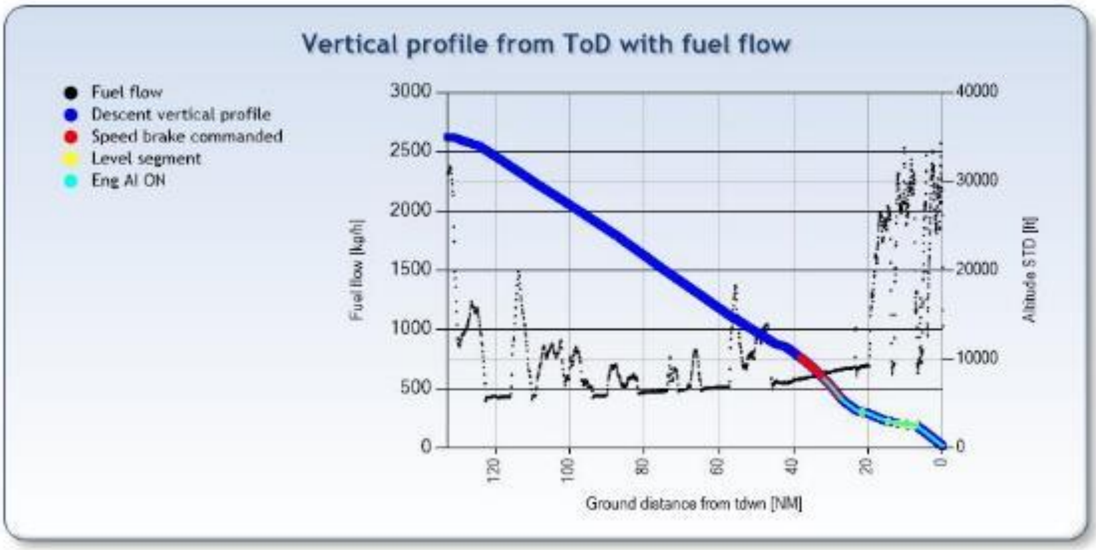


Figure 24 Vertical profile and fuel flow for the flight illustrated in Figure 23

A longer route than expected will always be detrimental to both the vertical efficiency and the absolute fuel consumption of a flight.

A re-clearance during descent for a shorter route than expected will affect the vertical efficiency negatively, but the absolute fuel consumption for the flight will be reduced compared to flying the longer route. However, had the shorter route been known before ToD, an even larger fuel saving could have been achieved.

To see how predictability affects the vertical efficiency, Novair flights arriving into ESSA and ESGG (Gothenburg Landvetter airport) using different kind of approaches were compared. The results can be seen in Table 19 and Table 20 below. Average Delta Burn Vertical, descent distance, time in level flight, delta distance compared to shortest route and number of flights included in the average calculations for each group are displayed.

ESSA	Avg Delta Burn Vertical	Avg descent distance[2]	Avg time in level flight from ToD	Delta distance compared to shortest route	Number of flights
All flights with one or more heading clearances **OPEN LOOP**	54 kg	133 NM	60 sec	10,5 NM	582
All flights with no heading clearance but not RNP AR (the majority of these flights did not fly a closed loop STAR but were cleared direct to a waypoint typically inbound RWY 01 or 26 and were cleared for approach from there)	30 kg	127 NM	22 sec	3,7 NM	194
All RNP AR flights **CLOSED LOOP**	30 kg	123 NM	5 sec	5 NM	47

Table 19 Comparison between flight arriving via open loop and closed loop procedures into ESSA

ESGG	Avg DBV	Avg descent distance[3]	Avg time in level flight from ToD	Delta distance compared to shortest route	Number of flights

[2] Descent air distance normalised to FL360

[3] Descent air distance normalised to FL360

All flights with one or more heading clearances **OPEN LOOP**	45 kg	127 NM	47 sec	9,5 NM	48
All flights with no heading clearance but not RNP AR **CLOSED LOOP** (P-RNAV STAR followed by ILS)	22 kg	125 NM	15 sec	7,5 NM	57
All RNP AR flights **CLOSED LOOP**	28 kg	126NM	29 sec	1,7 NM	65
All RNP AR flights that did not level off at FL100 **CLOSED LOOP**	24 kg	126 NM	16 sec	2,0 NM	38

Table 20 Comparison between flight arriving via open loop and closed loop procedures into ESGG

Comments regarding the two tables above:

- Both for ESSA and ESGG, the vertical efficiency is significantly lower for the groups being radar vectored compared to the ones flying closed loop procedures.
- For the flights being radar vectored into ESSA, the descent distance and time in level flight is on average longer than for the flights being radar vectored into ESGG. This indicates higher predictability (from an airborne perspective) when arriving into ESGG compared to ESSA, which is reasonable considering the lower traffic situation at ESGG compared to ESSA.
- Looking at all RNP AR flights into ESGG, the time in level flight is higher (resulting in also a higher Delta Burn Vertical value) than for the group of flights flying a closed loop P-RNAV STAR followed by an ILS. The reason for this is that the RNP AR approach procedure into RWY 21 (which is the runway most commonly used) is affected by an airspace constraint that typically results in level flight at FL100 for the RNP AR flights but not for the P-RNAV STARs. In some situations, the level flight can be avoided also for the RNP AR flights and looking only at these flights, the time in level flight and the Delta Burn Vertical value correspond very well with the values of the closed loop P-RNAV STAR group.
- The values for the closed loop P-RNAV STAR and RNP AR flights that did not level off at FL100 are representative for an unconstrained, closed loop approach procedure.
- The vertical efficiency of the RNP AR flights arriving into ESSA is lower than for the RNP AR flights arriving into ESGG. Many of the flights that performed an RNP AR approach at ESSA received the clearance for the RNP AR approach after ToD and thereby the descent was planned for a longer route, resulting in a high energy situation where the surplus energy

needed to be dissipated. As discussed earlier, giving a flight a shorter route after ToD is better than not giving it at all – less fuel will be consumed flying the shorter route than the longer one. But the full benefit of the predicable and shorter RNP AR approach procedure will only be achieved if giving the clearance for it before ToD.

- There are a few closed loop P-RNAV STARs at ESSA but they are very seldomly used. Most of the flights in the group arriving into ESSA that got zero heading clearances and were not RNP AR flights were typically given a direct clearance to a waypoint inbound RWY 01 or 26 and from that point were cleared for the approach (i.e. not flying a closed loop procedure). As can be seen in Table 19, these flights have on average the same vertical efficiency as the RNP AR flights into ESSA and they are the group of flights that on average has the lowest delta distance compared to the shortest route. They are typically flights arriving at low peak when the traffic allows a short and efficient route and when the Flight Crew expected this.

4. ATC clearance data analysis for ESSA

An analysis was performed combining the ATC clearance data with FDR data and Delta Burn values for flights into ESSA in the period 2019-2021.

All positioning flights were excluded to ensure similar operating conditions. Also, intra-Scandinavian flights were excluded. The clearance data contains clearances that were given within Swedish airspace, or in case of early hand over from a neighboring country, just outside Swedish airspace. For intra-Scandinavian flights, clearances related to the climb out from the departure airport are also present and therefore these flights were excluded to ensure that only clearances related to the arrival were considered.

There was a total of 903 flights meeting the above criteria and for which all three types of data were available.

In the ATC clearance data, there is one row for each clearance given to a flight. Each clearance is of one of the following four types and is also associated with a time stamp indicating when the clearance was given:

- Heading clearance
- Flight level clearance (FL clearance)
- Speed clearance
- Route clearance

Through the time stamp it is possible to identify the point in the FDR data for the flight in question and thereby get the altitude, coordinates, and all related flight parameters.

Distribution of clearance types in the ESSA ATC clearance data

To begin with, some statistics over the ATC clearances in the data are presented.

FL clearances

Figure 25 below is a histogram presenting how often different number of FL clearances were given to the flights arriving into ESSA in the analysed material. As can be seen, the most frequently occurring number of FL clearances for a flight was between 4-7, a very limited number of flights had 2-3 and quite a few flights had more than 7 FL clearances.

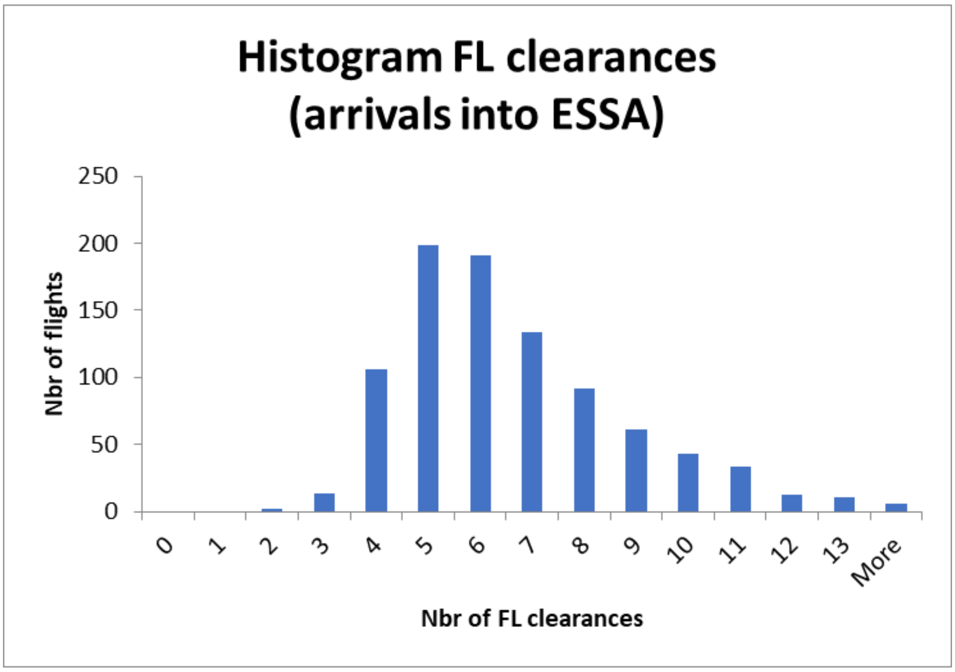


Figure 25 Frequency of different number of FL clearances per flight arriving into ESSA

Heading clearances

In Figure 26 below, the occurrence of heading clearances in the data is illustrated. Of the 903 flights arriving into ESSA, 28% did not get a heading clearance while 72% did.

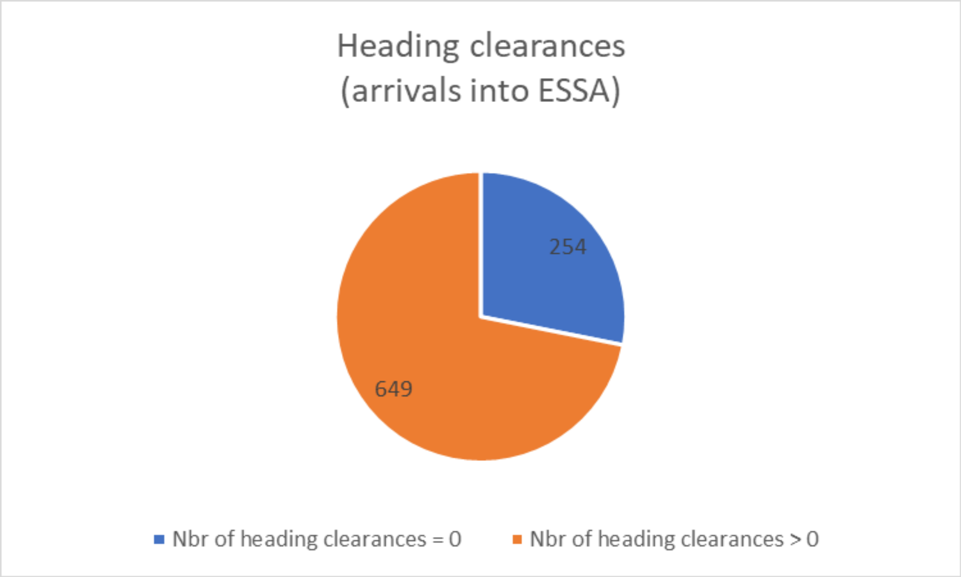


Figure 26 Number of flights with and without heading clearances for arrivals into ESSA

The frequency of different number of heading clearances is displayed in Figure 27 below.

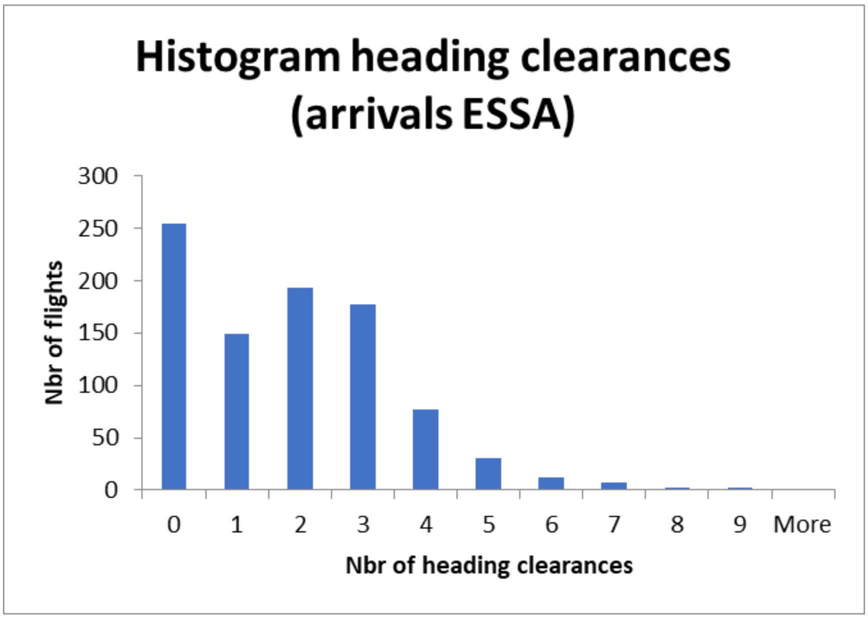


Figure 27 Frequency of different number of heading clearances per flight arriving into ESSA

IAS speed clearance

In Figure 28 below, the occurrence of IAS speed clearances in the data is illustrated. Of the 903 flights arriving into ESSA, 63% did not get an IAS speed clearance while 37% did.

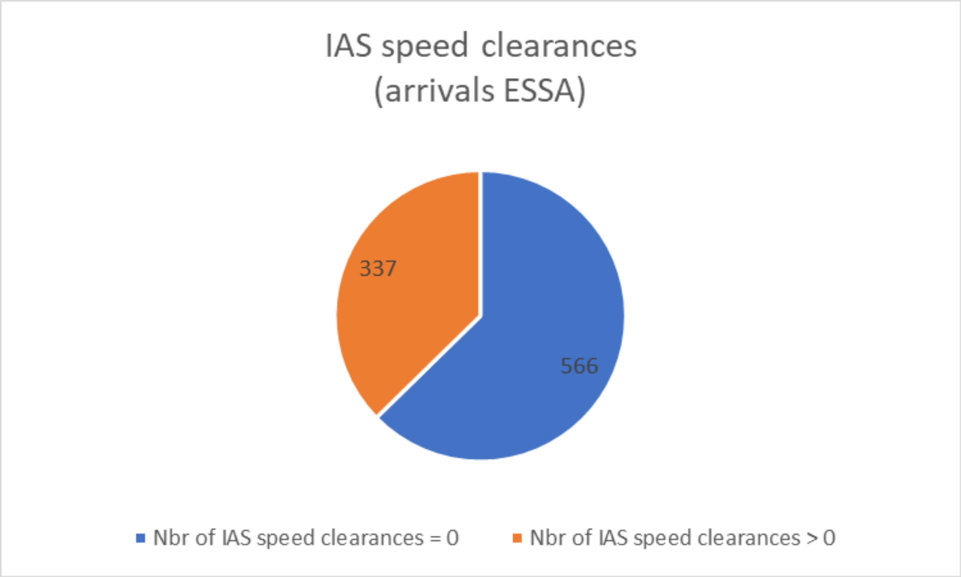


Figure 28 Number of flights with and without IAS speed clearances for arrivals into ESSA

However, of the flights that did get an IAS speed clearance, the absolute majority (86%) also got one or more heading clearances as illustrated in Figure 29 below. Hence, when IAS speed clearances were given, the most common scenario was that the flight also was given radar vectors.

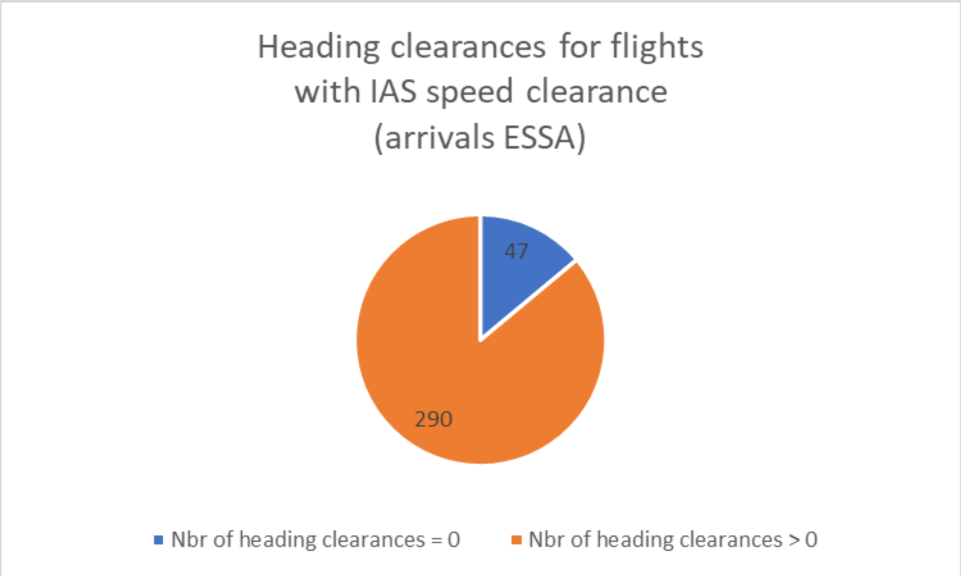


Figure 29 Number of flights with and without heading clearances for flights with IAS speed clearance arriving into ESSA

The opposite does not seem to apply though. Of all flights that have been given one or more heading clearances, only 45% also received an IAS speed clearance while 55% did not as can be seen in Figure 30 below.

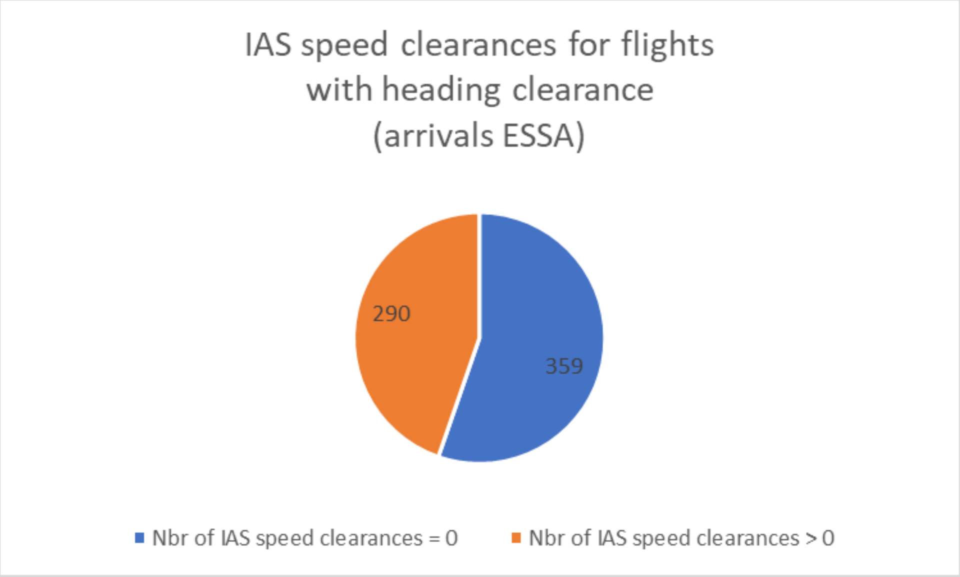


Figure 30 Number of flights with and without IAS speed clearances for flights with heading clearance arriving into ESSA

Correlation between ATC clearances and vertical efficiency

To analyse the correlation between ATC clearances and vertical efficiency, number of ATC clearances of the different types were plotted against average Delta Burn Vertical in Figure 31 below.

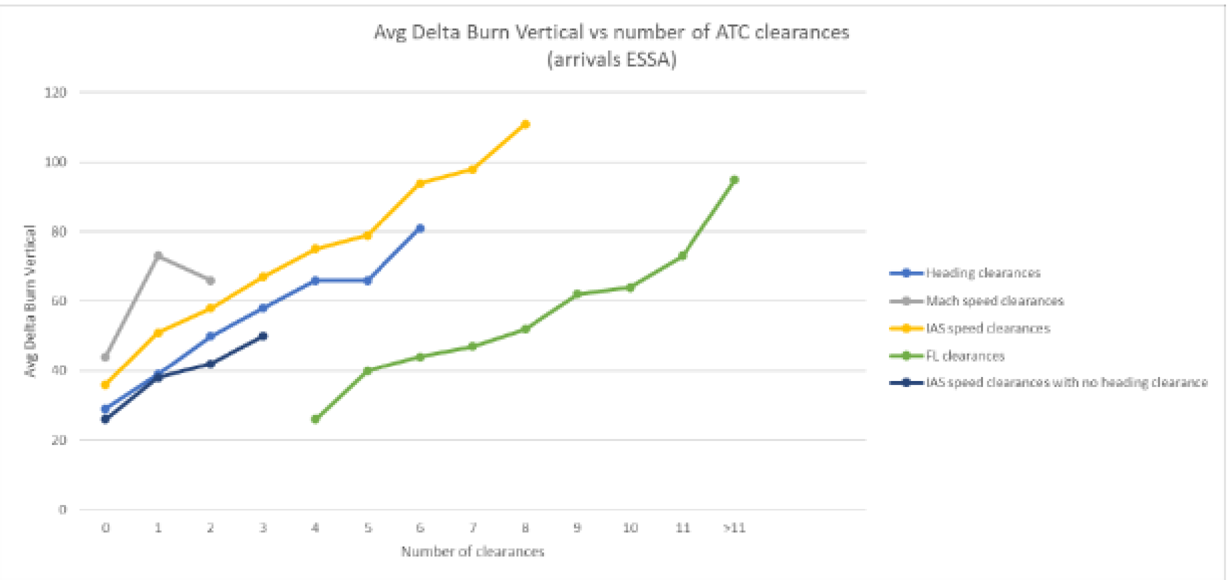


Figure 31 Average Delta Burn Vertical versus number of clearances given to a flight for arrivals into ESSA

Heading clearances

The presence of heading clearances indicate that a flight has been radar vectored at some point during the approach while flights with no heading clearance have followed a closed loop procedure (or been given a direct route to a waypoint and from there been cleared for approach).

Hence, a strong correlation between increased number of heading clearances and decreased vertical efficiency was expected and can also be seen in the chart. The correlation appears to be quite linear. A large number of heading clearances probably indicate a longer route, than only a few heading clearances. This can be confirmed in Figure 32 below where number of FL clearances have been plotted against the average delta distance compared to the shortest route (blue line). The orange line displays the number of flights that were included in each average calculation (on the secondary Y-axis). As can be seen, there are very few flights that received 6 or more heading clearances and therefore those points should be interpreted with great care.

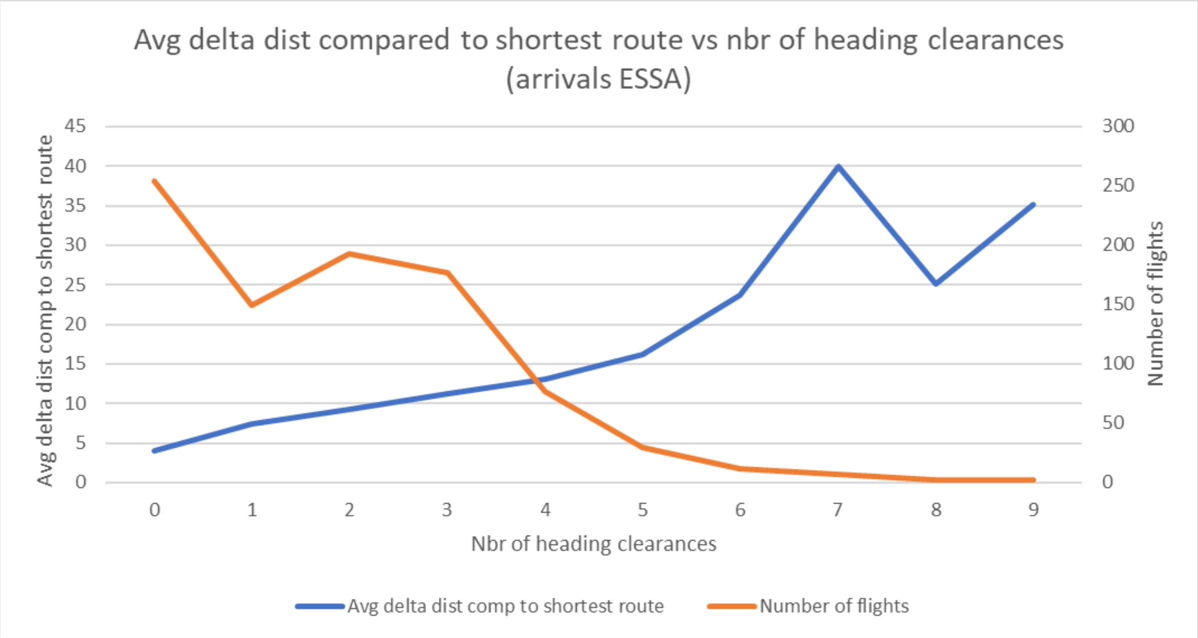


Figure 32 Average delta distance compared to shortest route versus number of heading clearances given for arrivals into ESSA

Figure 33 and Figure 34 below illustrate quite clearly the negative effect on vertical efficiency of radar vectoring compared to closed loop procedures. Figure 33 displays flights that had a high vertical efficiency; flights with a Delta Burn Vertical value less than 20. As can be seen, the most common number of heading clearances for this group of flights is zero.

Figure 34 displays flights that had a poor vertical efficiency; flights with a Delta Burn Vertical value greater than 70. In this group of flights, the most common number of heading clearances is three.

In the efficient group, there are flights with several heading clearances and in the less efficient group there are flights with zero heading clearances. There are always exceptions to the rules and many other factors affect the outcome of the vertical efficiency than just the lateral predictability. But the data clearly shows a strong correlation between radar vectoring and decreased vertical efficiency.

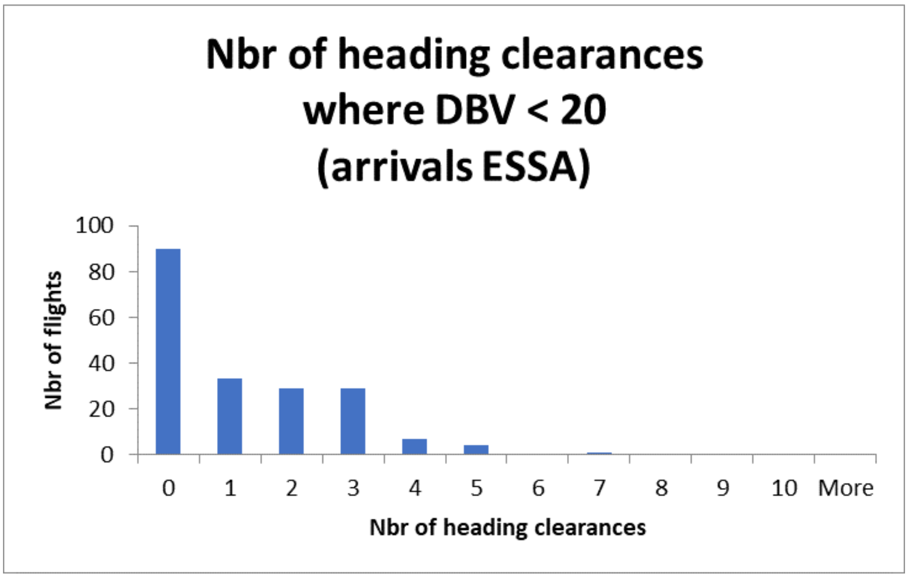


Figure 33 Frequency of different number of heading clearances per flight for vertically efficient flights for arrivals into ESSA

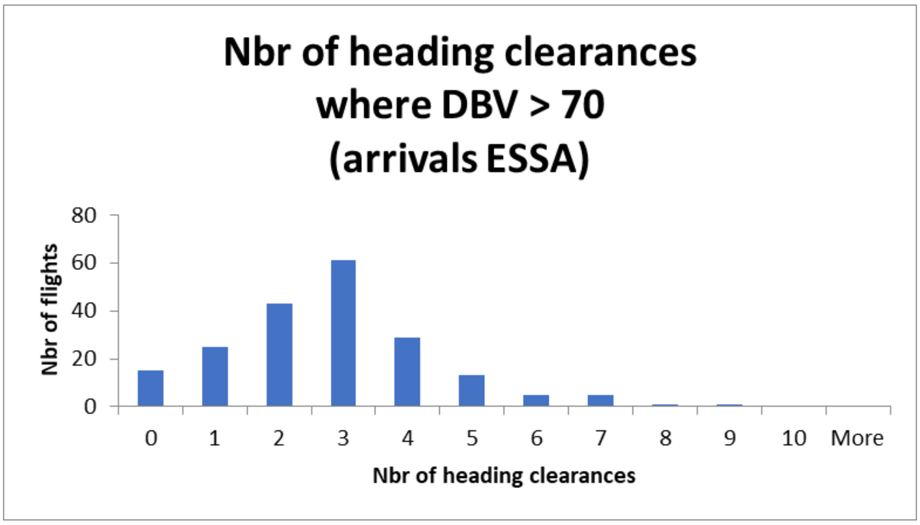


Figure 34 Frequency of different number of heading clearances per flight for vertically inefficient flights for arrivals into ESSA

Speed clearances

IAS speed clearances

Also, for IAS speed clearances there appears to be a strong linear correlation between increased number clearances and decreased vertical efficiency. The IAS speed clearance line in Figure 31 follows the heading clearance line quite well, but it is transposed upwards. The average Delta Burn Vertical value for zero IAS speed clearances is 12 kg higher than for zero heading clearances. The reason for this could be that there are a number of flights in the group with no IAS speed clearances that had heading clearances, which we have seen have a negative impact on the vertical efficiency, while the group of flights with zero heading clearances obviously does not contain any flights with heading clearances.

As we have seen before, in 84 % of the cases where there was an IAS speed clearance there was also a heading clearance. To assess if there is a correlation between increasing number of IAS speed clearances and decreasing vertical efficiency as well and that it is not only the “heading clearance effect” that we see, the average Delta Burn Vertical values for flights with a given number of IAS speed clearances but with no heading clearances was plotted. This line also shows a correlation between increasing number of clearances and increasing Delta Burn Vertical. Please keep in mind though that there is quite a small number of flights in this group since most flights with an IAS speed clearance also have heading clearances.

It seems reasonable that the line for IAS speed clearances is transposed upwards compared to the line for heading clearances since the presence of both speed and heading clearances probably indicate a more complex traffic situation than when only heading clearances are required.

Descent speed constraints known before ToD that are catered for in the descent planning do not affect the vertical efficiency (other than that a high descent speed is in absolute numbers is less efficient than a lower speed). But when a descent is planned to be executes with a given speed and that speed is changed after the initiation of the descent, the vertical efficiency of the flight is negatively impacted.

A lower descent speed than planned with results in a too high energy situation. Provided that the distance to go is not increased compared to planned, energy needs to be dissipated (e.g., using speed brake) to arrive at the Final Approach Point (FAP) with the right amount of energy. Had the lower speed been known before ToD, the descent could have been initiated earlier and fuel could have been saved.

A higher descent speed than planned with results in a too low energy situation. Provided that the distance to go is not decreased compared to planned, energy needs to be added (by using thrust). Partial thrust to stay on the correct vertical profile will be less detrimental to the vertical efficiency than performing an idle descent arriving at the FAP altitude too early and from there flying a level segment at low altitude.

The effect that predictability regarding descent speed has on vertical efficiency was assessed by analysing flights arriving into ESSA that were given a high descent speed constraint (270 kt IAS or higher). The flights were divided into two groups:

- Flights that received the high descent speed clearance one minute or more before ToD (Group 1)
- Flights that received the high descent speed clearance one minute or more after ToD (Group 2)

The average Delta Burn Vertical value, descent distance and time in level flight from ToD for the two groups were calculated and are displayed in Table 21 below.

ESSA	Avg Delta Burn Vertical	Avg descent distance[4]	Avg time in level flight from ToD	Number of flights
Group 1 (before ToD)	61 kg	127 NM	27 sec	26
Group 2 (after ToD)	70 kg	136 NM	68 sec	77
All flights into ESSA	51 kg	132 NM	53 sec	1192

Table 21 Comparison between flights receiving the high descent speed clearance before and after ToD

With a higher descent speed, the optimal the descent distance will be shorter than for a flight with a lower descent speed. In the group of flights that got their high descent speed clearance well ahead of ToD, the average descent distance was on average 9 NM shorter than for the group of flights that received the high descent speed clearance after ToD. With knowledge of the high descent speed before initiating the descent, ToD can be adjusted to the higher speed by delaying the initiation of descent. The Delta Burn Vertical value indicates that the group receiving the high descent speed clearance well ahead of top of descent on average was 9 kg more efficient and spent less time in level flight during the descent than the group receiving the clearance after top of decent. It should be kept in mind though that, especially for Group 1, there is quite few flights in the studied material so the results should be interpreted with care. However, the results are in line with what theoretically could be expected.

Mach speed clearances

A speed constraint applied in the cruise segment will not affect the vertical efficiency of the descent/approach. During descent, a Mach speed clearance would only be applied during the initial part of the descent (above the cross-over altitude), after that IAS speed clearances will be issued instead. For this reason, it is not common with many Mach speed clearances for a flight. Of the 903 flights arriving into ESSA, 88 received a Mach speed clearance. 75 of these also received IAS speed clearances. The line for Mach speed clearances in the chart shows a significant decrease of vertical efficiency when going from zero to one clearance. A speed constraint applied only in the initial part of the descent would normally not result in such a large efficiency decrease by itself, but since 85% of the flights with a Mach speed clearance also were given IAS speed clearances (and of those 84% also were given heading clearances) this seems reasonable.

Flight Level clearances

FL clearances, unless they restrict the descent, do not affect the vertical efficiency. Many FL clearances may be given to a flight that performs a perfect CDO as long as the next FL/altitude is given well enough in advance of reaching the cleared FL/altitude and thereby avoiding level offs. Below is a good example of such a flight. It received 7 FL clearances during its descent while it performed a CDO approach. All

[4] Descent air distance normalised to FL360

clearances for lower FL/altitude were given well ahead of reaching the currently cleared FL/altitude, resulting in no vertical constraints for the flight.

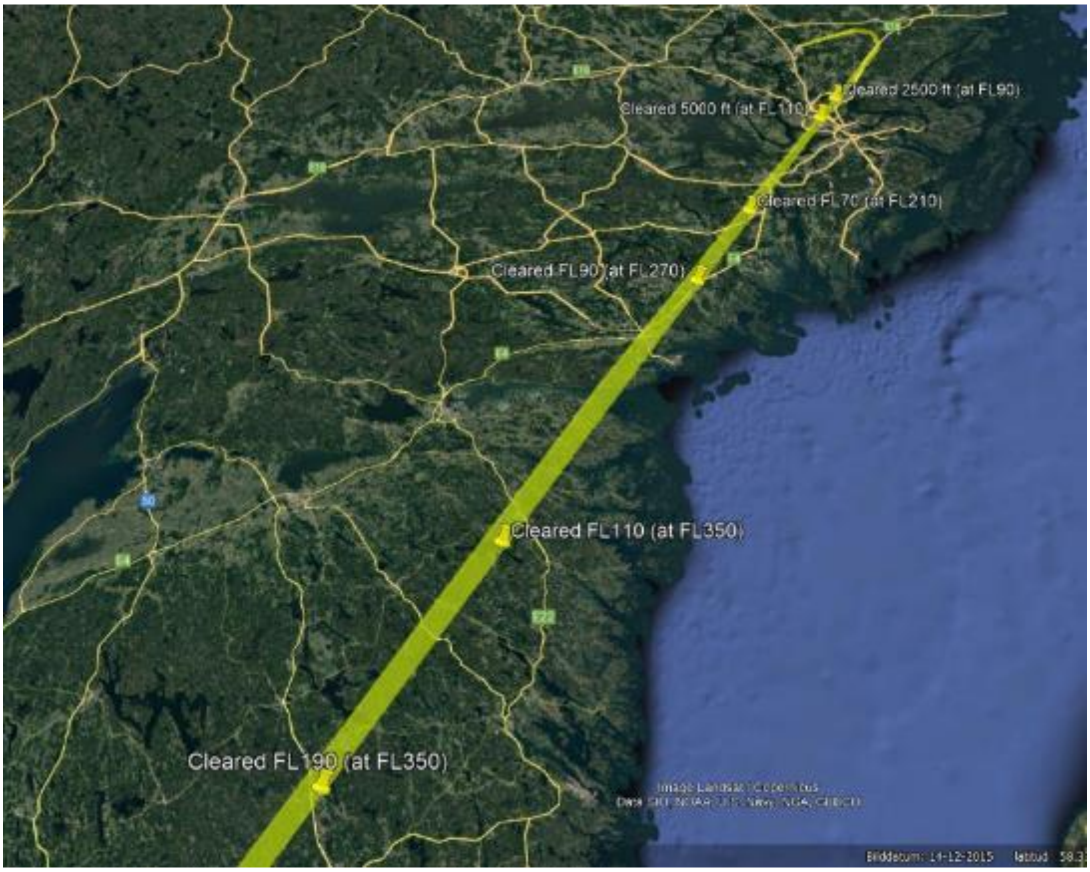


Figure 35 Flight path of a vertically efficient flight that received 7 FL clearances arriving into ESSA

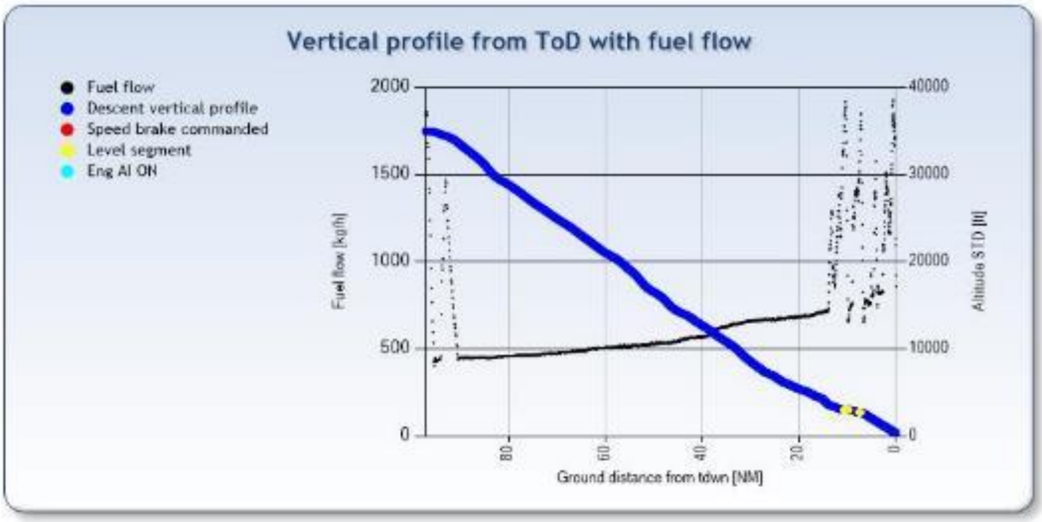


Figure 36 Vertical profile and fuel flow during descent for the flight illustrated in Figure 35

Even though many FL clearances may exist for vertically efficient flights, the FL clearances line in Figure 31 shows a decrease in vertical efficiency as the number of FL clearances increase. Once again, this is probably due to the fact that in denser traffic situations the amount of FL clearances generally increases compared to in a low traffic scenario.

5. Assessing efficiency related to the operational environment based on FDR data

Definition of the method

As the previous section illustrated, combining ATC clearance data with FDR data makes it possible to assess quite a lot regarding the impact of ATC constraints on flight efficiency. Based on the studies performed, combined with general flight theory, a method for assessing the efficiency/inefficiency related to the operational environment based on FDR data, but without ATC clearance data, has been defined and is described below. It can be used to assess the overall vertical efficiency of arriving flights into an airport and to get an idea of what kind of operational challenges there are causing vertical inefficiencies. It should be seen as another tool in the toolbox when working with improving flight efficiency.

The method is based on the assumption that the Flight Crew strives to leave the enroute segment at the optimal ToD, based on the information they have at their hands regarding distance to go and descent speed. They will not leave early or late just for the fun of it.

Provided that the Flight Crew tries to initiate the descent from the optimal point the following applies:

- A longer than optimal descent distance indicates a low energy scenario where thrust had to be added. It can have the following causes:
    - The actual route turned out to be longer than the Flight Crew had assumed/planned for (e.g. by longer vectoring than expected, change of clearance for a longer procedure, the need to circumnavigate cumulonimbus clouds etc.)
    - ATC required that the descent was initiated before the optimal descent point was reached due to traffic separation issues
    - The presence of an airspace constraint[5] in the form of a maximum altitude during descent, too low in relation to the distance to go from that point until landing
    - A higher descent speed than planned with was used
- A flight with a descent distance close to optimum but with poor vertical efficiency indicates that the energy during the descent could not be managed optimally. Reasons can be:
    - The need to level off (requiring thrust) followed by the need to use speed brake to catch up with the vertical profile
    - Speed constraints or uncertainties regarding distance to go resulting in situations where speed is increased, or speed brake is used followed by the need to add thrust at a later stage

[5] There can be may different reasons for the presence of an airspace constraint, e.g., to ensure that flights are conducted within controlled airspace, to achieve a certain traffic flow that is considered to be best for the big picture, to ensure that arriving and departing traffic are separated etc.

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- A flight with a descent distance close to optimum and with high vertical efficiency indicates optimal usage of the energy. Probably the predictability was high, and the flight turned out efficient.
- A shorter than normal descent distance indicates a high energy scenario where energy had to be dissipated. It can have the following causes:
  - The actual route turned out to be shorter than expected (e.g. by shorter vectoring than expected or change of clearance for a shorter procedure)
  - A lower descent speed than planned with was used
  - The presence of an airspace constraint[5] in the form of a minimum altitude during descent, too high in relation to the distance to go from that point until landing

Even though it is possible to calculate the optimal descent distance for a given set of flight conditions, all conditions affecting the flight are not known even though FDR data is available. Also, the scenarios listed above affect the descent distance to different extents. E.g. a very long, unexpected, radar vectoring will result in a considerably longer descent distance compared to a higher descent speed imposed after top of descent. And a speed constraint of 30 kt higher descent speed than planned with during the whole the descent will affect the descent distance more than 10 kt higher descent speed than planned with during only part of the descent.

Therefore, when applying the above logic to a large set of data, ranges must be used instead of a fixed value and the defined categories will blend where they meet unless a margin in inserted between two categories.

The logic has been applied like this in Figure 37 below. The differently coloured boxes represent the different scenarios. Note that Delta Descent Distance (see **Delta Descent Distance**) is used on the X-axis. The large dots in different colours represent the example flights described later.

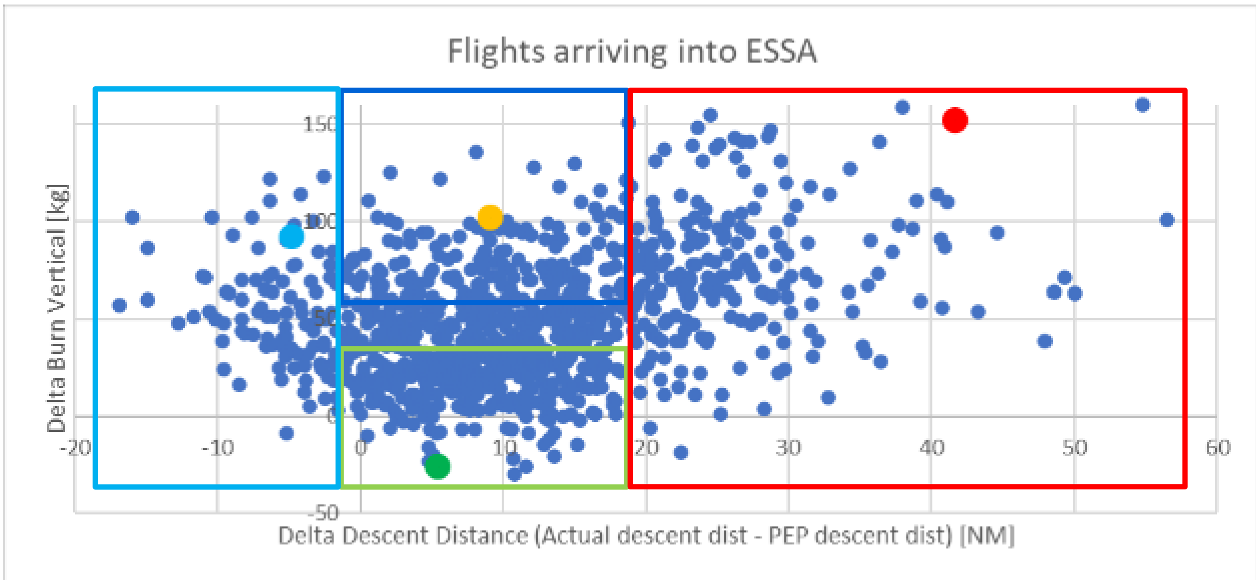

Figure 37 Flights arriving into ESSA, divided into categories based on Delta Descent Distance and Delta Burn Vertical

The boundaries

In Figure 37 above, the “normal” descent distance range (the yellow and green boxes) has been set to 20 NM ranging between -2 and 18. This range covers both the flights that had an optimal descent distance and those with a slightly too short and too long descent distance. The yellow and green boxes are placed right next to the blue and red boxes with no margin in between. This will result in some of the flights close to these borders are in the “wrong” box. Getting further away from the borders will increase the confidence of the flight meeting the criteria of the given box. For the sake of the performed analysis below, it is not a problem if a flight incorrectly falls into the red box instead of the yellow or in the green box instead of the blue. But in this chart, there is a margin between the yellow and green boxes because the green box indicates vertically efficient flights while the yellow box indicates vertically inefficient flights, and a flight does not go from being efficient to inefficient in one kg difference in Delta Burn Vertical. Depending on what kind of analysis to perform and the required confidence, the rangers may need to be set differently.

Below, the different boxes displayed in Figure 37 above are described.

<u>The red box</u>

A longer than normal descent distance. Reasons can be:

- Radar vectoring
- Re-cleared for a longer route after ToD (e.g., due to change of runway)
- ATC required that the descent was initiated early due to separation requirement
- An airspace design issue (a waypoint along the planned route during descent associated with a maximum altitude constraint too low in relation to the distance to go from that point until landing)
- Close to the yellow border, flights that had to use a higher than planned descent speed can be found

<u>The yellow box</u>

Descent distance within the normal range but with poor vertical efficiency. Reasons can be:

- Speed constraints during the descent
- Level offs during the descent
- Speed brake usage followed by the need for thrust

<u>The green box</u>

Descent distance within the normal range and good vertical efficiency. Probable reasons:

- High predictability
- Good planning
- Proactive ATC handling
- Low traffic situation

<u>The blue box</u>

A shorter than normal descent distance. Reasons can be:

- Re-cleared for a shorter route after top of descent

- Shorter radar vectoring than expected
- A lower descent speed than planned with was used
- The descent was planned with and used a high descent speed
- An airspace design issue (a waypoint along the planned route during descent associated with a minimum altitude constraint too low in relation to the distance to go from that point until landing)

Example flights from the different boxes

In this section one example flight has been selected from each box and it is presented together with some comments. The example flights can be identified in Figure 37 by the large coloured dots.

The red box – a flight with a longer than normal descent distance

(Id: 2516)

This flight, arriving into ESSA (landing time 21:51 UTC), was radar vectored in a long pattern for RWY 26. The Flight Crew expected a shorter route and hence the descent distance turned out to be much longer than optimal.

- Delta descent distance: 41,7 NM
- Delta distance compared to shortest route: 21,5 NM
- Delta Burn Vertical: 152 kg

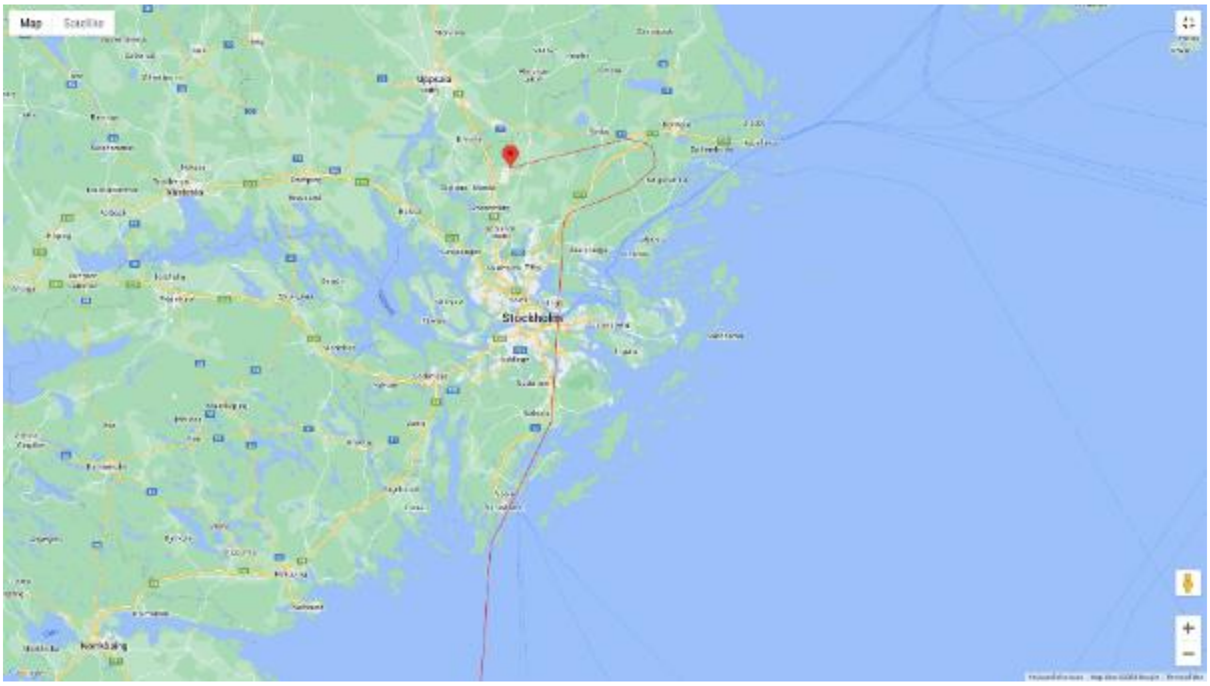

Figure 38 Lateral track of the example flight from the red box

In Figure 39 and Figure 40 below, the vertical profile is plotted from ToD to touch down. The ground distance from touch down is displayed on the X-axis. The blue line illustrates the altitude based on

1013 hPa (associated with the secondary Y-axis). In Figure 39, the black line illustrates the fuel flow (associated with the primary Y-axis) and in Figure 40, the black line illustrates the IAS (also associated with the primary Y-axis).

As can be seen in the vertical profile charts, this flight performed an almost idle descent until approximately FL140 and from there thrust had to be added to decrease the descent angle. Before intercepting the glideslope for the final approach segment, there is an approximately 30 NM long segment marked yellow. This indicates that the vertical speed was less than -300 ft/min, which by definition is considered a level segment.

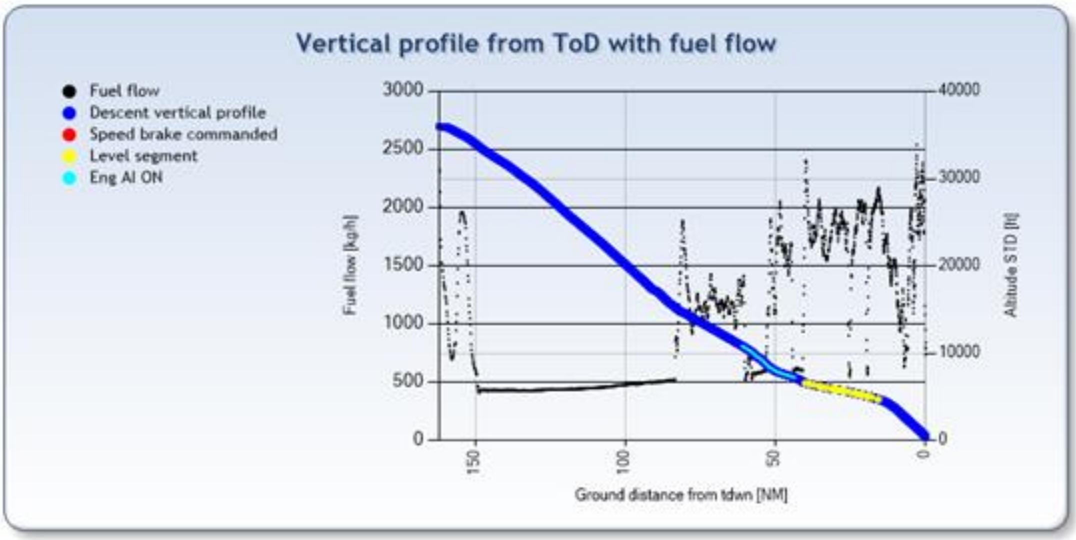

Figure 39 Vertical profile and fuel flow during descent for the example flight from the red box

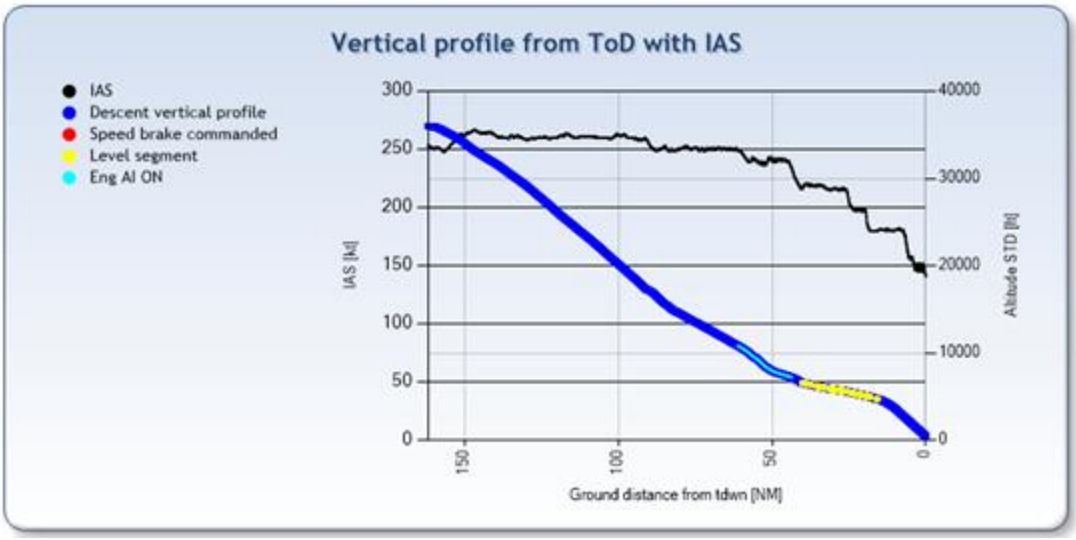

Figure 40 Vertical profile and speed during descent for the example flight from the red box

The yellow box – a flight with normal descent distance but poorly managed energy during descent

(Id: 2671)

This flight, arriving into ESSA RWY 26 (landing time 22:13 UTC), was given a descent speed clearance of 290 kt IAS at ToD. This is a good example of a flight where, for some reason, the energy managed during the approach was poor. A lot of thrust was added during the approach, followed by extensive use of speed brake.

- Delta descent distance: 9,1 NM
- Delta distance compared to shortest route: 1,2 NM
- Delta Burn Vertical: 102 kg

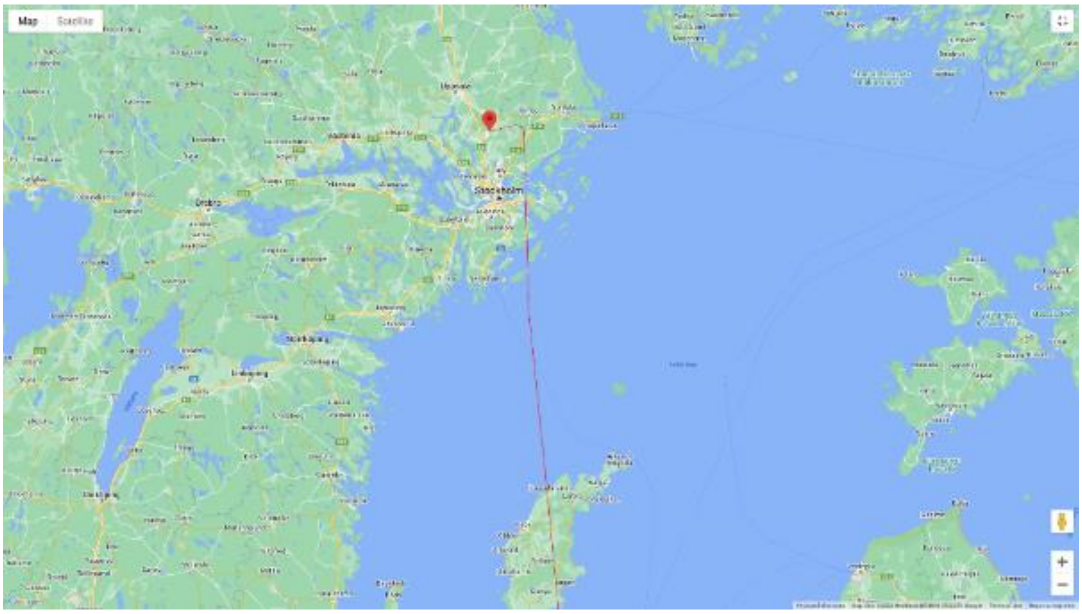

Figure 41 Lateral track of the example flight from the yellow box

As can be seen in Figure 42 below, a lot of thrust was added between FL180 and FL100 to keep 300 kt while staying on the vertical profile matching a lower speed schedule. This resulted in a high energy scenario when reaching FL100 when speed needed to be reduced (still staying on the same vertical profile). To dissipate the surplus energy, speed brake had to be applied between FL100-3000 ft.

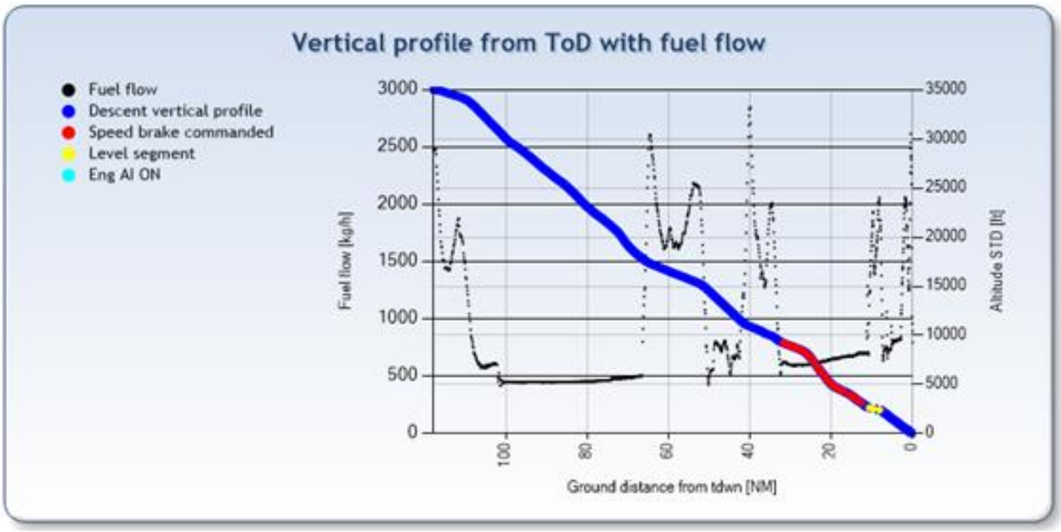

Figure 42 Vertical profile and fuel flow during descent for the example flight from the yellow box

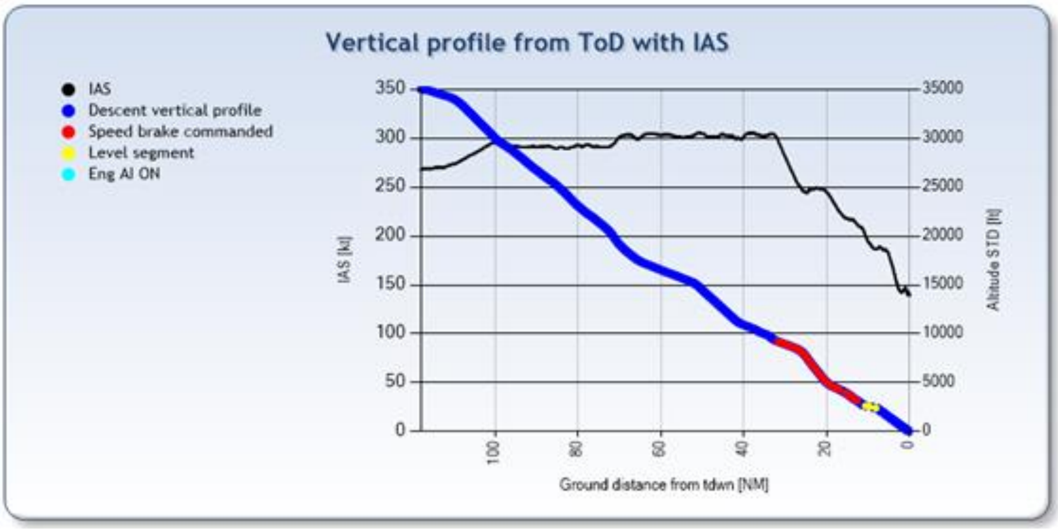

Figure 43 Vertical profile and speed during descent for the example flight from the yellow box

The green box – a flight with normal descent distance and high vertical efficiency

(Id: 3406)

This flight, landing on ESSA RWY 01L (landing time 04:15 UTC), is an example of an unconstrained, straight in approach performed in low traffic. The flight was conducted as a very efficient CDO approach.

- Delta descent distance: 5,4 NM
- Delta distance compared to shortest route: 1,1 NM

- Delta Burn Vertical: -26 kg

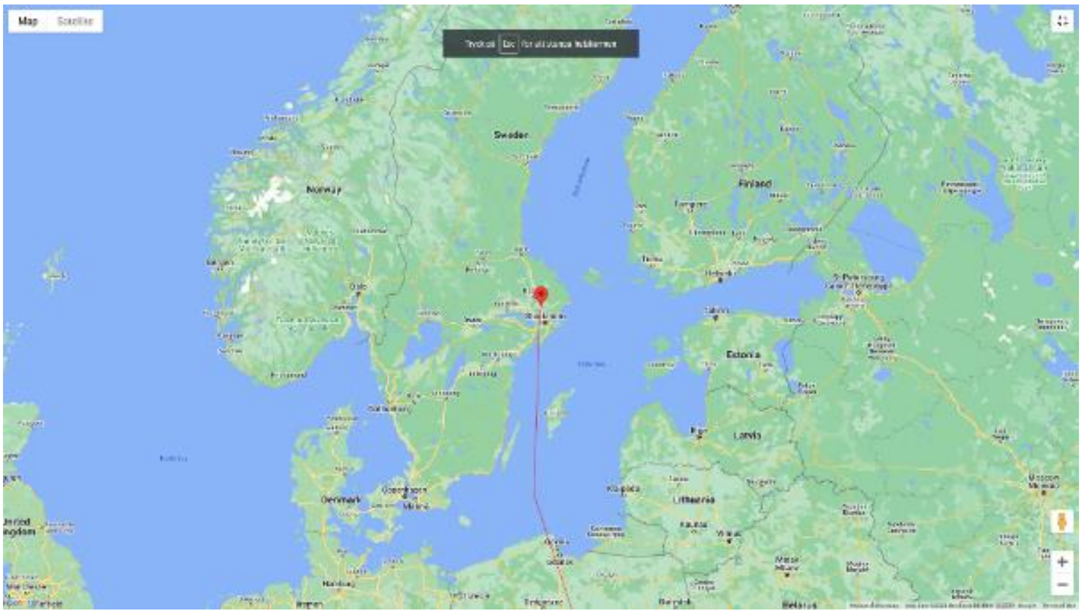

Figure 44 Lateral track of the example flight from the green box

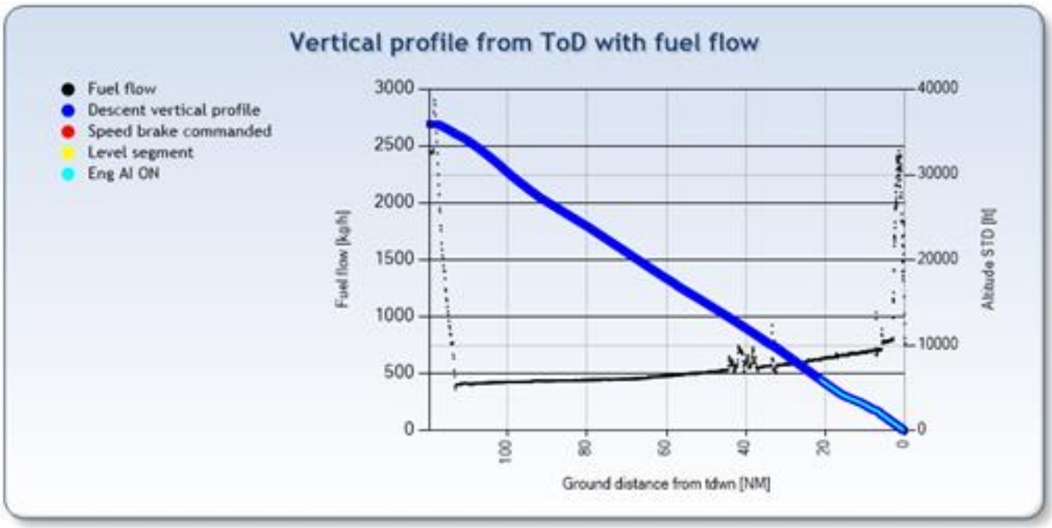

Figure 45 Vertical profile and fuel flow during descent for the example flight from the green box

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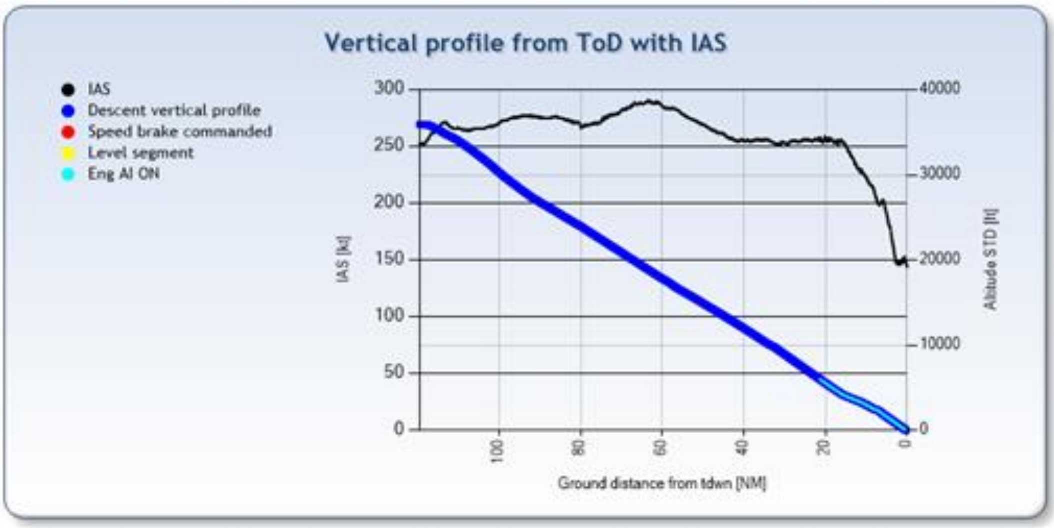

Figure 46 Vertical profile and speed during descent for the example flight from the green box

<u>The blue box – A flight with a shorter than normal descent distance</u>

(Id: 7648)

This flight, performing an RNP AR approach into ESSA RWY 26 (landing time 22:39 UTC), was given a high-speed descent clearance of 280 kt IAS before top of descent. The descent was hence planned with 280 kt, leaving the en-route segment at the optimal point for this descent speed.

At FL140, the assigned speed of 280 kt was changed to a much lower speed (250 kt followed by 230kt and then 210 kt), resulting in a high energy situation and speed brake had to be used between FL140 and approximately 3000 ft whereby energy had to be wasted.

- Delta descent distance: -4,8 NM
- Delta distance compared to shortest route: 1,7 NM
- Delta Burn Vertical: 92 kg

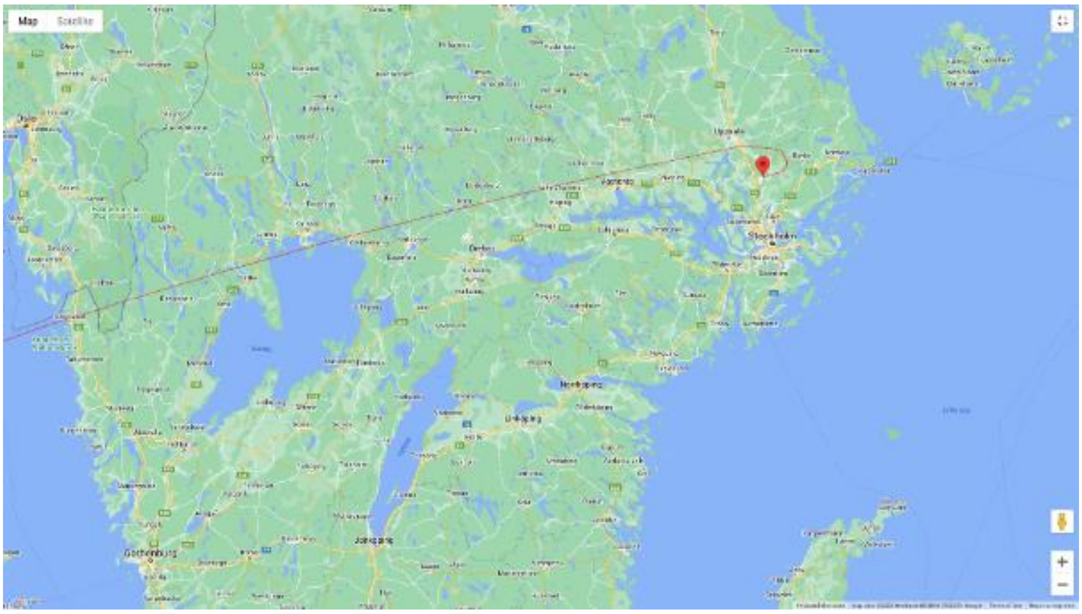

Figure 47 Lateral track of the example flight from the blue box

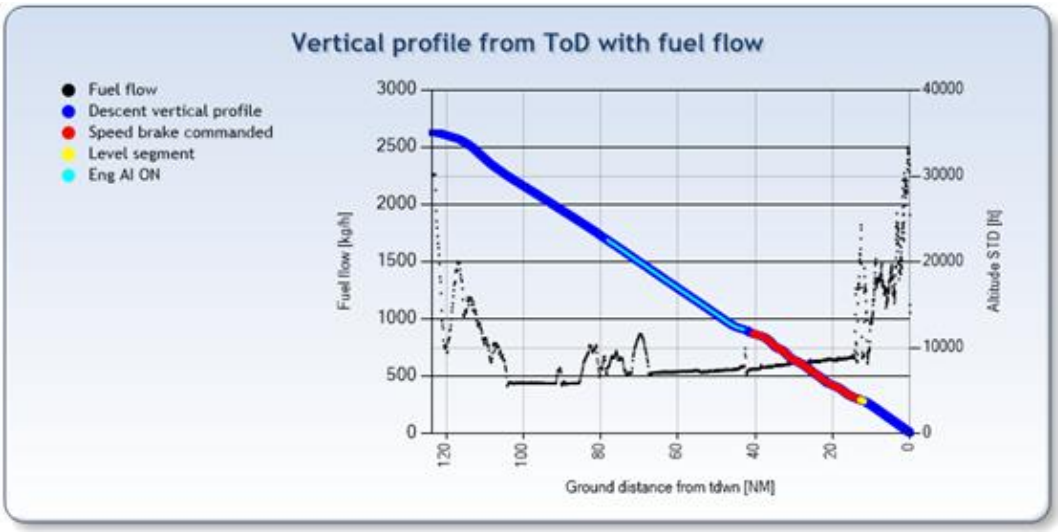

Figure 48 Vertical profile and fuel flow during descent for the example flight from the blue box

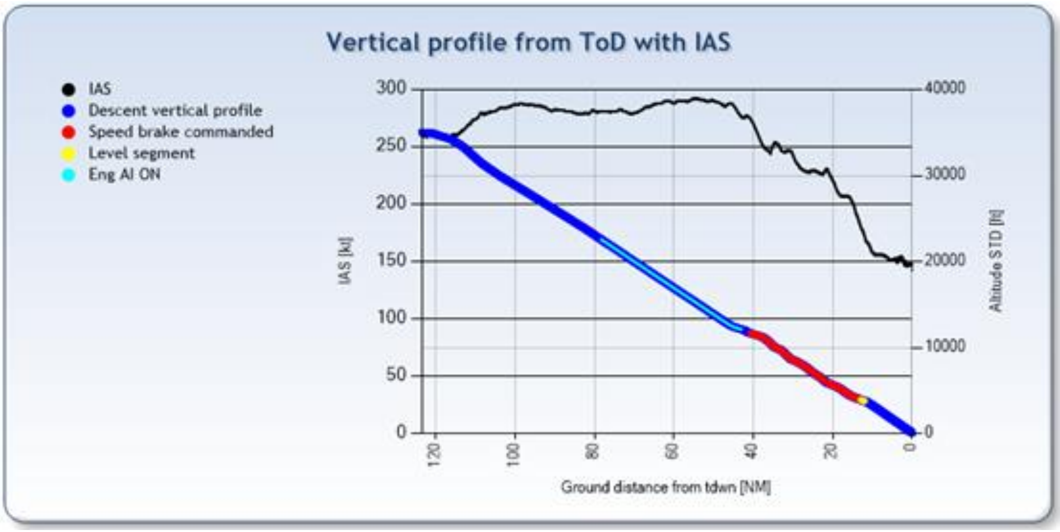

Figure 49 Vertical profile and speed during descent for the example flight from the blue box

Comparison of different airports using the coloured boxes

In this section, charts with the coloured boxes are displayed for a number of different airports to illustrate how this method can be used to assess the efficiency/inefficiency related to the operational environment in different places.

<u>ESSA</u>

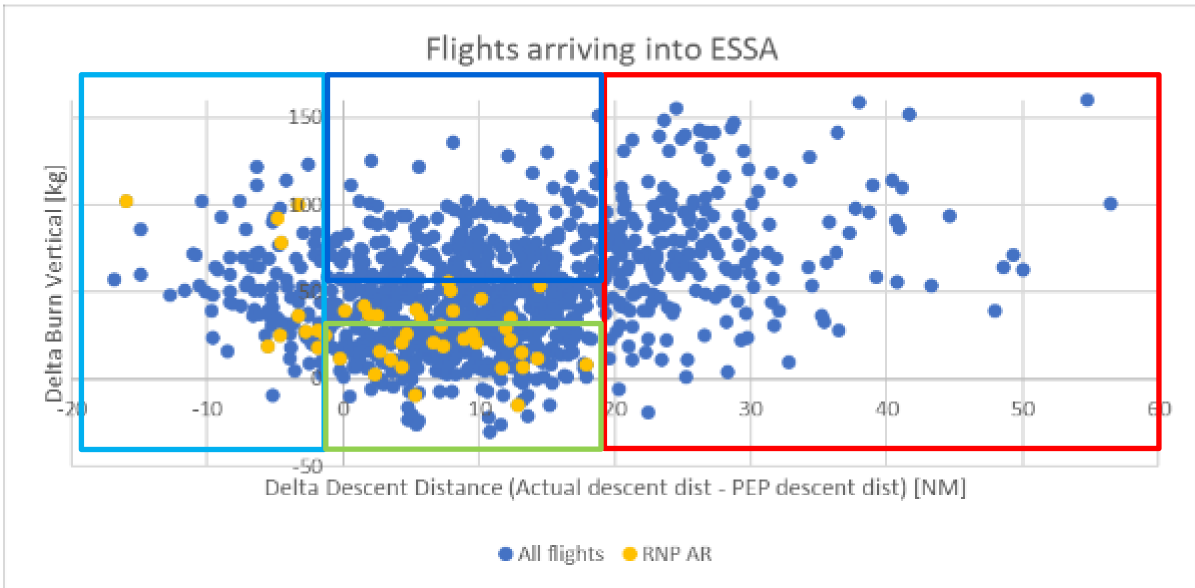

Figure 50 Flights arriving into ESSA, divided into categories based on Delta Descent Distance and Delta Burn Vertical

Figure 50 above is the same chart as seen earlier for ESSA. The only difference is that all flights that performed an RNP AR approach are marked yellow. The lateral track of RNP AR approaches is predictable and most of them are in the green box. The ones located close to the blue border and in the lower part of the blue box are typically flights that got the clearance for the RNP AR approach after top of descent. The ones that are in the top part of the blue box probably got some speed clearances affecting the vertical efficiency of the descent.

ESGG

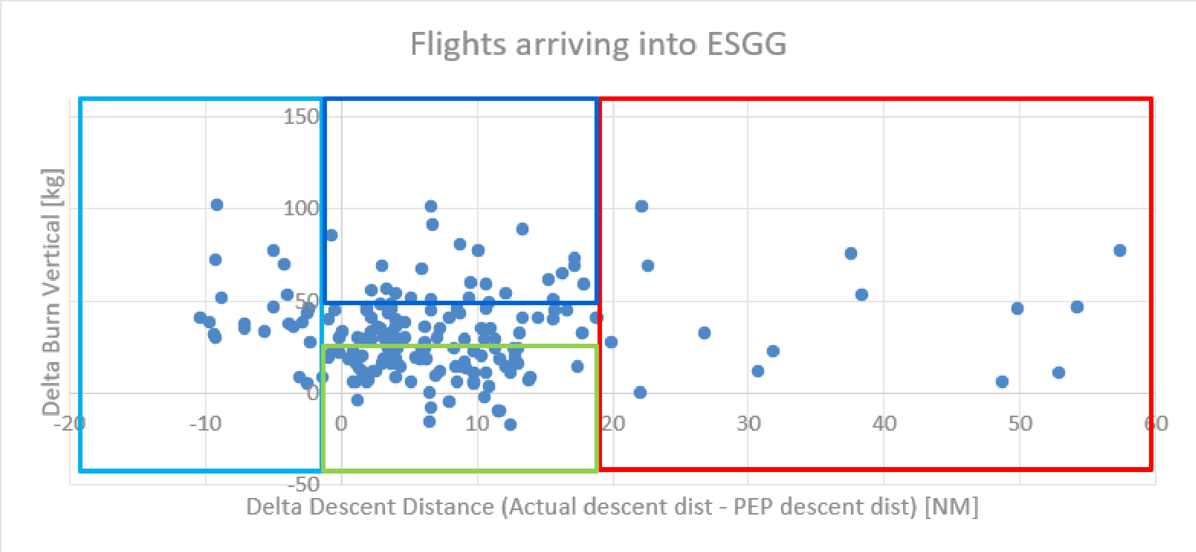

Figure 51 Flights arriving into ESGG, divided into categories based on Delta Descent Distance and Delta Burn Vertical

There is less data available for ESGG compared to ESSA and therefore there are less dots in all four boxes in Figure 51. However, a difference in the pattern can be seen. The data is more centered around the green box with lower density in the yellow and red boxes, especially in the top part of those. This indicates higher predictability than for ESSA. Considering the lower traffic situation at ESGG compared to ESSA, and also the much higher usage of closed loop procedures at ESGG, this seems reasonable.

GCLP (Las Palmas Gran Canaria)

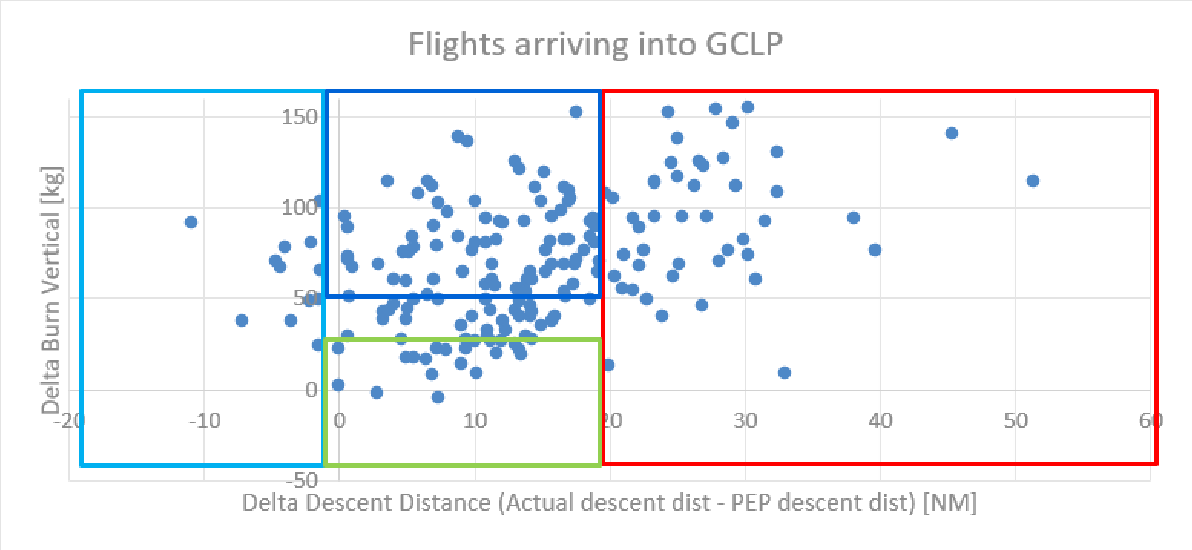

Figure 52 Flights arriving into GCLP, divided into categories based on Delta Descent Distance and Delta Burn Vertical

For GCLP, in Figure 52, the pattern is different in the opposite direction. The center of the data is moved upwards and to the right compared to ESSA. The majority of the flights are in the yellow and red boxes, indicating poor predictability. Few flights are in the blue box, meaning that it is uncommon that the flight turns out to be shorter than expected. When arriving into GCLP, coming from north, usually the flights are routed via the waypoint GDV, located northwest of the field. From there, if landing RWY 03 (which is the usual case) they are radar vectored in a right-hand circuit. Depending on the traffic situation, this circuit can differ a lot in distance, making it difficult to plan the descent and level segments are common during this vectoring.

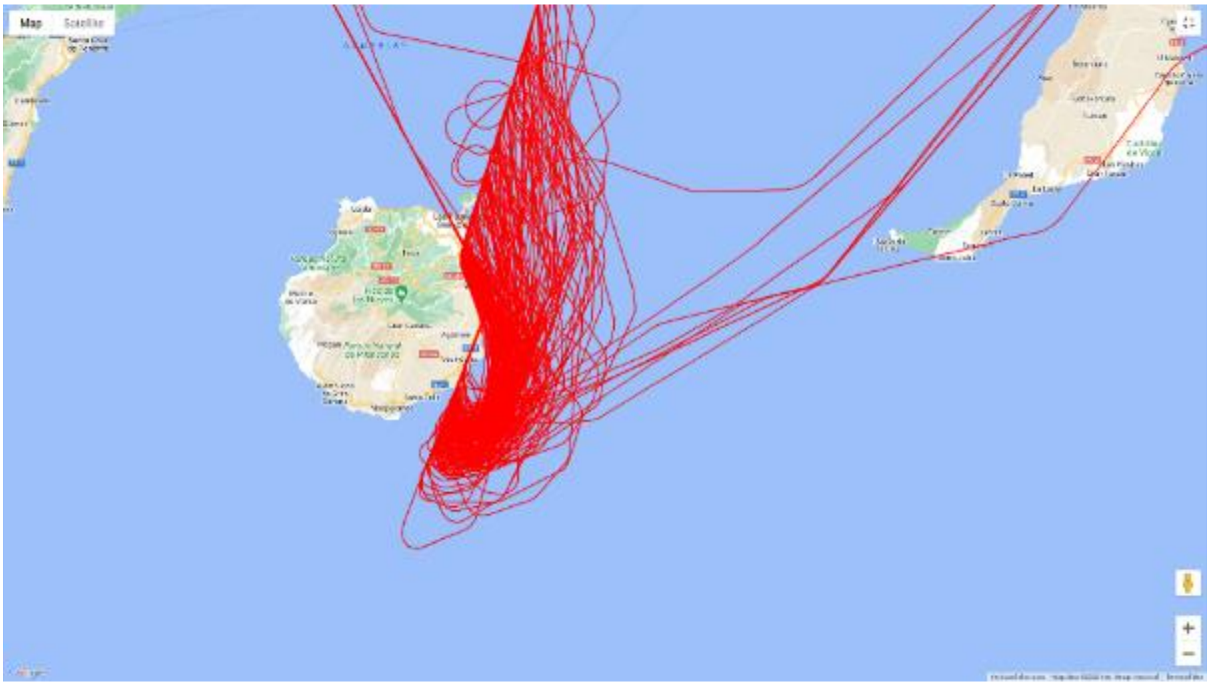

Figure 53 Lateral track of Novair flight arriving into GCLP for landing RWY 03

GCFV (Fuerteventura)

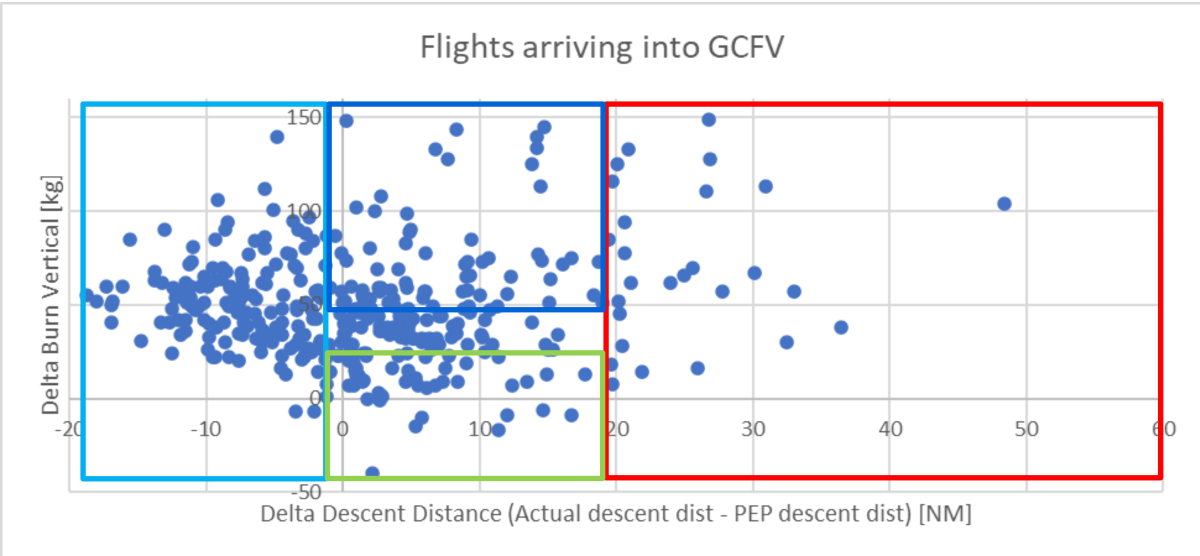

Figure 54 Flights arriving into GCFV, divided into categories based on Delta Descent Distance and Delta Burn Vertical

For GCFV, in Figure 54, we see a significantly different pattern compared to GCLP. The data is shifted downwards and to the left. The majority of the flights are below the yellow box and in the blue box, with much lower density in the red box and in the upper part of the yellow box. The large amount of flights in the blue box indicate that there is an issue with the descent distance often turning out too short. If, for these flights, the descent could have been initiated earlier, the vertical efficiency would have increased with fuel savings as a result. The STAR into GCFV RWY 01 (the runway usually used) contains a point merge structure. Looking at the lateral track of the flights into GCFV, it can be seen that the arc used for delaying activities is seldom used. There are also many flights that were turned inbound to final before even reaching the merge point. Beside the challenge of predicting the distance to go when planning the descent, there is also a minimum altitude constraint at the waypoint BUSAP. In cases of a lateral route shorter than to the merge point, this altitude constraint (unless canceled by ATC) usually prevents descent from the point that is optimal in relation to distance to go.

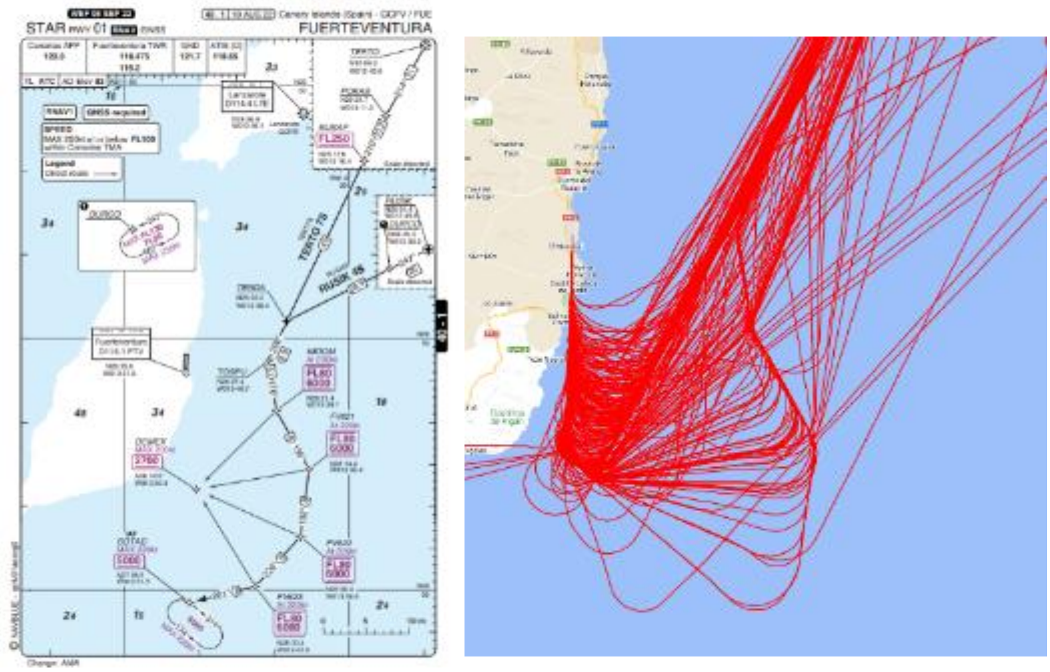

Figure 55 STAR GCFV RWY 01 and lateral track of Novair flights arriving into GCFV for landing RWY 01

LPMA (Funchal Madeira)

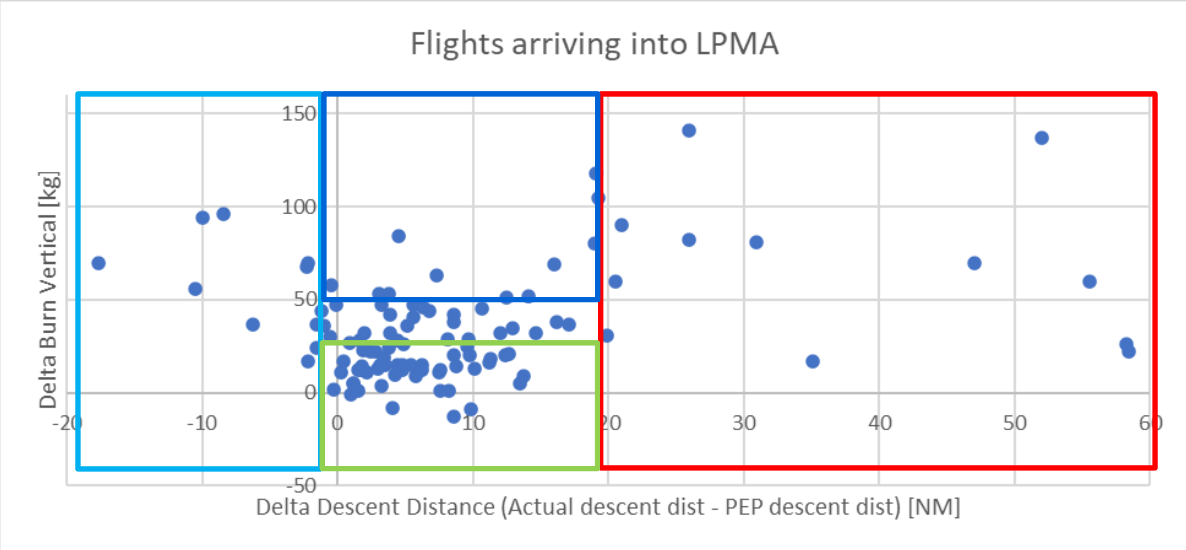

Figure 56 Flights arriving into LPMA, divided into categories based on Delta Descent Distance and Delta Burn Vertical

Almost all Novair flights arriving into LPMA use RNP AR approach procedures. And with RNP AR comes high predictability. This can be seen in Figure 56 above. The majority of the flights are below the yellow box and in the green box. All the flights in the red box were subject to wind related holding (there are wind limitations associated with all landings at LPMA).

B.1.2 Summary of Demonstration Exercise #02 Demonstration Objectives and success criteria

This exercise targets objective OBJ-VLD-ALBATROSS-001 : "To demonstrate that trajectories closer to the "optimum" can be executed or planned-and-executed."

In particular, the exercise described a method that allows to identify potential improvements on arrivals.

The success criterion is to show how the method allows to estimate the quantity of CO2/fuel reduction that could be achieved by improving the arrival profiles, at different scales and in different airports.

B.1.3 Summary of Validation Exercise #02 Demonstration scenarios

The exercise has targeted with particular detail the arrival procedures of Stockholm Arlanda airport (ESSA). Other airports where Novair flight recorder data is available have also been analyzed : Gotheborg (ESGG), Las Palmas Gran Canaria (GCLP), Fuerteventura (GCFV), Funchal Madeira (LPMA).

B.1.4 Summary of Demonstration Exercise #02 Demonstration Assumptions

Identifier	Title	Type of Assumption	Description	Justification	Impact on Assessment

Table 22: Demonstration Assumptions overview

No assumptions were formally tracked.

B.2 Deviation from the planned activities

The scope of EXE-02 “Swedish Cluster” has changed throughout the project lifetime. Initially, the plan was to introduce a number of ATC local ALBATROSS solutions at Stockholm Arlanda Airport (for example, direct routing within TMA, alleviate speed and altitude constrains on arrival and departure routes etc.). However, due lack of resources within Stockholm Arlanda ANSP (LFV), EXE-02 needed to change direction and revert to a reactive instead of proactive state. Given Stockholm Arlanda ANSP already provides several local solutions improving fuel efficiency within TMA, EXE-02 new scope was to derive flights at Stockholm Arlanda Airport where tangible efficiency measures are used. The scope focused on flights by NOVAIR and on NOVAIR's analysis method and internal fuel saving initiatives.

B.3 Demonstration Exercise #02 Results

B.3.1 Summary of Demonstration Exercise #02 Demonstration Results

Demonstration Objective ID	Demonstration Objective Title	Success Criterion ID	Success Criterion	Sub-operating environment	Exercise Results	Demonstration Objective Status
OBJ-VLD-ALBATROSS-001	Demonstrate trajectories closer to the "optimum"	CRT_VLD_ALBATROSS_001	Assess excess-fuel-burn	Arrivals (ToD to stabilization altitude)	closed-loop arrivals ESSA: vertical excess fuel reduced by 24kg; ratio of vert. ineff. best-/ worst-case nb. of clearances can be more than double	OK

Table 23: Exercise EXE-02 Demonstration Results

1. Results per KPA

The exercise focused on the "Environmental Efficiency" performance area.

Results are available in section B.1.1.

2. Results impacting regulation and standardisation initiatives

The results do not impact regulation or standardisation.

B.3.2 Analysis of Exercises Results per Demonstration objective

1. OBJ-VLD-ALBATROSS-001 Results

Results are available in section B.1.1.

B.3.3 Unexpected Behaviours/Results

The exercise consisted in post-ops data analysis. No unexpected results have been observed.

B.3.4 Confidence in the Demonstration Results

1. Level of significance/limitations of Demonstration Exercise Results

The level of significance is considered very high, since the analysis is based on actual fuel burn quantities retrieved from flight data recorders and (where applicable) on actual data of ATC clearances.

2. Quality of Demonstration Exercise Results

The quality of the results is considered very high. The Delta-fuel method devised by NOVAIR for arrivals has inspired the generalized methodology used throughout ALBATROSS, based on the "excess fuel burn compared to the Optimum Flight".

3. Significance of Demonstration Exercises Results

The analysis and calculations of the suggested method apply specifically for an individual airport; in other words, extrapolation of the calculations to other locations is not relevant.

They have been applied to several airports where NOVAIR operates : Stockholm Arlanda airport (ESSA), Gotheborg (ESGG), Las Palmas Gran Canaria (GCLP), Fuerteventura (GCFV), Funchal Madeira (LPMA).

B.4 Conclusions

The availability of a very large dataset of flight data, correlated with the specific conditions of the arrival airports, and correlated with the actual ATC clearances given to the flights made it possible to have very specific and detailed quantitative measurements of the impact of various constraints on arrivals (for illustration: for closed-loop arrivals into ESSA the average excess fuel due to vertical inefficiency is reduced by 24kg; the ratio of vertical inefficiency between best-case and worst-case number of clearances can be more than double). The works from the exercise were generalized into the definition of a method that can be used for assessing the efficiency/inefficiency related to the operational environment based on FDR data. This method can practically help to get an idea of what kind of operational challenges are causing vertical inefficiencies, in a specific TMA. The method also estimates the "excess CO2 emissions", from increased fuel-burn, that each inefficiency can cause.

B.5 Recommendations

B.5.1 Recommendations for industrialization and deployment

The Delta-fuel-burn method used by NOVAIR for arrivals has contributed to the generalized "ALBATROSS" method described in ALBATROSS Work Package 4 [22].

B.5.2 Recommendations on regulation and standardisation initiatives

No recommendation on regulation and standardisation.

Appendix C Demonstration Exercise #03 Report

EXE-03 is a unique exercise where, for the first time in the world, a demonstration and study was conducted to evaluate the benefits of closed-path PBN-to-ILS procedures with and without energy management pilot support system compared to radar vectoring procedures to the same runway. EXE-03 provides particularly valuable lessons for further widespread deployment of PBN-to-ILS procedures with the goal of maintaining high capacity and utilizing different types of aircraft energy management systems. In the case of EXE-03, the aircraft energy management system LNAS was used.

C.1 Summary of the Demonstration Exercise EXE-03 Plan

The objective of this exercise was to demonstrate Continuous Descent Approaches (CDA) using the pilot assistance system LNAS (Low-Noise Augmentation System) applied to closed-path PBN-to-ILS procedures. Closed-path PBN procedures offer the great advantage of completely eliminating the uncertainty of the lateral path distance, the so-called distance-to-go (DTG), while enabling optimized energy management. For this purpose, Skyguide defined a temporary PBN-to-ILS procedure, called “ALBATROSS Sequence”. It allowed a PBN-to-ILS onto Zurich's runway 14 during off-peak hours.

The "LNAS-CDA along closed-path PBN-to-ILS" Live Trials

For the purpose of the evaluation of EXE-03, the following flight data sets were collected during the demonstration period from July to December 2022:

1) **Baseline flights ‘Radar Vectoring’ (July to December 2022):** These are regular approaches under radar vectoring to LSZH runway 14 with SWISS Airbus A320neo aircraft.

2) **Reference flights ‘PBN-to-ILS without LNAS’ (July to August 2022):** These are closed-path PBN-to-ILS flights along the temporarily published ALBATROSS waypoint sequence for LSZH runway 14. The speed is managed by the pilots with a target speed of 170 kt at glideslope intercept and a standard configuration sequence (Flaps 1, Flaps 2, Landing Gear, Flaps 3, Flaps Full).

3) **Optimum flights ‘PBN-to-ILS with LNAS’ (September to December 2022):** These are closed-path PBN-to-ILS flights assisted by LNAS. The speed schedule and the configuration changes are executed by the pilots according to LNAS respecting initial TMA speed and glideslope intercept speed constraints (170 kt for this exercise).

The specific feature of EXE-03 is that the closed-path trajectory is already assigned by ATC to the pilots at the beginning of the descent when passing the IAF (Initial Approach Fix, either GIPOL or RILAX) of the STAR (Standard Arrival Route), avoiding tactical lateral instructions during the approach. Lateral tactical ATC instructions prevent optimized CDAs. If the distance-to-go (DTG) is not known a-priori at the beginning of the approach (unless ATC communicates an accurate DTG), it is not possible to estimate the aircraft’s energy state and hence decide on the energy dissipation strategy.

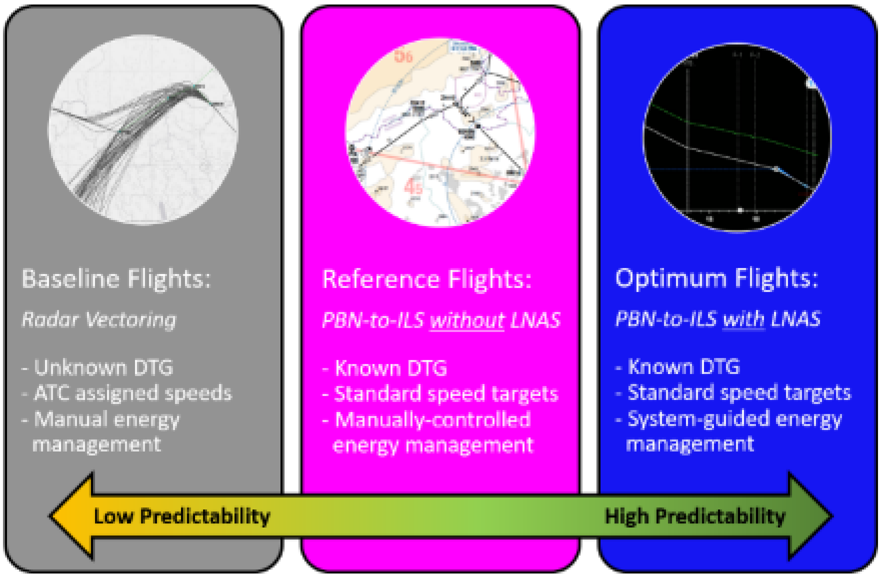

Figure 57: Principle of EXE-03.

DTG information for performing energy-optimized approaches was used for the profile computation in LNAS. The LNAS is a pilot assistance system developed by DLR helping pilots to optimize approaches in terms of fuel consumption and noise emissions by predicting both the optimum vertical flight path as well as the ideal speed schedule, location and timing for the flap configuration changes and landing gear extension. During the approach, recommendations are given by LNAS and executed by the pilots to obtain an energy-optimal profile at any given time.

LNAS runs as a demonstrator on an Electronic Flight Bag (EFB) and uses real-time flight data through an avionics interface device (AID). The pilot assistance system LNAS is a concept demonstrator for a **future FMS energy function** (currently under development) to support pilots in the conduct of the approach. The exercise helps to demonstrate the benefits of such an energy management functionality and to collect data and feedback for further development to transfer the LNAS capability into the next FMS generation.

LNAS starts the profile optimisation from the time of top of descent to the stabilisation altitude of 1’000 feet above ground. It also provides support from a flight safety perspective in ensuring precisely stabilized approaches.

In order to optimally integrate the ALBATROSS demo flights into the regular approach sequence, two speed constraints were defined. One is the initial TMA speed, which typically ranges between 220 kt and 250 kt. The other is the glideslope intercept speed, which was set at 170 kt for the demonstration flights. This corresponds to an unaccelerated speed on the glideslope in CONF 2 on an A320 at normal landing weights.

Within the framework of ALBATROSS EXE-03, the demonstration approaches were conducted in 2 phases.

- **Phase 1 (Reference flights without LNAS)**: includes approaches along the closed PBN-to-ILS trajectory without LNAS support.

- **Phase 2 (Optimum flight with LNAS)**: includes the same lateral approach trajectories, but with LNAS support to optimize the vertical profile and applying an engine thrust as close to idle as possible.

In the sense of a double-blind study, the results from Phase 1 and Phase 2 are compared with regular approaches (baseline flights). These are approaches under radar vectoring with tactical speed instructions. A comparison with these flights allows quantifying the benefit of

a) closed-path PBN procedures, and

b) the additional benefit of a pilot assistant function on noise and fuel consumption.

C.1.1 Exercise description and scope

Energy Management - General

In November 2022, the FAA published the Advisory Circular AC 120-123 subject to Flightpath Management. Chapter 6 of this AC provides recommendations concerning aircraft energy management. In this AC, energy management is defined as "*the planning and control of airspeed (or groundspeed), altitude, thrust, aerodynamic drag (speedbrakes, slats/flaps, and gear), and trajectory to achieve desired lateral and vertical flightpath targets appropriate for the operational objectives. Energy state is the combination of kinetic and potential energy of the aircraft, which means the combination of speed (kinetic energy), altitude (gravitational potential energy), and thrust (chemical potential energy) available. During maneuvering, these three types of energy can be traded, or exchanged, sometimes at the cost of additional drag.*"

The AC goes on to say: "*For example, the pilot needs to understand how to manage the vertical flightpath and aircraft energy during the arrival and approach phases; how the pilot does that will vary based on the type of approach flown (e.g., RNAV Standard Terminal Arrival (STAR) to an ILS approach or to a visual approach) and ATC interventions. Pilots need to be able to plan the tasks related to the desired aircraft energy state for the arrival and approach, in a timely manner. If the approach clearance or aircraft energy changes, the pilot needs to have the knowledge and skills to recognize actual or pending energy state changes to decide what actions need to be made to manage the flightpath and aircraft energy accurately and efficiently.*"

The FAA lists common errors in energy management, operational traps, and potential threats that could lead to errors, such as

- Late changes in assigned routing, clearance limit, altitude assignment, or arrival procedure.
- Untimely speed assignment changes, traffic avoidance altitude constraints, and other unexpected ATC restrictions.
- Current forecast and unexpected weather conditions (winds, icing, high density altitude, etc.) that affect aircraft performance and energy state.

The objective of this EXE-03 is to evaluate the advantage of implementing a PBN-to-ILS procedure and additionally using an aircraft energy management system to support pilots in the conduct of such approaches, to assess the environmental impact and to analyze the benefits on flight safety.

Energy Management - with LNAS

The tool used for Exercise EXE-03 is the LNAS software which runs as a demonstration platform on an EFB connected to the avionics bus through the AID. LNAS includes three parts: pre-planning, correction at runtime and an energy-based display. The pre-planning implements a simplified simulation model of an ideal vertical approach profile, which is applicable to any type of aircraft with existing data base. This pre-planning should ideally take place before the start of the actual approach. In doing so, optimal points in time for setting speed, high-lift devices and landing gear are determined in such a way that the approach can be carried out with minimum engine thrust and if possible without using the noise-intensive speed brakes. The optimal points in time depend on the wind conditions at current altitude and at the airport, which are already known at this time. In order to optimize the vertical approach profile, the current situation (aircraft mass, wind conditions, flight safety regulations and possible imprecise pilot actions) needs to be taken into account. Finally, LNAS shows all pilot actions at the optimal point in time with aim of stabilized approach.

For an energy-optimized approach, it is a prerequisite that the required speed reduction can be carried out to the next configuration point under the current boundary conditions without using speed brakes. In the course of the approach, the current wind situation on the aircraft is recorded, as well as possible time delays are taken into account by the necessary actions of the pilot, so that the best possible approach is displayed at any time. A delayed action may be, for example, setting the flap configuration too early or too late. In addition, ATC speed constraints (if any) can be entered by the pilot in order to optimize the approach under the new boundary conditions. The pilots are always informed about the energy balance during the entire approach as well as the necessary speed and height reductions. Impacts due to changes in wind conditions or new air traffic control instructions are immediately visualized. This basic concept and the functional structure in order to ensure the always up-to-date approach optimization are shown in Figure 58.

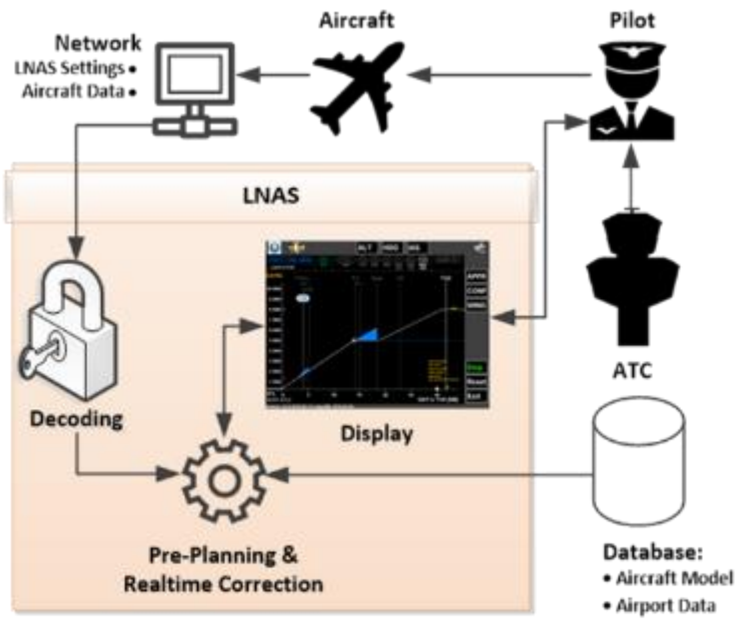

Figure 58: EXE-03 Demonstration exercise platform LNAS.

The LNAS software application has been adapted and extended for the selected aircraft type with the requested interfaces and equipment available at SWISS airlines.

EXE-03 included numerous preliminary preparation activities, which are briefly described in the following sections.

Simulation model adaptation to A320neo flight physics

LNAS was already successfully tested in 2019 as part of a flight test campaign at Zurich Airport on the DLR Airbus A320 ATRA. For a demonstration in the context of ALBATROSS on regular SWISS flights on their A320neo's, the performance model in LNAS had to be adapted accordingly. To make this possible, DLR modified the flight mechanics model in LNAS for the A320neo using an extensive data set of A320neo flight data. This required adjustments to both the engine and aerodynamic models.

The modified A320neo flight model was then verified on various flights at SWISS and Lufthansa in shadow mode during **2021 and early 2022**.

LNAS-Aircraft Interface Testing

The avionics interface between LNAS and the Airbus A320neo aircraft was implemented and first tested on ground at SWISS on **February 18, 2021**.

LNAS HMI Improvement

The LNAS HMI on the EFB consists primarily of a status bar showing the timing and location of vertical mode changes (OPEN DES, V/S), speed mode changes, and aircraft configuration changes (flaps/slats and landing gear). Additionally, the vertical profile can be visualized to increase situational awareness by the flight crew.

Numerous improvements to the existing LNAS HMI were implemented for the ALBATROSS demonstration flights and tested intensively on the AVES research simulator in Braunschweig beforehand on **June 5, 2022**. After successful testing, videos were produced to enable the project team to conduct appropriate pilot training due to Covid's travel restrictions and the airline's internal constraints that required on-screen training instead of on-site training in Braunschweig. For that reason, the funding allocated to the simulator training had been shifted to support additional efforts to prepare and conduct simulator trials to produce required training videos. Predefined ALBATROSS sequences were implemented and tested on the simulator prior to the actual demonstration flights.

The most important interface functionalities are described below. It should be noted that LNAS is a demonstration environment and parallel SESAR projects (SESAR ER4 DYNCAT) are working on the implementation into a Flight Management System (FMS).

LNAS calculates a Continuous Descent Approach (CDA) profile that consists of the following segments (see Figure 59):

1) **OPEN DES Segment**: The first segment is in OPEN DES, which leads generally to a lower thrust setting than a geometrical managed descent (depending on the FMS idle factor).

2) **CDA DECEL with V/S -500 ft/min Segment**: LNAS uses a slope descent segment with -500 ft/min for deceleration. This makes the deceleration segment longer than in a level segment, but reduces noise emission on ground.

3) **G/S Segment**: LNAS calculates to intercept the glideslope at FAF or slightly before FAF (depending on the energy state). The target speed at glideslope intercept is defined by the

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pilot. For the ALBATROSS demonstration 170 kt was used which provides a constant-speed idle-thrust segment in CONF 2.

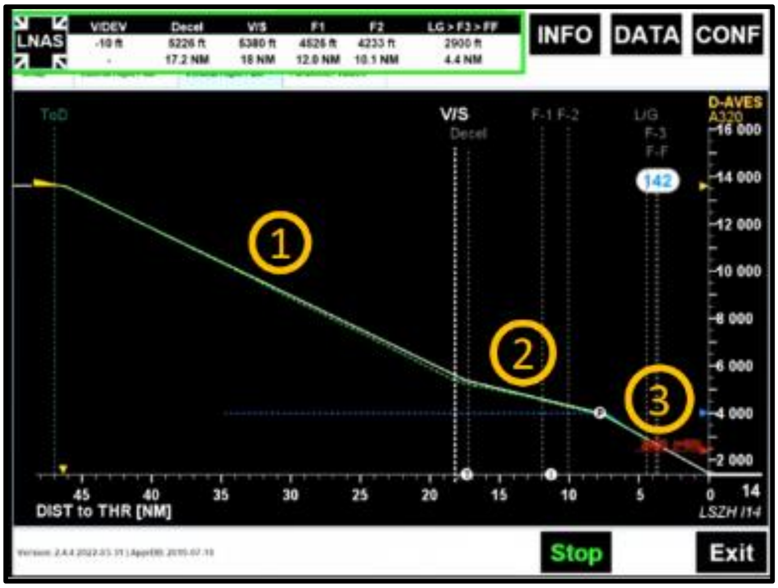


Figure 59: The 3 segments of the LNAS Advanced CDA computation.

All LNAS information is displayed on the so-called LNAS status bar. It is an overlay bar that can be displayed on top of the approach chart or any other EFB application.

Figure 60: LNAS status bar on top of the approach charts.

LNAS calculates two different vertical profiles (see Figure 61):

1) **Backward Calculation**: The reference profile in white is based on a simple performance model and calculated along a straight line. It is updated at 10Hz rate and available as soon as the LNAS application is running. The profile is adjusted to the actual airspeed. It is displayed in white dashed as long as forward prediction is not started. The backward profile is frozen after the start of Forward Prediction. The reference profile then becomes full white.

2) **Forward Prediction**: This shows the actual predicted vertical profile in green dashed. It is based on a 6DOF full-flight simulation model with 2Hz update rate. It takes into account curve flight dynamics, ballooning, etc.

Figure 61: Display of the backward profile (white) and the forward prediction (green dashed).

3) **V/DEV Indication**: The V/DEV is the difference between actual position and the backward-profile. It is displayed on the LNAS status bar. It becomes amber if no G/S intercept is possible between localizer intercept point and the FAF (based on a -500ft/min DECEL segment).

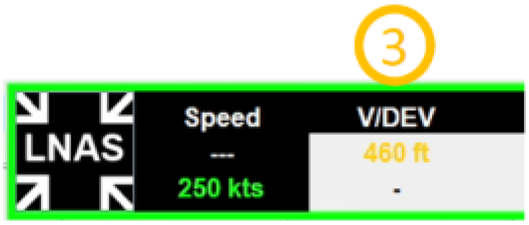


Figure 62: V/DEV indication on the LNAS status bar.

In the Forward Prediction, LNAS calculates dynamically the location (distance from threshold and altitude) of the pseudo-waypoints (see Figure 63).

1) **V/S and DECEL**: The change from the OPEN DES segment to the deceleration segment is indicated by the waypoints DECEL and V/S. In a low-energy situation, the V/S segment is extended with a thrust segment until the initiation of DECEL to prevent level off's. However, on the LNAS status bar, the sequence DECEL → V/S remains. Low-energy can be recognized if the DECEL distance is smaller than V/S distance (in Figure 63: 16.7 NM vs. 19 NM). At the DECEL pseudo-waypoint the G/S intercept speed of 170 kt is selected at the FCU.

2) **Configuration Changes**: F1, F2, LG/F3/FF. The position of F1 and F2 corresponds to where the aircraft reaches green dot and S-speed during DECEL.

Figure 63: The pseudo-waypoints of the LNAS status bar.

LNAS does not have access to the FMS flightplan information. Therefore, it is necessary to define manually the lateral flightplan additionally to the FMS flightplan in order to calculate the vertical profile (see Figure 64). LNAS contains the ALBATROSS waypoint sequences as pre-defined flightplan. Any flightplan can be manually defined or manually modified. The active flightplan is automatically sequenced (flyby or overfly). It is used for both, the forward prediction and backward calculation.

Figure 64: Definition of the waypoint sequence in LNAS for the ALBATROSS demo flights along a closed-path PBN-to-ILS trajectory.

The LNAS status bar contains all necessary information to execute an LNAS approach. It was fine-tuned for the purpose of the ALBATROSS demonstration flights.

Figure 65: The LNAS status bar.

The status bar contains the following information to execute an advanced CDA:

1) **Speed**: Displays the target speed and vertical speed requested by LNAS for the next pilot action, becomes green if FCU SPD = LNAS SPD.

2) **V/DEV**: Difference between actual aircraft altitude and the simple backward computed vertical profile. Becomes yellow if the forward prediction profile does not find a glideslope intercept with -500 ft/min on the e.g. ZH413 – OSNEM leg.

3) **250 kts**: Location (always FL100) of speed reduction to 250 kts. Since the ECON descent speed with NEO is around 250 kts, there is no significant deceleration observed on the NEO flights at FL100.

4) **DECEL**: Location and altitude of initiation of deceleration from initial TMA speed (ranging from 220 kt to 250 kt) to glideslope intercept speed (e.g. 170 kt).

5) **V/S**: Equal to DECEL, except in low-energy situation where there is a power-on segment with -500 ft/min before DECEL.

6) **F1, F2**: Location and altitude of F1 and F2 extension (green dot speed and S-speed). F2 may be extended below S-speed according SWISS OM B policy to avoid unnecessary engine spool-up.

7) **LG > F3 > FF**: Location and altitude of the single waypoint for landing gear and F3/Flaps Full extension.

Operational Risk Evaluation

Prior to conducting the LNAS demo flights, an internal SWISS operational risk evaluation was conducted on **September 7, 2021**, to identify potential mitigations. The following risk mitigations were defined:

- Optimized HMI and training program to improve data acquisition and to reduce pilot head down time.
- Training program to include awareness of LNAS system limitations.
- Training program to include awareness of data entry errors and consequences.
- Flight model validation with past flight data. LNAS validation in shadow-mode during actual flight but not used as active guidance.
- Handpicked group of crewmembers for demonstration flights. LNAS to be used only by trained flight crewmembers.
- LNAS to warn flight crew if data quality not reliable.
- Have a backup EFB readily available in the checklist stowage compartment.

Evaluation Pilot Recruitment

On **March 8, 2022**, SWISS launched an internal call for volunteers to fly the ALBATROSS demo flights using LNAS. Of a total of around 300 pilots, 44 volunteered to take part in these demo flights. The decisive factor for participation was that an appropriate training syllabus had been worked through. The training program included the study of exemplary flights recorded on a full-flight simulator and a familiarization with LNAS before the actual execution of the LNAS-assisted approaches to runway 14 in Zurich.

In the training syllabus, videos of approaches were provided for the following situations:

- General introduction to the software
- How to enter wind and a flightplan
- How to correct a high energy situation with speedbrakes until the forward prediction displays a valid solution (closed line to glideslope)
- How to deal with low-energy situations
- How to deal with tactical early speed reductions assigned by ATC

Approval from Civil Aviation Authority

In addition to the mitigations from the risk evaluation, a flight data monitoring process was defined with regard to approach stabilization as a prerequisite for the CAA approval. As a result, CAA approved the conduct of the ALBATROSS demo flights using LNAS on **August 29, 2022**.

Skyguide Operational Service Order

On **June 27, 2022**, Skyguide published an Operational Service Order to all air traffic controllers, which enabled the start of Phase 1, the reference flights along the closed PBN-to-ILS trajectory.

Today, there is no RNAV transition to Runway 14 at Zurich Airport. This means that all approaches are always guided by radar vectoring. With the ALBATROSS demo flights, a temporarily closed procedure was made possible for the first time to this runway.

The following operational procedures were defined in the service order for the demonstration flights. A specific instrument flight procedure had been defined for this purpose, called «**ALBATROSS APPROACH**».

Flight crews were able to request an ALBATROSS Approach on initial call to APP (approach control) and only when landing runway 14 is in use (ILS APCH).

The clearance for an ALBATROSS APCH was given if traffic permits and within the following pre-defined time windows:

- Mon-Fri: 07:00-07:45LT; 09:00-10:00LT; 13:00-15:30LT; 17:30-20:30LT.
- Sat/Sun/Pub. Holidays: 09:00-10:00LT; 13:00-15:30LT; 17:30-19:30LT.

When approving an ALBATROSS APCH, the ATCO cleared the flight via one of the following predefined ALBATROSS waypoint sequences:

1) **RILAX ALBATROSS sequence**: RILAX – ZH382(=SONGI) – TRA – ZH413 – OSNEM
2) **AMIKI ALBATROSS sequence**: AMIKI – TRA – ZH413 – OSNEM
3) **GIPOL ALBATROSS sequence**: GIPOL – ZH412 – ZH413 – OSNEM

The final intercept was always flown on own navigation.

Special ALBATROSS Phraseology

For the purpose of the ALBATROSS demonstration flights, a special phraseology was defined:

> **Flight Crew**: ZURICH ARRIVAL, SWISS (flight identification), PASSING (level), DESCENDING TO (level), AIRBUS 320 NEO, INFORMATION ZULU, REQUEST ALBATROSS APPROACH.
>
> **ATCO**: SWISS (flight identification), ZURICH ARRIVAL, CLEARED VIA RILAX ALBATROSS SEQUENCE FOR ILS APCH RWY 14, [DIRECT TO ZH382], [DESCEND TO FL110].

To enable an optimum descent profile with idle power, the following speed control scenarios were given by ATC:

«**NO [ATC] SPEED RESTRICTIONS**»: Without ATC speed restrictions, the initial approach is be flown with around 250kt IAS. Deceleration will commence approx. 8NM before OSNEM to overfly OSNEM at 170kt IAS.

«**REDUCE SPEED TO 220 KNOTS OR LESS**»: The initial approach is be flown with 220kt IAS. Deceleration to 170kt IAS will commence approx. 4NM before G/S intercept.

The waypoint sequence used for the closed-path PBN-to-ILS ALBATROSS flights looks as follows:

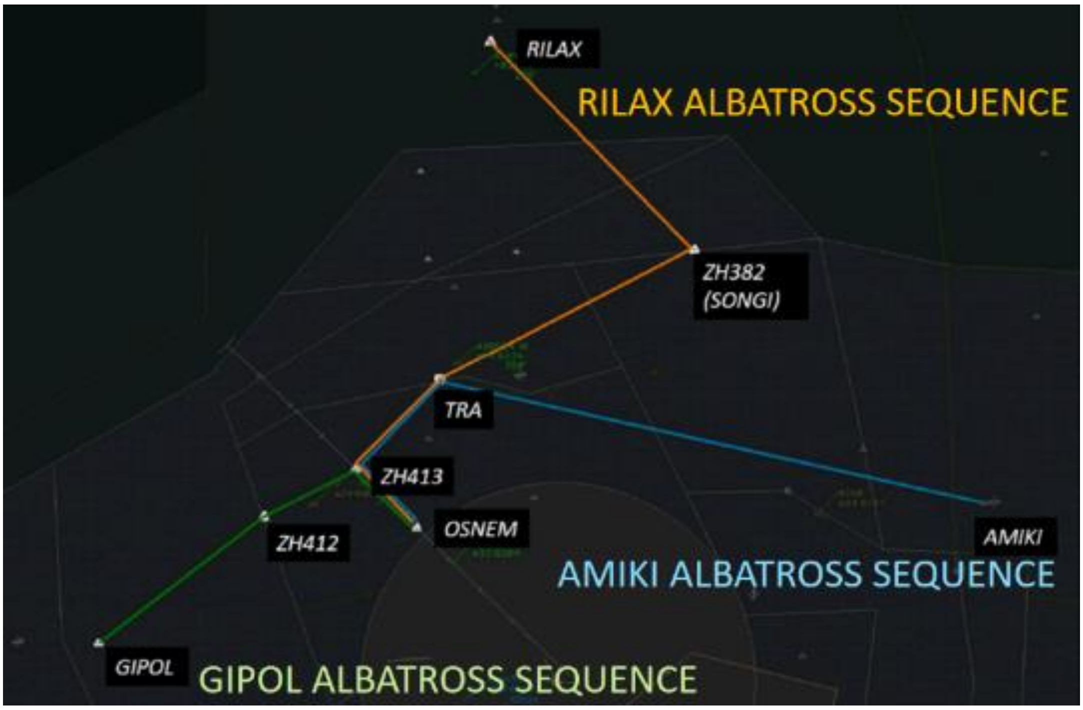


Figure 66: ALBATROSS waypoint sequence for the closed-path PBN-to-ILS approaches.

Demonstration Flights

Phase 1 (Reference flights)

On **July 7, 2022**, the first closed PBN-to-ILS approach to RWY14 along the mentioned so-called ALBATROSS sequence was conducted as part of the reference flight data set. The reference flights are conducted without LNAS assistance. Different to the baseline flights, for the reference flights the pilots have full knowledge about the distance-to-go (DTG) and may adjust their energy management to achieve glideslope intercept at a speed of around 170 kt. The reference flights of Phase 1 allow to demonstrate the impact of a closed-path procedure compared to radar vectoring.

Phase 2 (Optimum flights with LNAS)

On **September 21, 2022**, the demonstration flights with use of LNAS started. The LNAS flights are the culmination of the demonstration flights in this exercise. During these flights, the defined PBN-to-ILS trajectory is flown with the support of LNAS. This means that the energy management (determination of the time of speed reduction, time of landing gear extension) no longer has to be estimated by the pilots but is calculated by LNAS. Phase 2 was completed on **December 1, 2022**.

C.1.2 Summary of Demonstration Exercise EXE-03 Demonstration Objectives and success criteria

The objective of EXE-03 'Energy-optimized descent profiles' is to demonstrate fuel reduction solely by optimizing the vertical descent profile and speed profile for a specified lateral path. No lateral optimizations are considered in this exercise.

During the demonstration, the fuel flow values of the engines are recorded. An integration in the range between the stabilization altitude of 1'000 ft AGL and the begin of intermediate approach allows a statement about the absolute and average fuel consumption with and without LNAS assistance:

$$Fuel\ Save = \frac{\overline{\sum Fuel_{LNAS\ OFF}} - \overline{\sum Fuel_{LNAS\ ON}}}{\overline{\sum Fuel_{LNAS\ OFF}}}$$

Two ALBATROSS objectives were addressed by EXE-03:

OBJ_VLD_ALBATROSS_001: To enact operational procedures (applicable under specific operational circumstances) that achieve a reduction of CO_2 and noise emissions during final approach.

> Success criteria: Over the duration of the " LNAS-CDA along closed-path PBN-to-ILS" live trials (Q3/Q4 2022) measure a reduction of CO_2 emissions on the production flights arriving to Zurich ZRH (the procedure was implemented on runway 14).

OBJ_VLD_ALBATROSS_002: To apply on as many concerned flights as possible, during initial, intermediate and final approach procedures (devised as part of objective No. 1) achieving a reduction of CO_2 emissions.

> Success criteria: The trials have the purpose to confirm, in practice and on a significant scale, the feasibility of the concept: show that pilots and ATCOs correctly handle the procedures that have been designed, coded and published.

C.1.3 Summary of Validation Exercise EXE-03 Demonstration scenarios

The EXE-03 reference scenario is based on approaches at Zurich Airport with the same aircraft type and onto the same runway.

The EXE-03 solution scenario is based on vertical profile optimization and speed profile optimization for an approach with closed-path lateral track. The solution scenario uses the LNAS tool to calculate the following pilot action steps:

1) Speed reduction to 250 kts (or less according ATC) when passing FL100
2) Calculation of the optimum time to initiate speed reduction from 250 kts (or less) on a continuous descent segment within the TMA through reduction of vertical descent angle with engine thrust in idle

3) Calculation of the best time for aircraft configuration changes to achieve stabilization with final approach speed at 1'000 ft AGL

These recommendations for pilot action are displayed to the pilot on an EFB using the LNAS demonstration software.

C.1.4 Summary of Demonstration Exercise EXE-03 Demonstration Assumptions

For the demonstration flights with LNAS, a temporary closed-path PBN-to-ILS procedure was defined with Skyguide for Zurich Airport runway 14. This allows the LNAS optimization algorithm to use as input value the accurate value of the remaining flight path distance. Without complete knowledge of the path distance, vertical optimization is not possible.

Identifier	Title	Type of Assumption	Description	Justification	Impact on Assessment
#1	Lateral path	Predefined lateral path	The pilot assistance system LNAS requires accurate information about the remaining flight distance.	To perform vertical profile and descent speed profile optimization, the lateral path has to be known.	low
#2	Number of LNAS-CDA approaches for comparison study	Approach number	Over 100 reference and 100 valid LNAS-CDA approaches needs to be flown on Swiss A320 Neo aircraft to evaluate fuel and environment efficiency	DLR expects 100 valid approaches per approach type and Airport/Runway as sufficient for evaluation	low

Table 24: Demonstration Assumptions overview

C.2 Deviation from the planned activities

The application of the closed-path PBN-to-ILS, the so-called ALBATROSS sequence, proved to be challenging. As an additional constraint, the demonstration flights were required to have no tactical speed interventions by the ATCOs. This further shifted the time window outside of the peak times. At the same time, the Phase 2 LNAS flights required that several requirements coincided simultaneously:

- Predefined time window outside peak hours
- Trained pilot (part of the evaluation pilot group)

- Aircraft A320neo (6 aircraft at SWISS at time of demonstration flights)

C.3 Demonstration Exercise EXE-03 Results

C.3.1 Summary of Demonstration Exercise EXE-03 Demonstration Results

The LNAS system provided its own data recording capability. In addition to the aircraft data (i.e. autopilot modes, navigation data, aircraft configuration, airspeeds and lever / switch positions, fuel flow), all pilot inputs to the system and all system recommendations were stored for evaluation. For the reference flights, recordings of comparable flights were taken from the standard FDR (flight data recorder). All data required for the analysis was provided in anonymous form.

In order to demonstrate the advantages of the pilot assistance system LNAS compared to conventional approaches without LNAS, each individual approach was examined for its comparability and validity. During the flight tests, the fuel flow rates of the engines were recorded. An integration in the area between the stabilization altitude and the beginning of the approach enables a statement to be made about the absolute and average fuel consumption. In order to understand the results more precisely, the configuration and speed management data as well as the system recommendations for action were also evaluated without losing focus of the stability conditions of the individual flights. The methods and the criteria for the evaluation are described in detail in D4.1.

For EXE-03, the baseline flights are normalized according the methods described in WP4. The same aircraft type (same engine) is used and flights onto the same runway.

A series of trials at Zurich Airport and other European airports for interface testing and for familiarization of the pilots involved was conducted. As described above, 3 routes have been agreed with Skyguide for testing. In addition to the familiarization and interface flights mentioned above, a total of **63** flights were conducted for the trial phase including familiarization flights. 7 flights were landed in Runway 28 and 34, respectively, and are no longer considered here in the analysis. **13** flights were made without LNAS support along the PBN-to-ILS procedure and served as reference flights in the evaluation.

Objective ID	Title	Success Criterion ID	Success Criterion	Sub-operating environment	Exercise Results	Objective Status
OBJ_VLD_ALBATROSS_001	Greener descents	CRT_VLD_ALBATROSS_001	Application of operational procedures that achieve a reduction of CO_2 during final approach.	TMA	Performed	Achieved

OBJ_VLD_ ALBATROSS_002	Demonstration flights	CRT_VLD_ALBATROSS_002	Apply on as many concerned flights as possible, during initial, intermediate and final approach.	TMA	Performed	Achieved

Table 25: Exercise EXE-03 Demonstration Results

Summary of EXE-03 results with regard to vertical and speed profile

Lateral paths of PBN-to-ILS compared to radar vectoring

The following graphic shows the plan view of the Baseline Flights (grey), the Reference Flights (magenta), and the Optimum Flights with LNAS (blue). It is well seen how the reference and optimum flights follow the PBN-to-ILS procedure.

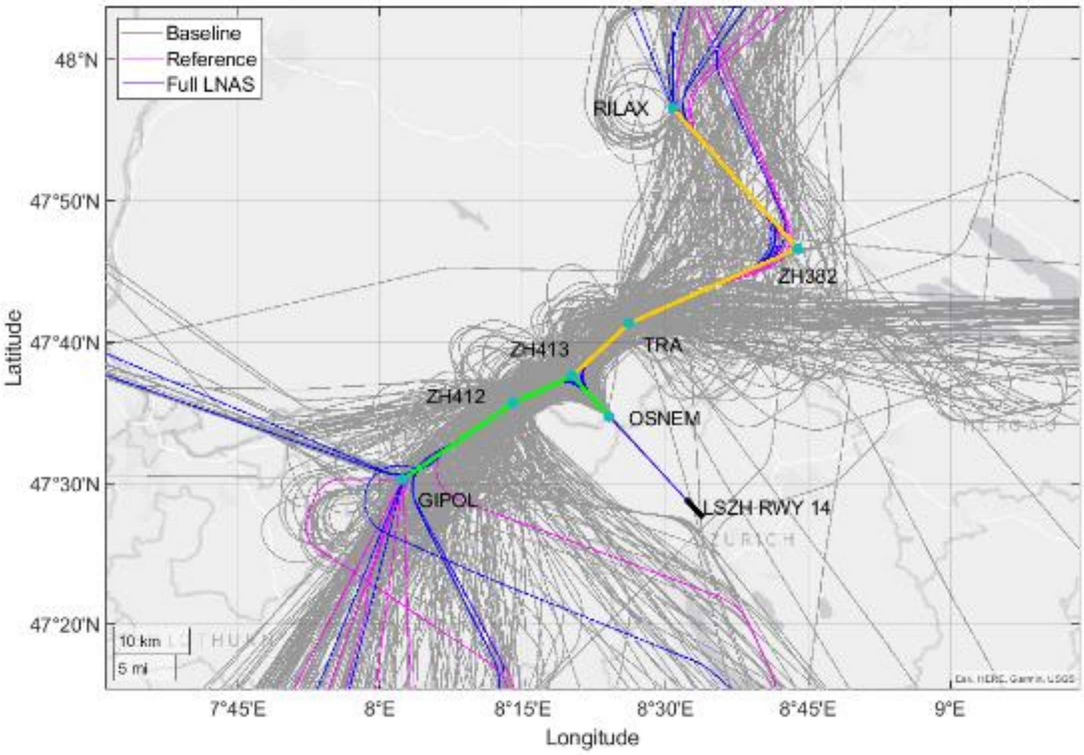


Figure 67: Baseline flights under radar vectoring vs. PBN-to-ILS procedure (without LNAS in magenta and with LNAS in blue) to RWY14 inbound southwest via GIPOL in green and inbound north via RILAX in yellow.

Vertical profiles of PBN-to-ILS compared to radar vectoring

Figure 68 displays the vertical profiles for the reference flights (PBN-to-ILS without LNAS) together with the baseline flights. It appears that some level offs could not be avoided for the reference flights in a manually-controlled energy management. In case of the reference flights, such profiles can be interpreted as a sign of conservative flying in order to achieve the speed constraint as glideslope intercept. The lateral path was known a-priori by applying the PBN-to-ILS procedure. Their target was to reach OSNEM (8 NM to threshold) as fuel-efficient as possible, respecting the standard configuration sequence according FCOM and intercepting the glideslope with a target speed of 170 kt.

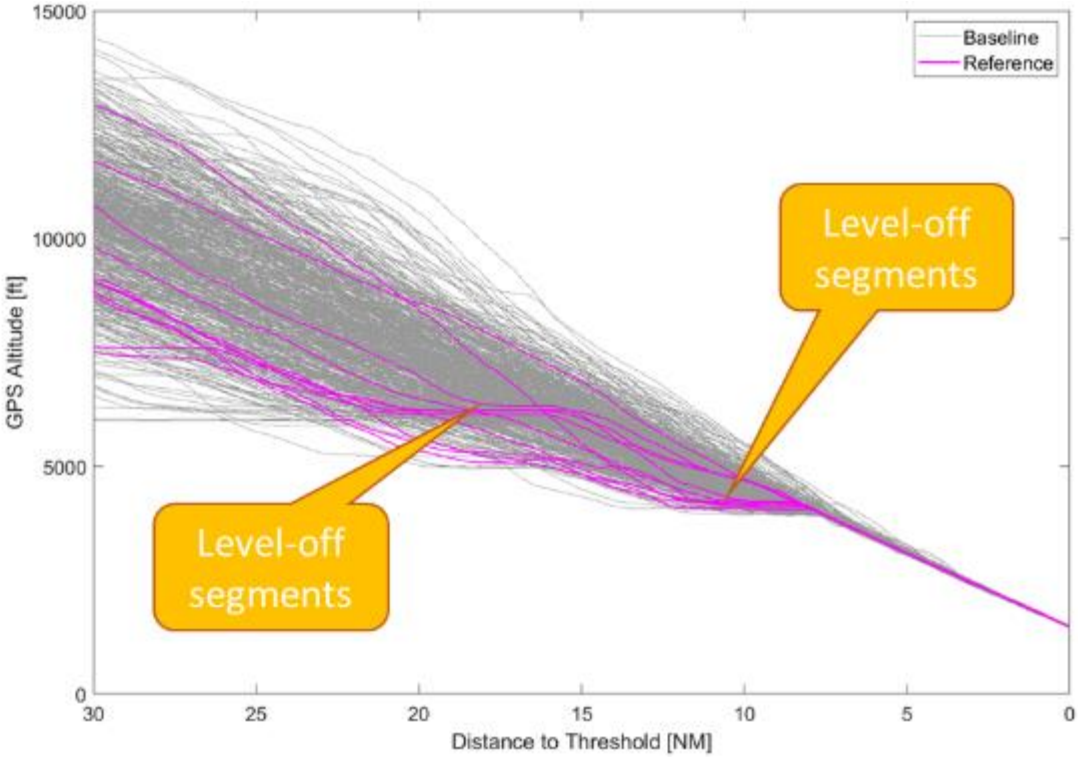


Figure 68: Vertical profiles of reference flights together with baseline flights along the projected distance to go.

Figure 69 displays the vertical profile of the baseline flights and the optimum flights along the PBN-to-ILS using LNAS flights for the last 30 nm until touchdown. It can clearly be seen, that level-offs were entirely avoided for all LNAS flights. The pilots were able in each case to perform continuous descent approaches (CDA). It can also be observed that the V/S segments with a sink rate of 500ft/min are clustered horizontally. The deceleration point is very predictable in a range between 19 to 21 NM for all LNAS flights. From 16 NM all flights are in a V/S segment approaching the glideslope before or at the FAF. Such a CDA profile helps to facilitate the energy management to intercept the glideslope in a suitable energy state and renders the flight very predictable for ATC.

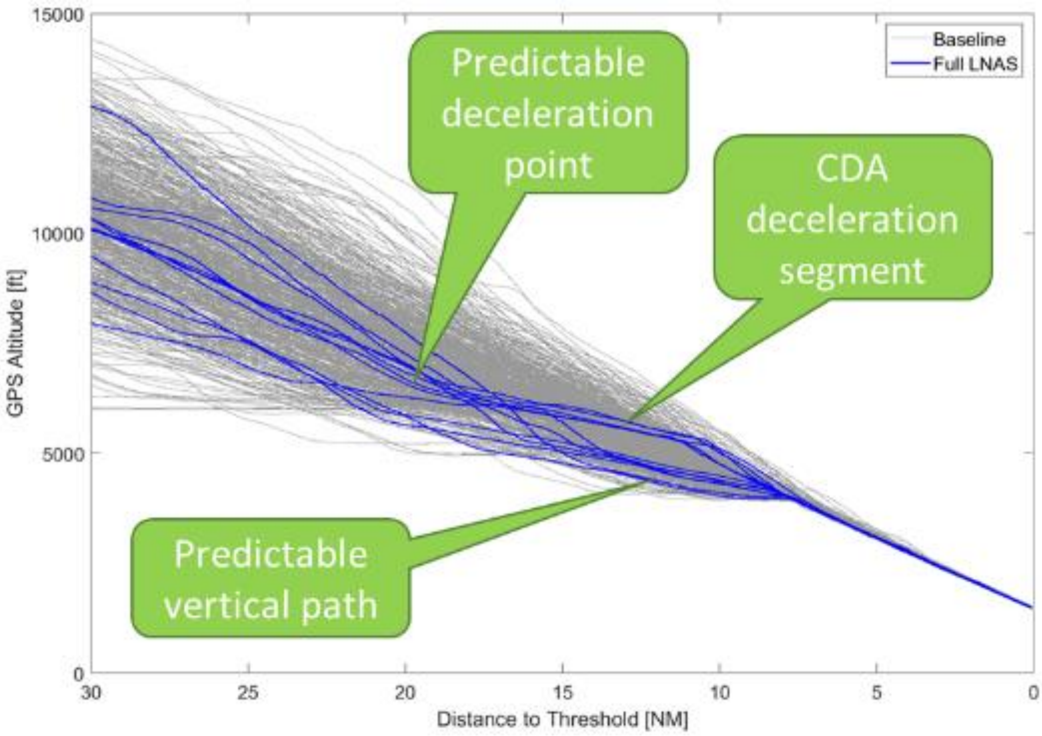


Figure 69: Vertical profile of optimum flights using LNAS along the PBN-to-ILS vs. baseline flights under radar vectoring along the projected flight path.

When comparing all flights along the closed-path PBN-to-ILS trajectory with LNAS (optimum flights) vs. without LNAS (reference flights) the benefit of a predictable vertical flight path particularly on the last 20 NM becomes clearly visible (Figure 70). The recordings are performed from two different directions. With predominantly westerly wind conditions, this yields two clusters of deceleration points for the flights with LNAS.

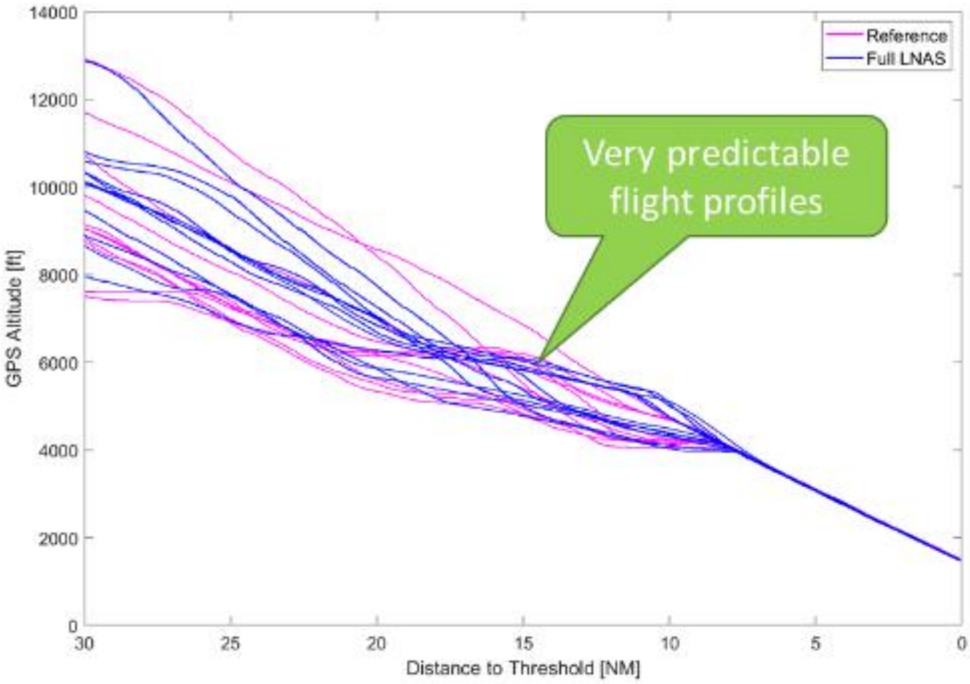


Figure 70: PBN-to-ILS reference flights without LNAS (magenta) and PBN-to-ILS optimum flights with LNAS (blue). The approaches shown are from both directions east and west, with predominantly westerly wind conditions which affects the location of the deceleration point.

Speed profiles with and without LNAS of PBN-to-ILS compared to radar vectoring

For the baseline flights, all flights are considered which includes flights with tight speed restrictions and flights without any speed restrictions.

The reference flights (Figure 71) were not entirely free of speed restrictions, the target was to reach the glideslope at a speed of around 170 kt to ensure a standard configuration sequence. Flights without any speed restrictions tend to be high on energy on the last 15 NM and hence require deviation from the standard configuration sequence (e.g. gear down before high lift devices or use of speed brakes). We can observe that pilots comply with the speed target in the reference flights at 8 NM but some of the flights reached this speed already very early during the approach.

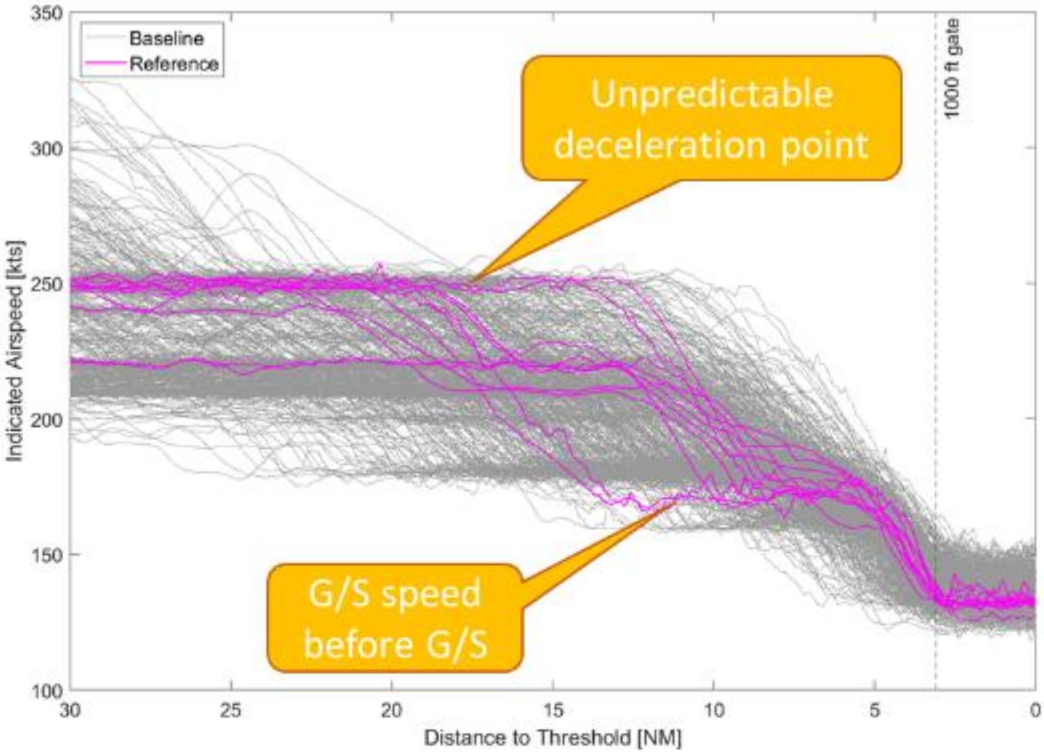


Figure 71: Indicated airspeed for the reference flights along the PBN-to-ILS trajectory and the baseline flights under radar vectoring.

The speed profiles become much more predictable for the optimum flights when using the help of the pilot assistance system LNAS, see Figure 72.

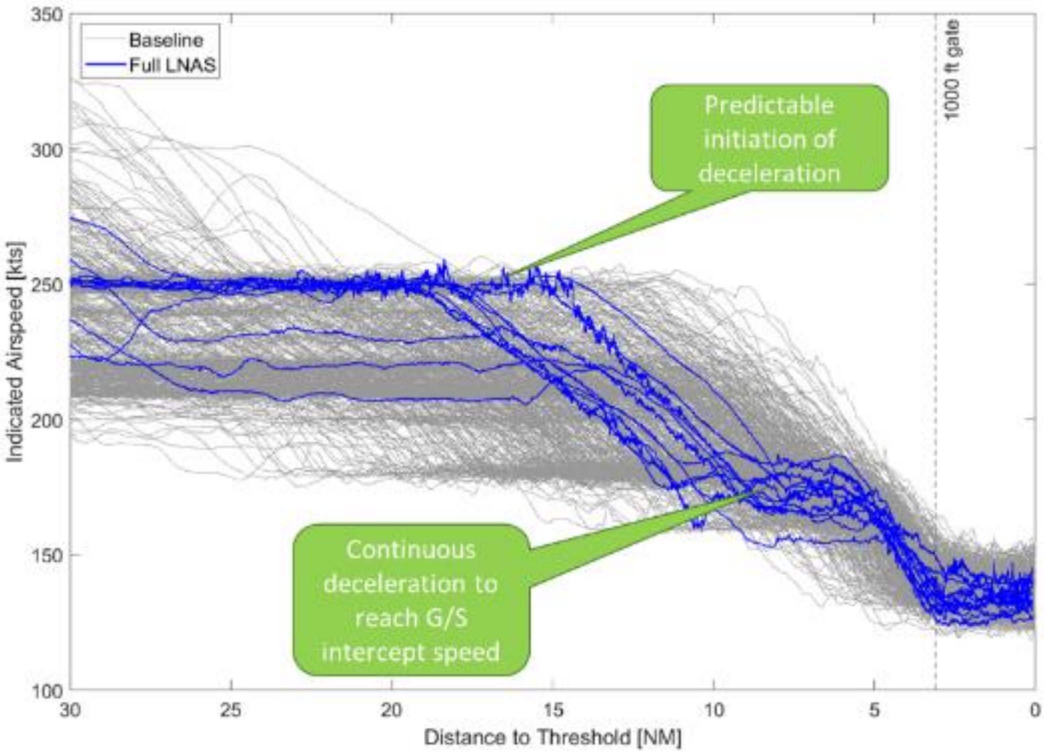


Figure 72: Speed profiles for optimum flights with LNAS (blue) along PBN-to-ILS trajectory vs. baseline flights under radar vectoring.

The comparison of reference flights to the optimum flights with LNAS shows an even further reduced spread of the speed distributions, see Figure 73. The full LNAS speed profiles are repetitive and speed reductions are almost linear. The intercept speed for the glideslope is predictable and the spread during the final approach minimized.

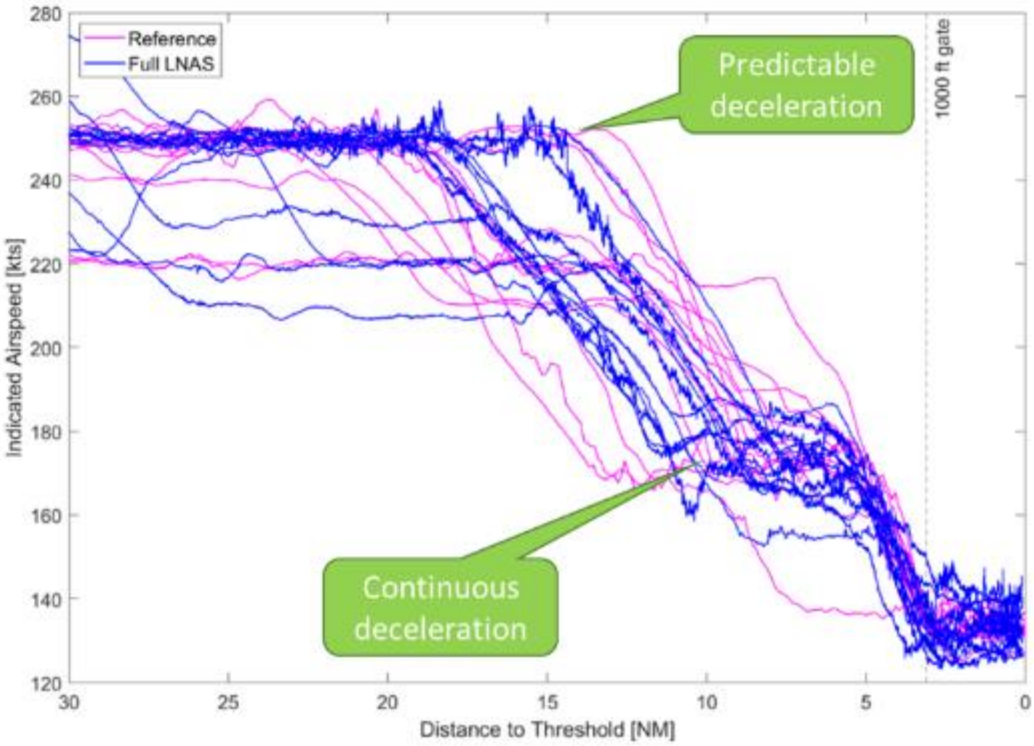


Figure 73: Recorded indicated airspeed signals for the reference and the full LNAS Flights.

Thrust profiles of PBN-to-ILS with and without LNAS compared to radar vectoring

Figure 74 displays the N1 values for N1 for the reference flights in contrast to the baseline flights. In a short segment from 15 to 13 NM before threshold all reference flights along the PBN-to-ILS trajectory are observed in idle thrust. The thrust profiles allow to assess the 1’000 ft stabilization criteria. One of the criteria is to be at the defined approach speed, with engine thrust out of idle, and all the configuration set. It can be well seen, that with the assigned target to be stabilized at 1’000 ft, the reference flights complied well with this requirement.

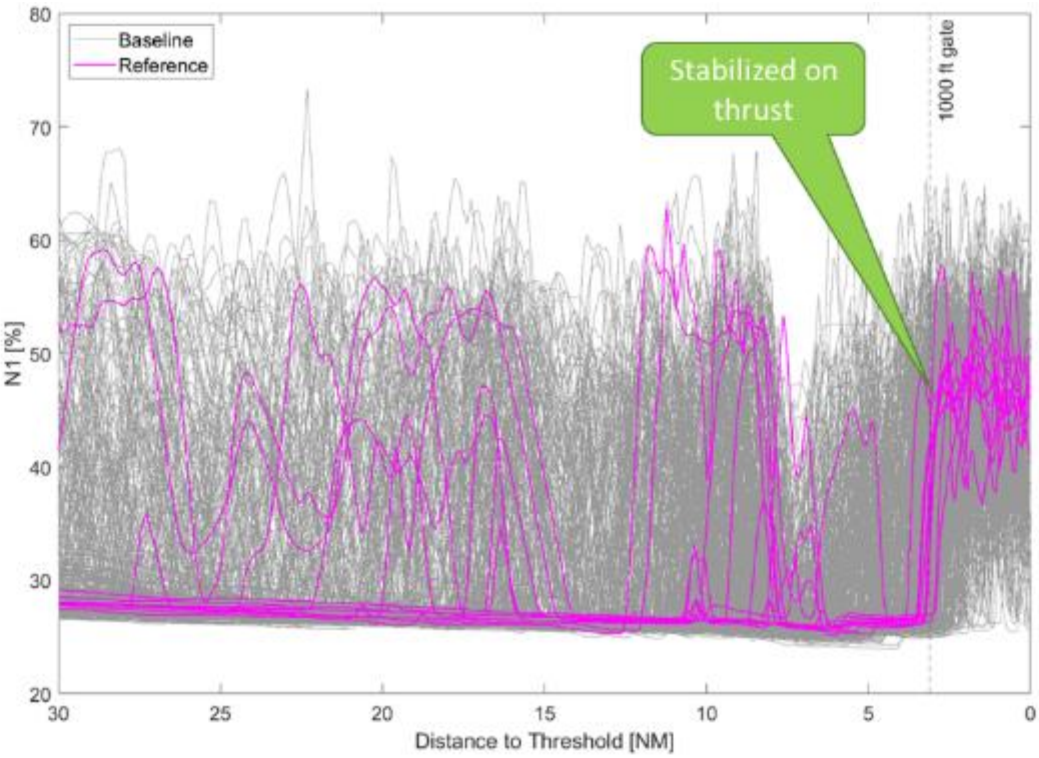


Figure 74: Fan speed N1 for reference flights without LNAS along the PBN-to-ILS trajectory and baseline flights under radar vectoring.

The thrust profiles for reference flights without LNAS and the optimum flights with LNAS are compared in Figure 75. The main observation is the avoidance of high thrust settings with LNAS assistance between 15 NM and glideslope intercept. Without LNAS it is very difficult to assess the aircraft's energy state to and thus to avoid a too early speed reduction and to achieve a continuous deceleration before glideslope intercept.

A minor peak of thrust increase can be observed at the FAF (glideslope intercept). This is due to the change of configuration with a simultaneous target speed at glideslope intercept. More precise wind information may prevent such a thrust increase. Furthermore, it has to be noted that pilots used LNAS with little training. Further training may even further improve the thrust profiles.

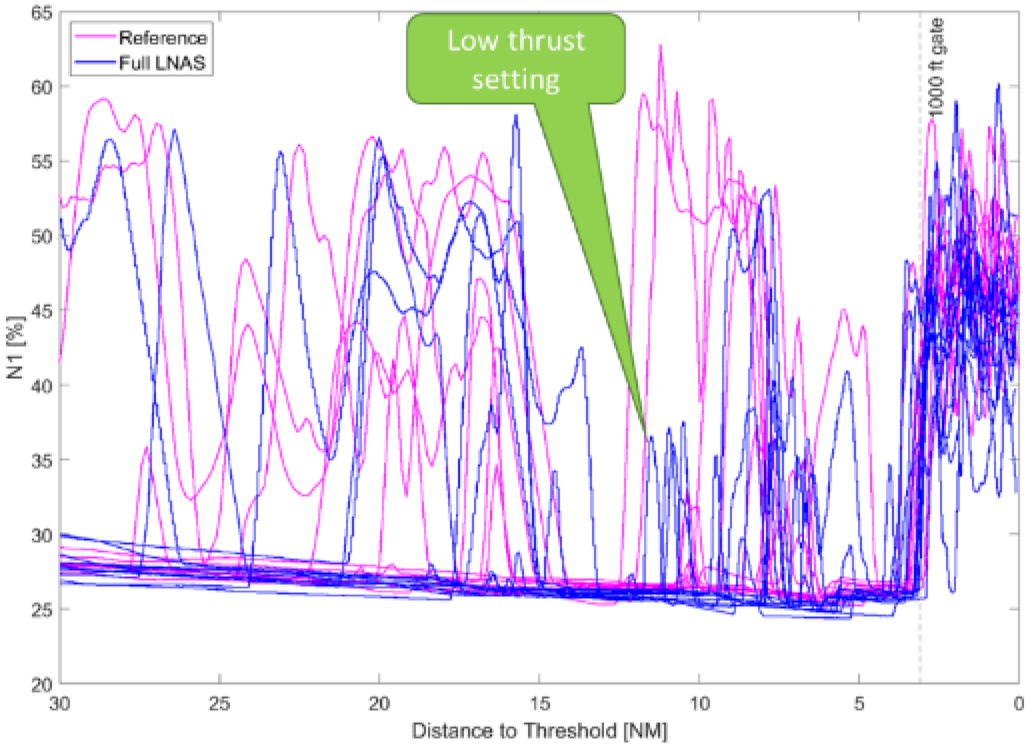


Figure 75: Fan Speed N1 for reference flights and baseline flights

Fuel burn with PBN-to-ILS with and without LNAS compared to radar vectoring

The following impacts on fuel consumption are observed for the demonstration flights with and without LNAS along the PBN-to-ILS trajectory compared to the baseline flights, see Figure 76.

It is important to state that the interpretation of the data must consider a manifold of aspects. The fuel consumption is computed from the threshold backward. Baseline flights that do not comply with the engine thrust stabilisation criteria (no spool-up at 1’000 ft AGL) yield an advantage compared to the reference and optimum flights. However, this effect in favour of the baseline flight is not considered in this report.

- The benefit of fuel consumption along the PBN-to-ILS trajectory compared between manually-controlled **reference flights** and system-guide **optimum flights** is 8.8% less.

- Due to the clearly defined target speed at glideslope intercept, the standard configuration sequence and strict 1’000 ft AGL stabilization criteria, the manually-controlled energy management **reference flights** along the PBN-to-ILS trajectory are more conservative and are using 2.9% more fuel than the **baseline flights**. This conservativism can be observed in the initial total energy (kinetic and potential, see Figure 76) at 30 NM of the reference flights which is lower than the baseline and optimum flights. Additionally, different to the baseline flights, the reference flights do not contain any high-speed approaches.

- On the other hand, for the **optimum flights** when using LNAS along PBN-to-ILS trajectory, this results in a fuel burn of 6.1% lower than the **baseline flights**. This result clearly shows how a system-guided energy management beats the manually-controlled approaches in terms of fuel efficiency along a PBN-to-ILS trajectory.

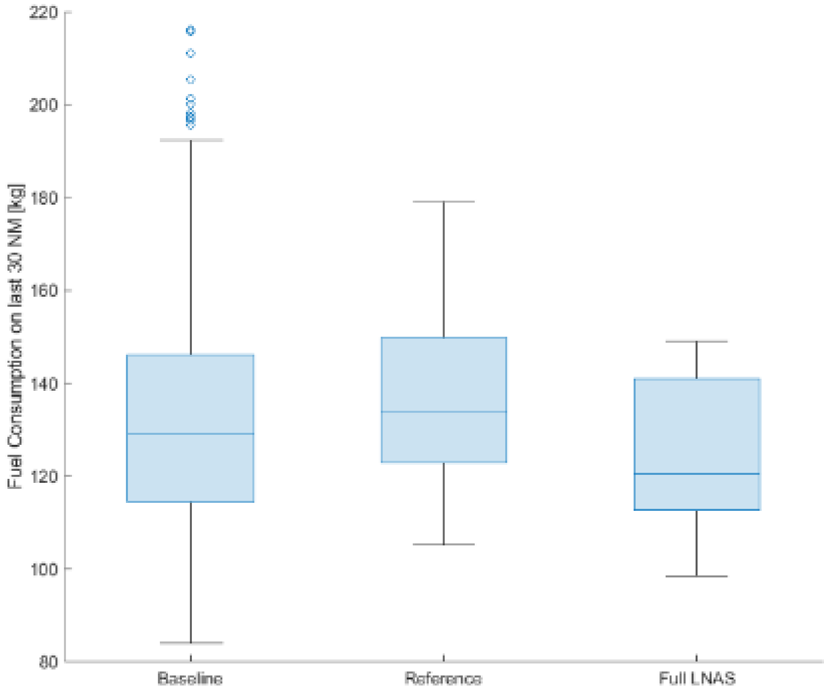


Figure 76: Fuel consumption (boxplot showing median framed by lower and upper quartile and whisker)

Figure 77 shows the fuel consumption for the last 30 NM along the trajectory. From 1'000 ft back to the glideslope intercept the same gradient can be found. The values presented in Figure 77 are the average fuel consumption values for all flights for one of the three groups.

- A first split appears at around 10 NM for the reference flights. This can be explained by the out-of-idle segments observed in the reference flights before G/S intercept for both higher amount of level segments and too early speed reduction.
- The second split is at roughly 15 NM. The fuel consumption until that distance is lower on the optimum flights due to the continuous deceleration of all LNAS guided approaches, which supports engine thrust remain at idle.
- The third split can be observed for the optimum flights at around 20 NM. This is due to a short constant speed segment along the V/S-500 ft CDA segment to join until the deceleration point and changeover to idle thrust.

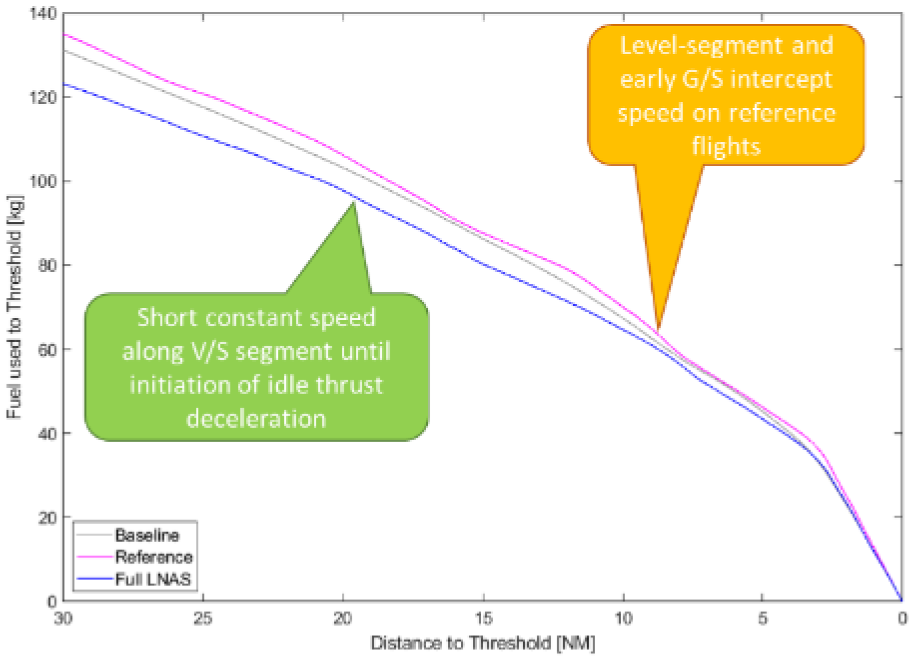


Figure 77: Fuel consumption over the final 30 miles along the flightpath

Information provided by Figure 77 must be further interpreted with the knowledge of the aircraft's energy state. The next Figure 78 shows the total energy of the baseline, reference and optimum flights. Since the reference flights in average start at a lower energy level, the fuel reduction effect is also lower.

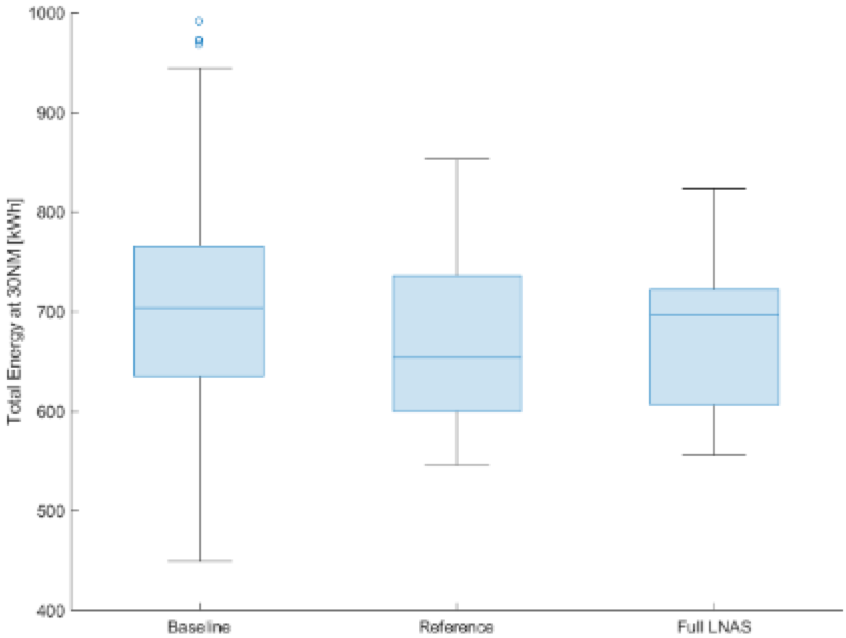


Figure 78: Total energy scheme at 30 NM to threshold for baseline, reference and optimum flights.

Aircraft configuration management of PBN-to-ILS with and without LNAS compared to radar vectoring

Speed profiles, thrust profiles and the resulting fuel burn are affected by the pilot's flightpath management as described in the FAA Advisory Circular 120-123. A first very interesting inside into aircraft energy management can be obtained by analyzing the use of speedbrakes. Speedbrakes are used to dissipate excessive energy. When applied at lower altitudes and closer to the runway, speedbrakes are a major contributor for an increase in noise emission.

In Figure 79 the application rate of spoiler is presented. The reference flights following the PBN-to-ILS trajectory show a higher tendency to correct flightpath or speed by deploying spoiler at a range of 15 to 10 NM to the runway. The usage of spoiler for the optimum flights with LNAS is to be found in an earlier phase of flight. The pilots approaching with high energy correct the flightpath already early. This has positive effects on noise emissions in low altitudes near the airport. Usage of spoilers shall be prevented or at least shifted to higher altitudes and higher distances from the final approach.

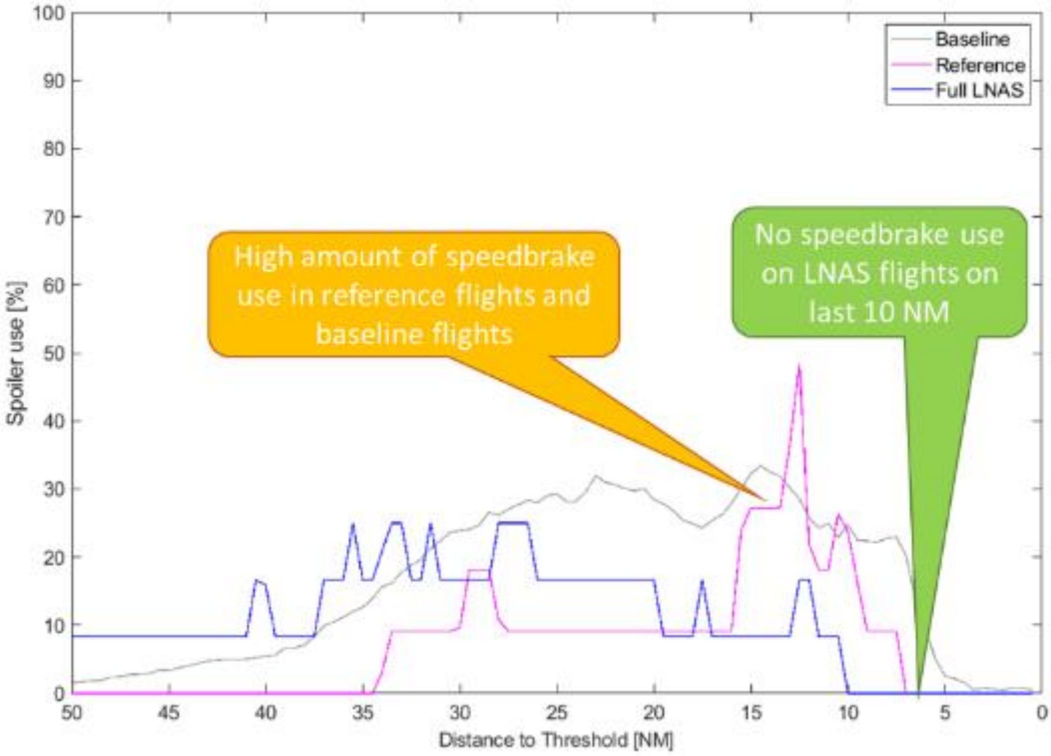


Figure 79: Application of spoiler in percentage according to the different groups of flights

In the setting of the first configuration in preparation of the landing phase, a high distribution can be found for the baseline flights. In contrast to that it can be found that the optimum flights using LNAS show a geographical accumulation mostly in the downwind segments, see Figure 80.

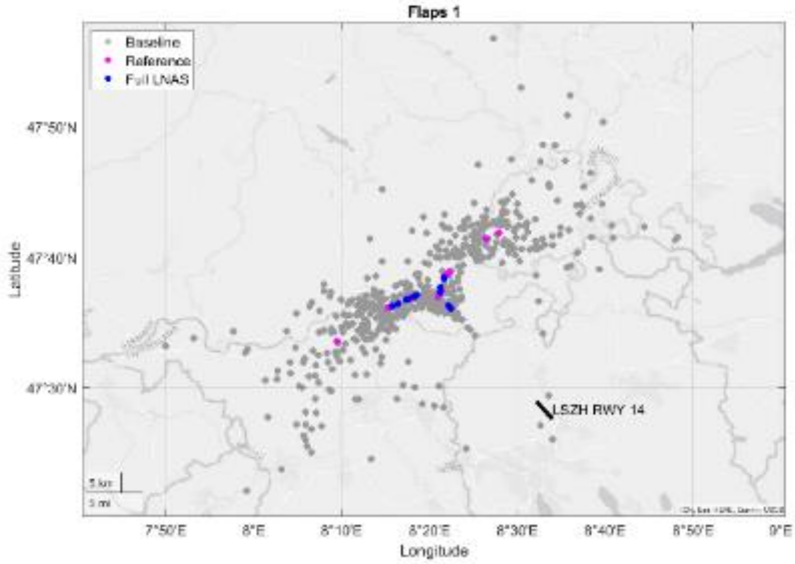


Figure 80: Locations of configuration changes to Flaps 1

Also, the positions along the projected trajectory are most condensed for the optimum flights with LNAS. The spread for the baseline flights as well as the reference flights is much higher, see Figure 81.

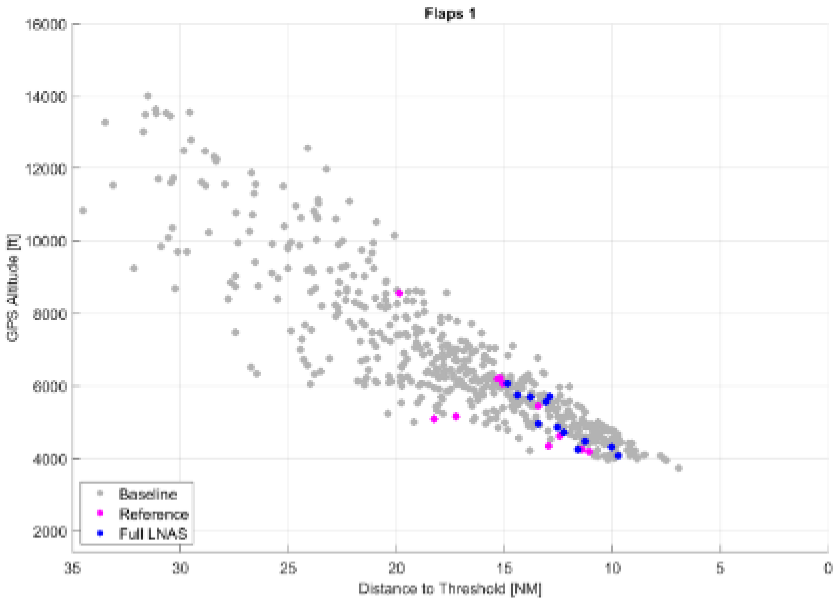


Figure 81: relative position and altitude of first configuration change to Flaps 1

The same con be found for the configuration change to Flaps 2, see Figure 82. Interestingly, there is the appearance of a plateau that indicates that some of the reference flights flew a horizontal segment while changing to configuration Flaps 2. Since LNAS prevents flying in such level segments, this is not observed on the optimum flights.

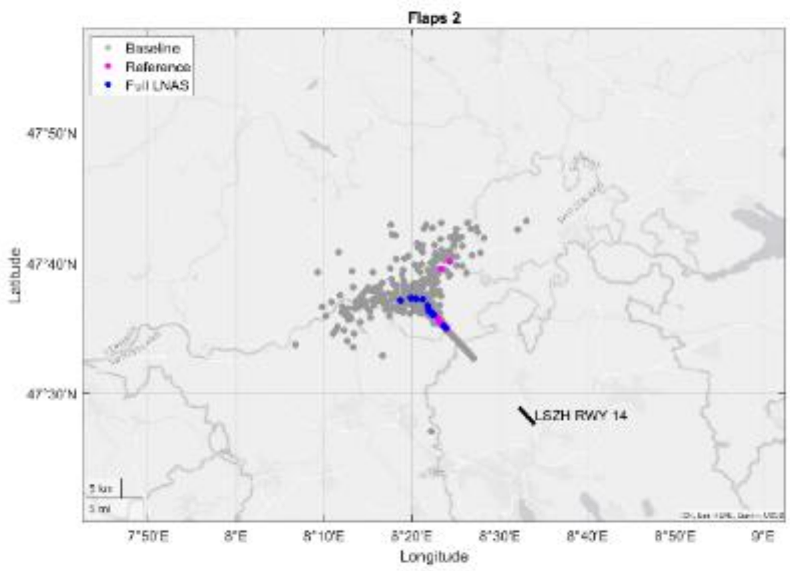


Figure 82: Position of configuration change to Flaps 2

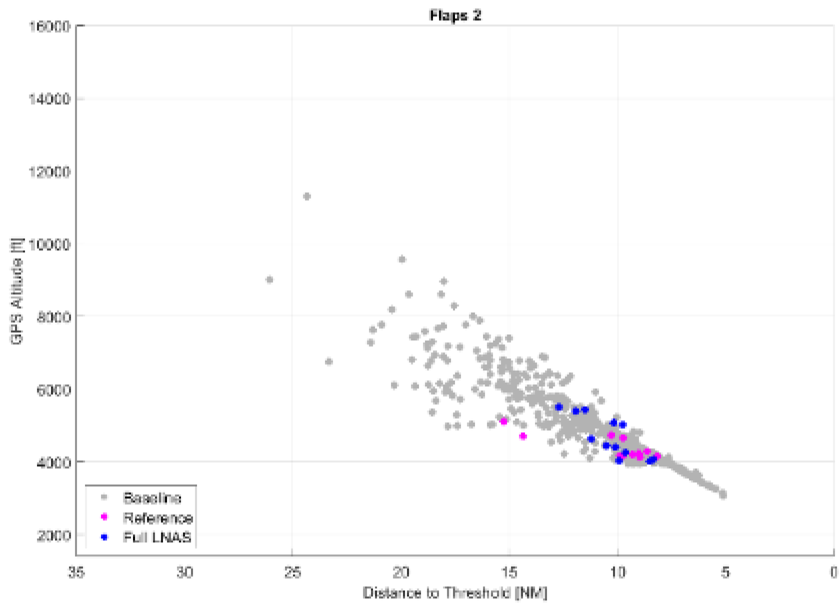


Figure 83: Relative position and altitude of configuration change to Flaps 2

LNAS recommends the extension of the landing gear to achieve a perfect stabilisation at 1’000 ft AGL with engine spool-up not before. This yields on average an extension point around 6 NM as shown in

Figure 84. The earliest landing gear extension with LNAS is at 6.5 NM. Outliers of the baseline flights are up to 12 NM before touchdown and for the reference flights up to 11 NM.

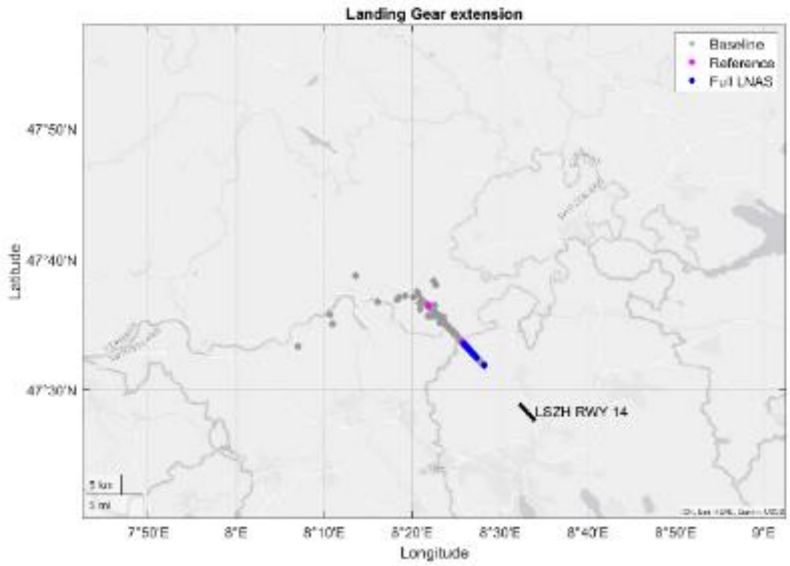


Figure 84: Position of landing gear extension

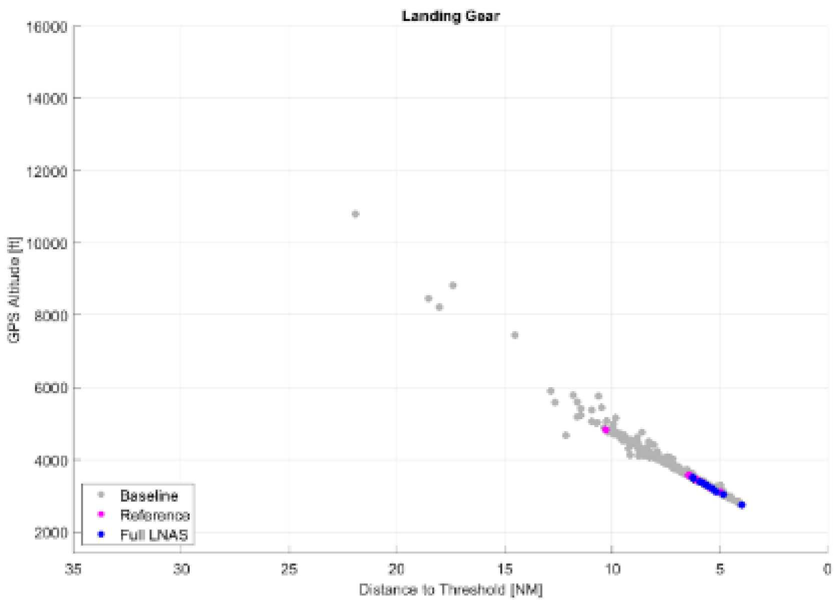


Figure 85: Relative position and altitude of landing gear extension

Environmental Assessment

The mathematical framework for environmental assessment of aircraft trajectories and the possibility to apply this assessment in a Python-based open-source manner was developed within the Sesar-EU project FlyATM4E (‘Flying Air Traffic Management for the benefit of environment and climate’). Concepts on future implementation of such advanced meteorological services into air traffic management and trajectory planning by relying on environmental change functions (ECFs), climate change functions (CCFs), and algorithmic climate change functions (aCCFs) are presented in Matthes et al. 2017, Dietmüller et al. 2023 and Matthes et al. 2023.

Prototypic algorithmic climate change functions, which provide spatially and temporally resolved information on aviation’s climate effects in terms of future near-surface temperature change (average temperature response), can be used to assess the climate effects of flight missions. These aCCFs are combined with meteorological input data obtained from e.g. numerical weather prediction models. aCCFs that provide a quantitative estimate of the specific climate effect of a climate agent, e.g. temperature increase per kilogram NO_x emitted (as NO_2), can be used for quantifying the climate effect, hence assessing environmental performance for the purpose of trajectory planning.

The weather dependent environmental assessment of flight trajectories in order to quantify the climate effect of air traffic needs the information on spatially and temporally resolved climate effect of aviation, and also the location of those regions that are highly sensitive to aviation emissions. Re-routing when planning for climate-optimized trajectories has a large potential to reduce the air traffic’s contribution to climate change by avoiding such climate hotspots. Even small changes in the flight trajectory can lead to significant reduction of the climate effect (see e.g. Matthes et al., 2017, 2020; Lührs et al., 2021; Castino et al., 2021; Rao et al., 2022; Dietmüller et al. 2023). The performance assessment of the KPI environment, more specifically environmental and climate effects, requires a quantitative estimate of the total non-CO_2 climate effect as a specific quantity (e.g. K per NO_x emitted) as four dimensional data set (latitude, longitude, altitude, time). This location and time dependent quantitative estimate can be generated by combining the individual aCCFs of water vapour, NO_x induced ozone and methane changes and contrail-cirrus to a merged non-CO_2 aCCF by means of a consistent climate metric. However, for combining the individual aCCFs, it has to be considered that the aCCF algorithms provide their estimates in average temperature change per emitted mass of the relevant species, e.g. in K/kg(NO_2) for the ozone aCCF. Thus, before merging the individual aCCFs, all individual aCCFs have to be converted to the unit of K/kg(fuel). For this conversion the information on NO_x emission indices and flown distance per kg burnt fuel (specific range) is needed. It is possible to choose between three different aircraft types within the aCCFs: regional (small aircraft with short range (up to 100 seats)), single-aisle (short to medium-range narrow-body aircraft) and wide-body (medium to long-range aircraft (250-600 seats)). An example for a summer day of the individual aCCFs of water vapour, NO_x, contrail-cirrus together with merged aCCFs at a pressure level 250 unit hPa over Europe on 15 June 2018 (12 UTC) can be seen in Figure 86 and Figure 87. In Figure 86, two different assumptions for the metric (ATR20 and ATR100) were applied. Figure 87 shows the effect of four different assumptions for the NO_x emission index and the specific range values (typical transatlantic fleet mean (first row), regional aircraft type (second row), single-aisle aircraft type (third row) and wide-body aircraft type (last row)).

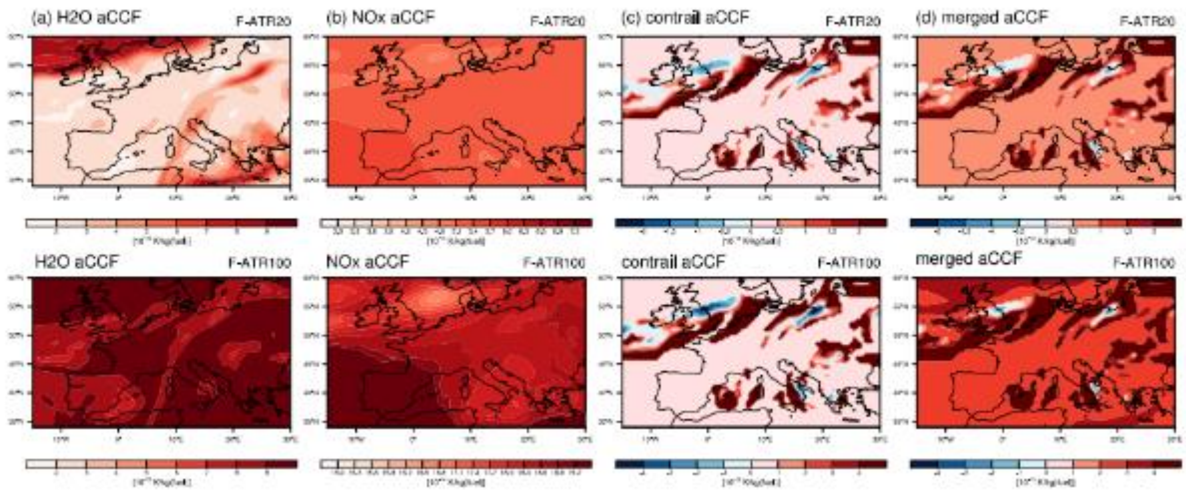


Figure 86: Individual aCCFs of water vapour, NO_x, contrail-cirrus together with merged aCCFs at pressure level 250 unit hPa over Europe on 15 June 2018 (12 UTC), using two different assumptions for the metric: ATR20 and ATR100. Units are all given in [K/kg(fuel)] (Dietmüller et al. 2023).

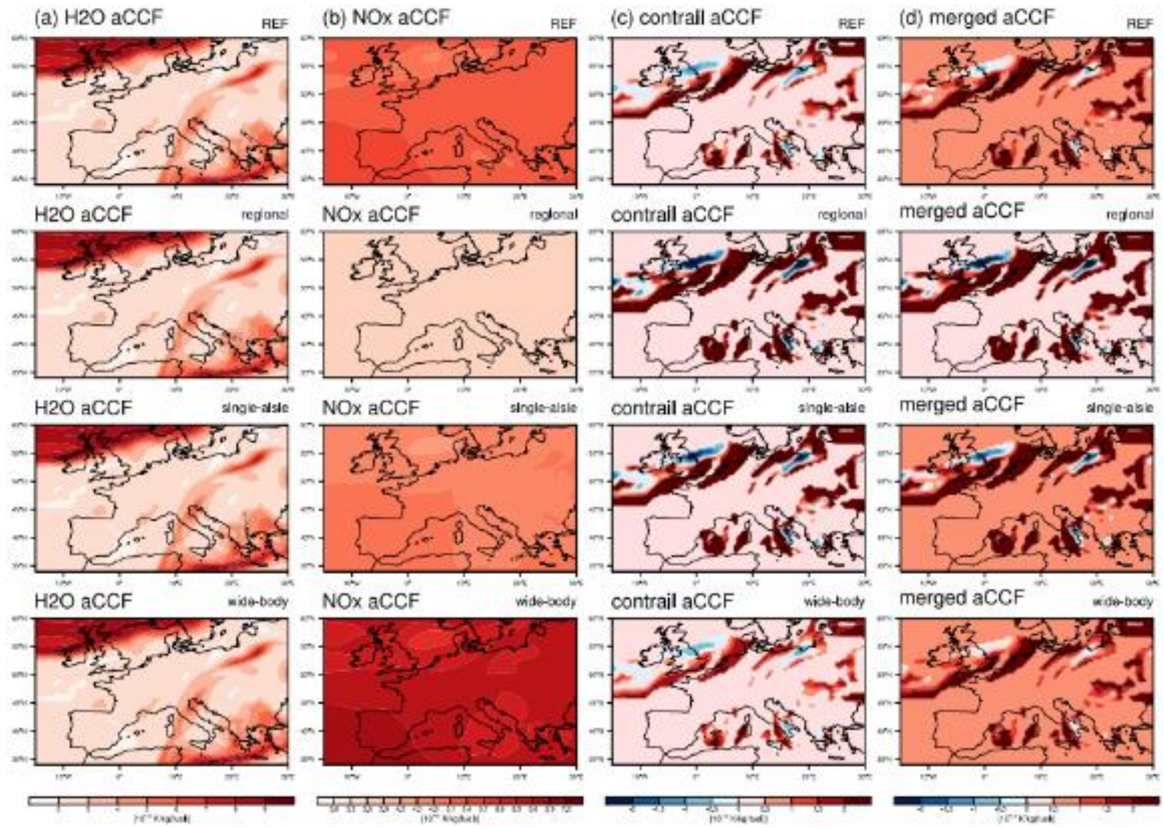


Figure 87: Individual aCCFS of water vapour, NO_x, contrail-cirrus together with merged aCCFs at pressure level 250 unit h Pa over Europe on 15 June 2018 (12 UTC), using four different assumptions for the NO_x emission index and the specific range values (typical transatlantic fleet mean (first row), regional aircraft type (second row), single-aisle aircraft type (third row) and wide-body aircraft type(last row)). Units are all given in [K/kg(fuel)] (Dietmüller et al. 2023).

Based on these generated merged non-CO_2 aCCFs, climate effects determining environmental performance indicators can be calculated efficiently. In addition, the total merged aCCF (non-CO_2 as well as CO_2 effects included) informs the airspace users on locations with high sensitivity to aviation emissions. We recall here, that the CO_2 aCCF is a constant in location and time, while non-CO_2 effects vary. For an efficient application of such type of assessment, the open-source Python Library CLIMaCCF was developed and is available on Zenodo (software DOI: 10.5281/zenodo.6977272) (Dietmüller et al. 2023).

The current aCCFs represent prototypes, which are associated to uncertainties, as current scientific understanding still recognizes uncertainties in the quantitative estimates of weather forecast and prediction of climate effects. Concepts are required that incorporate these uncertainties in order to assess robustness of identified aircraft trajectories.

For illustration of the application of the aCCFS, a prototypic performance analysis is shown in Figure 88. Possible solutions range between a climate-efficient solution (upper left green square) and a cost-efficient solution (lower right red square). For fitting both strategic targets, an eco-efficient solution (middle yellow star) can be identified.

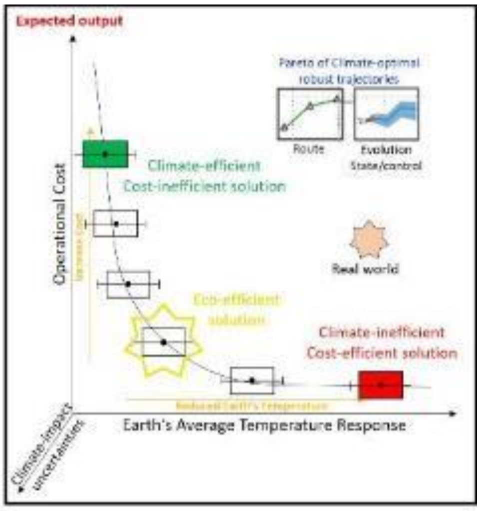


Figure 88: Performance analysis (FlyATM4E, D4.2 - Organisation of a Stakeholder Webinar for dissemination of final FlyATM4E results)

Hence, in case of the available flights within ALBATROSS, the climate effect is calculated for the different flight trajectories based on the application of the system LNAS. Direct benefits in terms of environmental effects can be expected from the reduced consumption of fuel and the corresponding reduced emissions.

C.3.2 Results per KPI

The following KPIs are calculated for EXE-03:

- **FEFF8 (SESAR, 2019) TMA Arrival Fuel Burn Off (ARRFUBO)**: Total TMA arrival fuel burn off, calculated via FOB/GW differences. TMA Departure: from touchdown to an altitude computed from XNM radius from ARP (suggested to compute 40nm).

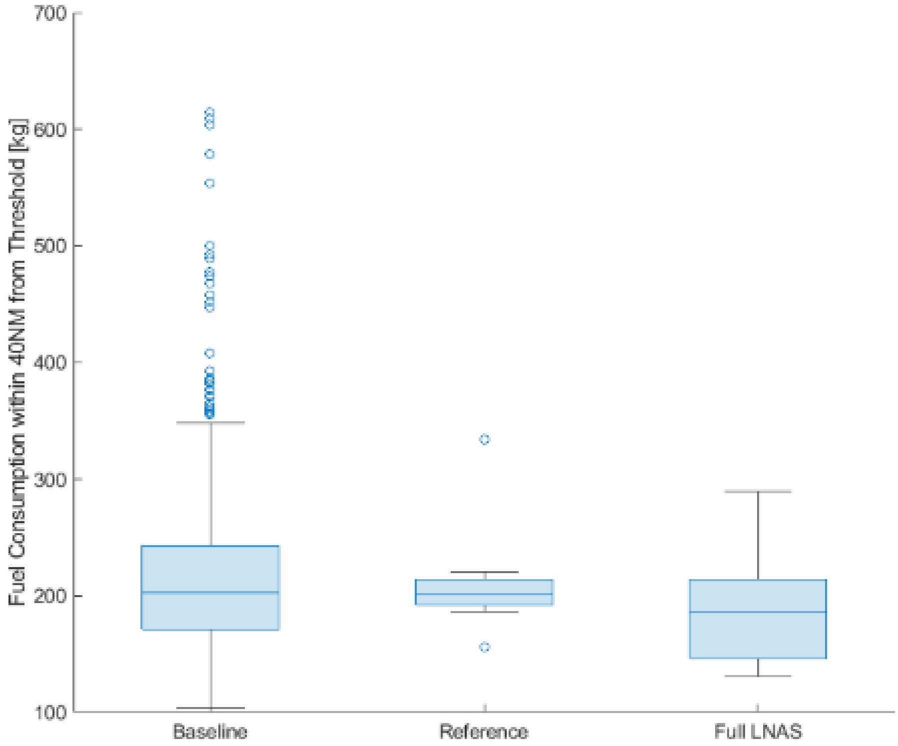


Figure 89: Total fuel burn off for the last 40 nm radius to threshold

Figure 89 presents the results for KPI 8.2. For all groups of flights, the fuel consumption for a 40 nm position out of the threshold position are given. Baseline flights that had to perform any kind of holding procedure can be identified as outliers. For the PBN-to-ILS flights (Full LNAS and Reference) those holdings could be prevented which has significant influence for each specific flight.

- **FEFF8.2 Approach Fuel Burn Off (APPFUBO)**: Total approach burn off, calculated via FOB/GW differences. Approach Phase: from to 3000ft AGL or initial altitude where flaps are extended (whichever is higher) to touchdown.
    - C.3.1 shows the results for the LNAS trials and treats the approach fuel burn off. The curves of the fuel consumption are presented together with detailed background information on configuration setting, altitudes and speeds.
- **KPI LAQ1.1** is related to the average total climate effect over a certain time horizon related to CO_2 and non-CO_2 gridded input data. These quantities can be calculated by applying aCCFs for the individual place and time of operation, in particular requiring weather parameters as input. A respective python code was applied within the project. In our study, we compare environmental performance of a set of flights with and without the LNAS system and are able to identify differences.
- **KPI LAQ1.2** is the relationship between the amount of emitted CO_2 and non-CO_2. These quantities can be calculated by applying the aCCFs in addition to weather parameters. A respective python code was applied within the project.

C.3.3 Results impacting regulation and standardisation initiatives

Due to the high flexibility for ATCOs, radar vectoring and tactical speed instructions are preferred methods in the TMA. The majority of all approaches at airports in Europe are performed using these two methods. However, a PBN-to-ILS procedure implies that the lateral degree of freedom is restricted at a relatively early stage of the approach. This in turn means that the sequence and separation must be established earlier. At the same time, however, it is exactly the knowledge of the distance-to-go (DTG) on-board that enables energy management optimization with the goal of flying the approach at idle thrust. Alternative procedures to PBN-to-ILS are e.g. Point Merge, which determine the DTG from the moment of the instruction "direct to merge point" down to the threshold.

In order to achieve a high capacity even with a limited lateral degree of freedom, tactical speed instructions are unavoidable. However, on a PBN-to-xLS (to include RNP or LPV approaches), ATC speed instructions should be

a) as predictable as possible, and

b) should occur at a time that takes flight physics into account.

For example, an idle thrust approach along a PBN-to-ILS procedure can still be flown with tactical speed instructions if, for example, the reduction from 220 kt to glideslope intercept speed is assigned before the final approach fix rather than on the glideslope.

The findings from EXE-03 can be directly translated into SOPs for ATCOs and pilots. These recommendations are elaborated later in this report in C5.2.

C.3.4 Analysis of Exercises Results per Demonstration objective

OBJ_VLD_ALBATROSS_001 Results

For this exercise, a temporary PBN-to-ILS procedure with a glideslope intercept target speed along the trajectory to runway 14 at Zurich Airport was established together with the ANSP.

From the aircraft side, procedures were established in the area of 'green descent', i.e. reference flights during which the pilots consciously aimed to fly in an energy-optimal manner without assistance system. Additionally, pilots were trained for the use of the LNAS assistance system.

With these elements, the effect of a PBN-to-ILS procedure on energy management was investigated in a first phase and, in a second phase, how the assistance system further improves energy management.

OBJ_VLD_ALBATROSS_002 Results

The demonstration flights were executed along PBN-to-ILS trajectories with and without system-assistance for aircraft energy management.

C.3.5 Unexpected Behaviours/Results

The execution of EXE-03 has fully met the initial expectations.

C.3.6 Confidence in the Demonstration Results

1. Level of significance/limitations of Demonstration Exercise Results

In order to increase the acceptance by local residents and to avoid conflicts, the topics of environmental and noise protection will play an important role in the future among other themes like flight safety and will continue to be a key driver for the aviation industry as a whole. The challenge is to reduce continuously the environmental impact in the face of continuing expansion in aviation. The Advisory Council for Aviation Research and Innovation in Europe ACARE presents a summary of the objectives for future air transport: In 2050 technologies and procedures available allow a 75% reduction in CO2 emissions per passenger kilometre and a 90% reduction in NOx emissions. The perceived noise emission of flying aircraft is reduced by 65%. These numbers are seen relative to the capabilities of typical new aircraft in 2000. The ambitious aims will drive the need to deliver revolutionary technology solutions at an increasing rate. Even if the absolute amount of fuel saving per flight is comparably small to the total consumption, the concentrated high number of low altitude and confined space aircraft movement plays a very important role.

The EXE-03 demonstration is intended to contribute to supporting aviation stakeholders and decision makers in policy making to reduce the impact of aviation on the environment.

2. Quality of Demonstration Exercise Results

In preparation of the analysis data was collected for Swiss A320 neo. For the evaluations flight mechanical data (trajectory, speed, AOA,…) and controller specific data (modes,…) had to be synthesized. Furthermore, the predictions and calculations produced by the LNAS system itself had to be treated.

Additionally, the LNAS system itself demands for all relevant aircraft parameter to be able to calculate correctly and give advice to the cockpit crew.

Table 26 gives example of a typical data set used for the evaluations. The LNAS input parameter additionally reflect information on the envisaged airfield as well as according data from the approach data base.

Table 26: Example input for flight data assessment

Longitude (deg)	Landing Gear Nose (1 = Down)	Spoiler Position 1 Left (deg)
Latitude (deg)	Landing Gear Right (1 = Down)	Spoiler Position 2 Left (deg)
GPS Altitude (ft)	Landing Gear Left (1 = Down)	Spoiler Position 3 Left (deg)
Baro Corr Altitude CAP (ft)	Spoiler (degrees)	Spoiler Position 4 Left (deg)
QNH Setting CAP (hPa (mbar))	Glideslope Deviation (dots)	Spoiler Position 5 Left (deg)
True Heading (deg)	Localizer Deviation (dots)	Spoiler Position 1 Right (deg)
Pressure Altitude (ft)	Static Air Temperature (DEG C)	Spoiler Position 2 Right (deg)
True Track (deg)	Wind Speed (knots)	Spoiler Position 3 Right (deg)
FPA (deg)	Wind Direction (deg)	Spoiler Position 4 Right (deg)
Bank Angle (deg)	Static Pressure (hPa (mbar))	Spoiler Position 5 Right (deg)
Pitch Angle (deg)	Air Density (kg/m^3)	Flight Phase
Corr AoA (deg)	AP 1 (1 = Engaged)	Vman (kts)

Indicated AoA (deg) Selected Altitude (ft) Selected HDG (deg) Selected SPD (knots) Selected Vertical Speed (ft/min) IAS (knots) TAS (knots) Mach Ground Speed (knots) Ground Speed GPS (knots) Vertical Speed (inertial) (ft/min) Approach Speed (knots) VLS (knots) S Speed (kts) F Speed (kts) Flap Speed Limit (knots) Gross Weight (kg) N1 (%) Flap Handle Position Gear Lever (1 = down)	AP 2 (1 = Engaged) ATHR (1 = Engaged) Nav Hold Mode (1 = Engaged) Open Descent Mode (1 = Engaged) Glideslope Hold (1 = Engaged) Glideslope Capture Localizer Hold (1 = Engaged) Localizer Capture Altitude Hold (1 = Engaged) Altitude Capture (1 = Engaged) FPA Mode (1 = Engaged) Vertical Speed Mode (1 = Engaged) Managed Speed (1 = Engaged) Engine Anti-Ice (1 = on) Wing Anti-Ice (1 = on) QNH selected on EFIS (CAPT) QNH selected on EFIS (FO) Fuel Flow Left (kg/hr) Fuel Flow Right (kg/hr) Flap Angle (deg+=TED)	Vmax operational (knots) V alpha prot (kts) V alpha max (kts) Gross weight (metric tons) Side Slip (deg) Drift Angle (deg) Acceleration longitudinal (g's) Acceleration lateral (g's) Acceleration normal (g's) Corrected MSL Altitude (ft) Speed Brake Deployed (1 = Deployed) Landing Gear Position (0 = up, 1 = in transit, 2 = down) Active Lateral Mode Active Vertical Mode Approach Speed Target (knots) Great-circle distance to threshold (nm) Selected Speed MCP (knots) Phase of Flight

3. Significance of Demonstration Exercises Results

Pilots feedback

The LNAS system was generally found to be very helpful. The additional workload after setting up the system and starting the forward prediction was judged to be low. Due to the boundary conditions for the start (stabilized TMA speed, updated waypoint sequence), an increased workload is often noticeable between about FL150 and FL100. Here, an automatic query of the individual inputs would provide relief.

The estimation of the energy status both with own line-up and under radar vectoring succeeds very well with the vertical profile. It would be worth considering converting the energy difference between actual speed and FCU selected speed into a virtual altitude supplement and displaying it.

Since the pilot focus is primarily on PFD/ND, especially in the late phases of the approach, an attention cue such as a flashing indication or a color change should be implemented when the assistance system requests a mode or configuration change.

C.4 Conclusions

For the first time in the world, a demonstration and study was conducted in EXE-03 to evaluate the benefits of a closed-path PBN-to-ILS procedure with and without an energy management pilot assistance system (LNAS) compared to radar vectoring procedures to the same runway.

Flights along the PBN-to-ILS trajectory conducted with LNAS support resulted in significantly more predictable vertical and airspeed profiles, lower average thrust settings, lower use of speed brakes particularly at low altitudes, and overall lower fuel burn from the last 30 NM compared to PBN-to-ILS approaches without a pilot assistance system and compared to approaches using radar vectoring.

C.5 Recommendations

C.5.1 Recommendations for industrialization and deployment

In this EXE-03, it was successfully demonstrated that an energy assistance system applied to a PBN-to-ILS yields a direct benefit in terms of aircraft energy management. LNAS was used as a demonstrator tool on top to applying a PBN-to-ILS procedure instead of radar vectoring.

Today there are already supporting functions in an FMS that improve descents along a closed trajectory, such as the improved vertical profile DPO (Descent Profile Optimization) or the CDA profile on the A350 aircraft. The latter, however, struggles when tactical speed instructions follow along the CDA profile. However, the big difference and advantage with the LNAS concept is that such an assistance system enables fully dynamic optimization, with tactical airspeed instructions from ATC also dynamically taken into account. Therefore, it is necessary to industrialize the LNAS concept into full maturity integrated within the avionics environment.

In the SESAR ER4 project DYNCAT (2020-2022), the LNAS concept was integrated into an FMS for the first time and successfully tested on a testbed.

As shown in EXE-03, the efficient interaction between ATC and aircraft is crucial if CO_2 and noise optimizations are to be achieved within the TMA. In the upcoming SESAR IR project DYN-MARS (2022-2024), the FMS prototype function will be further developed and data exchange (ADS-C EPP) of relevant information (e.g. ATC information related to sequencing and separation) within the TMA will be further developed.

However, in order for such future FMS functions to be deployed in an effective manner, it is important that for now PBN-to-xLS procedures (including RNP or LPV approaches) are deployed to as many flights as possible to be conducted along closed path trajectories within the TMA until FAF.

Where no PBN-to-xLS procedures can be deployed, it is still possible that SOPs of approach controllers are updated on airports with a trombone-shaped RNAV transition and using early approach clearances such as “*Proceed direct DH51x, DH51y, cleared for the approach, reduce speed to establish on the glide at 180 kt*".

Also, Point Merge (PM) procedures provide a similar benefit as PBN-to-xLS procedures by giving an improved precision about the DTG which allows optimization of the vertical profile. However, PM may be less efficient in terms of fuel efficiency compared to PBN-to-xLS if there are level-off constraints along the arc segment.

C.5.2 Recommendations on regulation and standardisation initiatives

In terms of standardization, much could be already achieved by assigning more closed-path trajectories in the intermediate to final approach segment and refraining from tactical radar vectoring (with unknown DTG from the flight deck perspective). Furthermore, it is recommended for tactical ATC speed instructions to be standardized so that they take into account the flight physics aspects and do not result in pilots having to stabilize the flight path with energetically very unfavorable interventions (e.g. speed brakes or high-thrust level segments, early extension of the landing gear on the 3° final approach, etc.). It helps a lot if the expected speed profile is known on the flight deck as early as possible. EGLL is a good example for predictability, where tactical speed instructions are very predictable, allowing the flight crew to optimize the energy management to yield a low emission (fuel, CO_2, noise) approach in the TMA.

Appendix D Demonstration Exercise #04 Report

D.1 Summary of the Demonstration Exercise #04 Plan

Within the scope of the exercise "TMA Optimization", an analysis of the TMA is to be carried out by means of machine learning (artificial intelligence) and suitable algorithms, with the aim of identifying correlations and features, which lead to inefficient trajectories.

D.1.1 Exercise description and scope

Since this approach is novel and has not been applied before, the development of the methodology was first worked out at FRA airport. The findings will then be used to transfer the approach to the DUS/CGN airspace system.

To achieve the previously mentioned goal, it was first necessary to filter the days within the database according to suitable criteria (e.g., weather conditions, sector utilization). The goal here is to guarantee equal operational boundary conditions. These are achieved in a first step by analyzing the operating concepts. At this point, an operational concept at Frankfurt Airport is defined by the specific approach and departure directions and has been identified as BR07 and BR25. If, over a given period (30 min), was no clear assignment possible, the operating concept was set to “0”. This approach allows a first filter for outliers. In a next step, the traffic flow at the airport over the day was taken and compared to all other days recorded. This comparison was conducted using the dynamic time warping algorithm, which allows to measure dissimilarities between temporal sequences. In a third step, the approach directions of all flights are used to identify traffic flows and to classify each trajectory as part of a particular flow. These flows are finally used to be further clustered into trajectories operated under similar conditions and similar profiles, achieved by dimensional reduction and density clustering.

This procedure was elementary as it ensures comparability of the trajectories. This comparability is a core element of the AI-supported trajectory analysis.

Since regression models (prediction of continuous values) failed to reproduce the trajectories, models for classification (prediction of labels) where test and implemented successfully. Here, lateral and vertical trajectories in the TMA were examined and differentiated into the labels "good" and "less good" trajectories and "bad and less bad" trajectories compared to the prior identified average trajectory (trajectory with closest distance to all other trajectories).

An analysis of the vertical profiles showed that the average flight had a too shallow descent angle, although better trajectories were present under the same conditions. This leads to the question, which factors lead to good or less good trajectories.

To identify these factors, an analysis was made using the SHAP approach. This approach allows a better explanation of the results of classification approaches (understanding of the machine learning model) than other approaches, such as feature permutation importance. SHAP (SHapley Additive exPlanations) is a game theoretic approach to explain the output of any machine learning model and shows a weighted contribution of the respective factor to the result to be achieved.

In addition to factors such as weather and the number of arrivals and departures, the influence of the individual sectors was also considered.

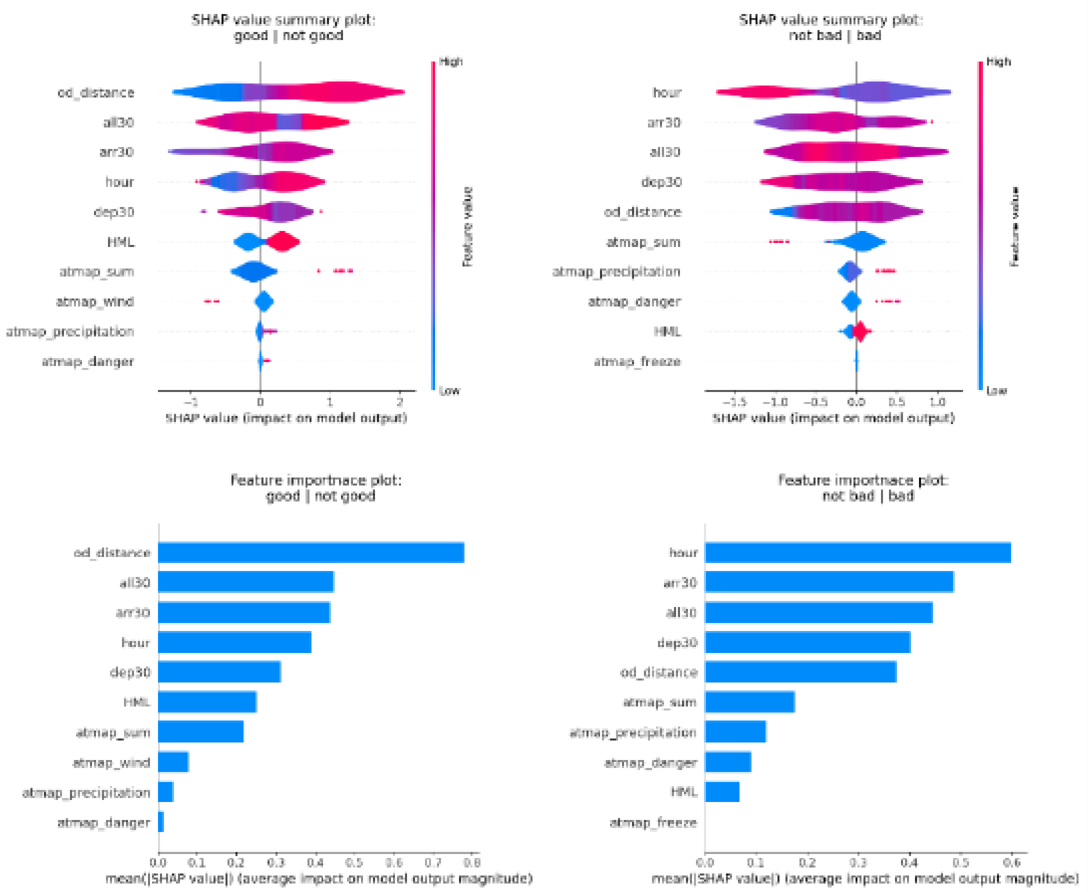


Figure 90: **Shap-Value Analysis for Cluster "north-east" of FRA TMA**

The influence of these factors is examined in more detail in the following sections.

Already at this stage, it can be stated that the demonstration of analyzing airspaces and traffic flows with the help of machine learning (AI) was successful.

D.1.2 Summary of Demonstration Exercise #04 Demonstration Objectives and success criteria

D.1.3 Summary of Validation Exercise #04 Demonstration scenarios

D.1.4 Summary of Demonstration Exercise #04 Demonstration Assumptions

Identifier	Title	Type of Assumption	Description	Justification	Impact on Assessment

Table 27: Demonstration Assumptions overview

No assumptions were formally tracked.

D.2 Deviation from the planned activities

There was no deviation from the planned activities.

D.3 Demonstration Exercise #04 Results

D.3.1 Summary of Demonstration Exercise #04 Demonstration Results

Efficient sequencing of flights in an airport terminal is crucial for ensuring that limited resources such as capacities of runways or airspace sectors are used optimally. Inefficiency indicated by deviations from the best approach, by means of lateral path stretching and vertical deviations from the optimal glide angle.

However, operational and procedural requirements, as well as interactions between flights, can necessitate the adjustment of individual flight trajectories to ensure safe flights.

ATCOs possess extensive expertise and problem-solving skills, allowing them to develop and implement approaches to specific and recurring situations while considering their respective areas of responsibility and workload.

The ALBATROSS project demonstrated a way, how impact factors, under which more efficient flight trajectories could be achieved, can be identified, by using machine learning methods in various traffic demand situations.

These methods considered not only local phenomena, such as load factor or weather conditions at the airport but each flight was evaluated with respect to the state of the entire air traffic system with a radius of 120NM around the airports of Frankfurt (EDDF), Düsseldorf (EDDL) and Cologne-Bonn (EDDK).

First, different clusters of trajectories were systematically generated by means of unsupervised learning, reference trajectories were calculated, and the flight trajectories in each cluster were analyzed. Unsupervised learning is a type of machine learning where the algorithms are not provided with labeled data, and instead, it identifies patterns or clusters in the data on its own.

In this case, the ALBATROSS project utilized unsupervised learning to generate clusters of flight trajectories based on comparable operational constraints, allowing them to identify efficient and less efficient flights within each cluster.

For each cluster, a model was developed, trained, and validated by means of supervised learning to classify flights as efficient or less efficient. Supervised learning is another type of machine learning where the algorithms are trained on labeled data, enabling them to identify patterns or make predictions on new data.

The analysis of the validated classification models provides the opportunity to identify the most important factors influencing the classification and their underlying correlation.

To optimize flights in the airport terminal area, the controller can rely on more efficient flights already observed to improve instructions and flight performance.

This practice-oriented approach reinforces positive controller decisions and allows for appropriate adjustment of identified influencing parameters.

Overall, the ALBATROSS project demonstrated that machine learning methods can be applied to identify factors that can lead to more efficient flight trajectories in various traffic demand situations.

This can ultimately help optimize flights in the airport terminal area, improve the efficiency of airport operations, and enhance safety.

Following shows an excerpt of the achieved observations on the example of FRA, Sector 030x.

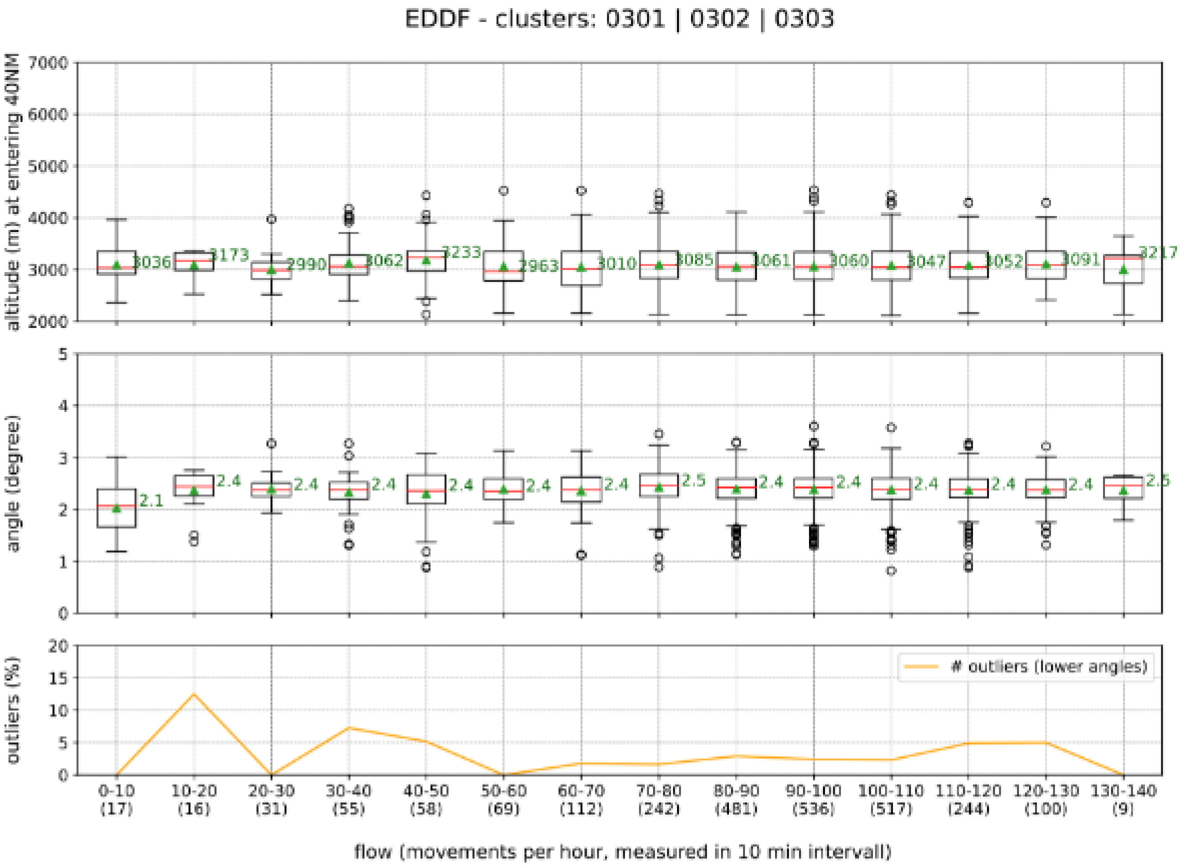


Figure 91: Example of achieved observations

The figure above shows a plot analysis of flight altitudes and angles (altitude/ distance to fly) at EDDF (Sector 030x). Mean values are marked with green triangles. Outliers are marked as circles and the percentage of outliers (based on angles) is shown below. The analysis is performed with respect to the observed traffic flow.

It could be demonstrated that the mean entry altitude and the descent angle is below an optimum and does not alter with higher traffic flows. Apparently, the flow has a neglectable impact in the optimum vertical trajectory, considering all other factors (e.g. airspace configuration, weather) as similar.

Further analysis is shown in the figure below, where a relation of “distance to fly and altitude” is plotted against entry altitude, considering different amounts of traffic flows. Best performing flights are marked blue without yellow circle. Yellow circle indicate a lower performance. On the right side, the occurrence of flights with lower performance is additionally highlighted with reference to the time of day.

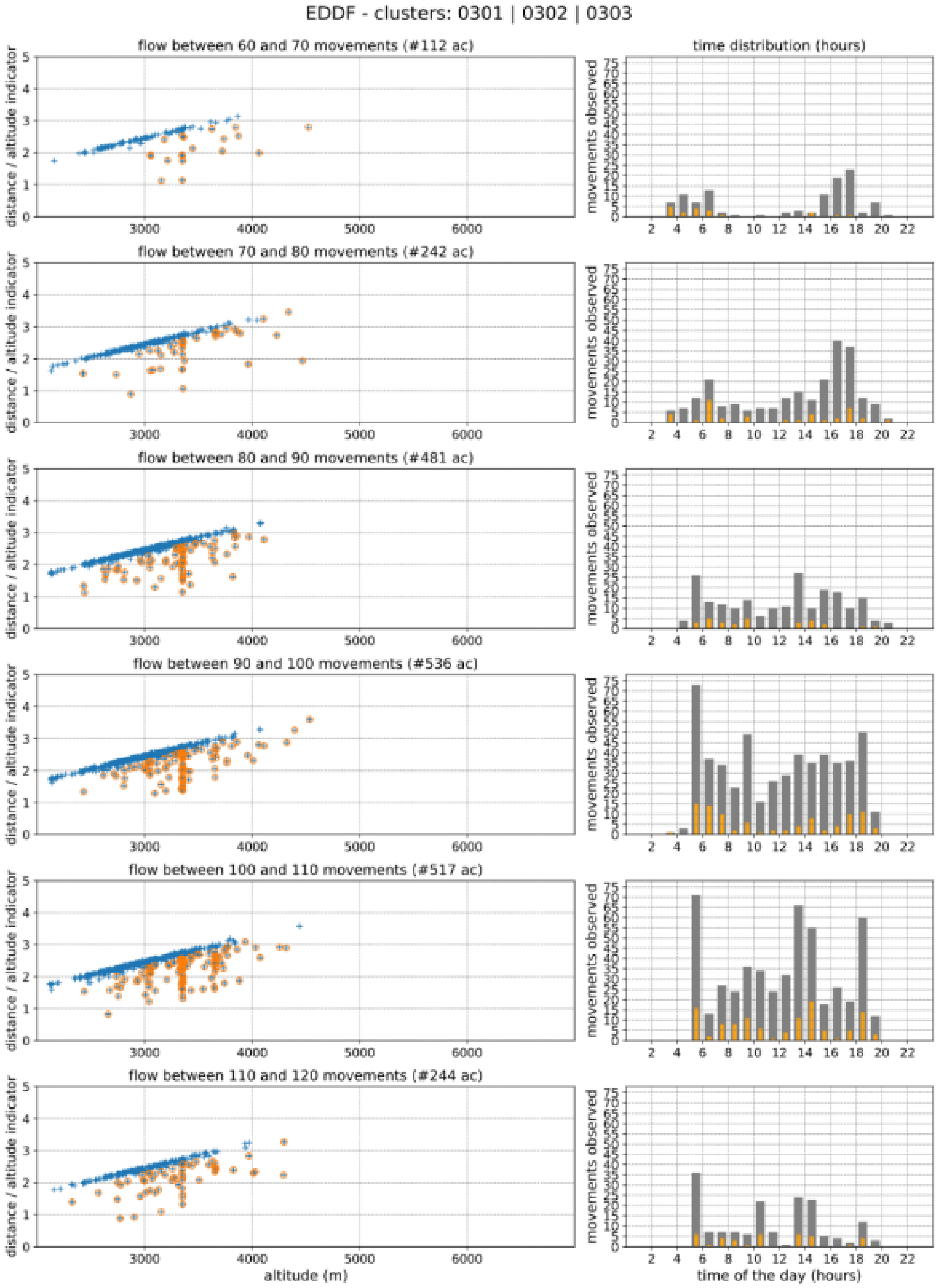


Figure 92: Relation of "distance to fly and altitude" against entry altitude

In the next step, a feature importance analysis has been conducted, using the SHAP-value method. The following figure shows an impact analysis of input vector importance, with two classifications 'good (shortest times, 5%) or not good' and 'not bad or bad (longest times, 5%)'. Importance of each input factor (left) and correlation of input factor (right). Additionally, an impact analysis of sector and airport utilization has been made.

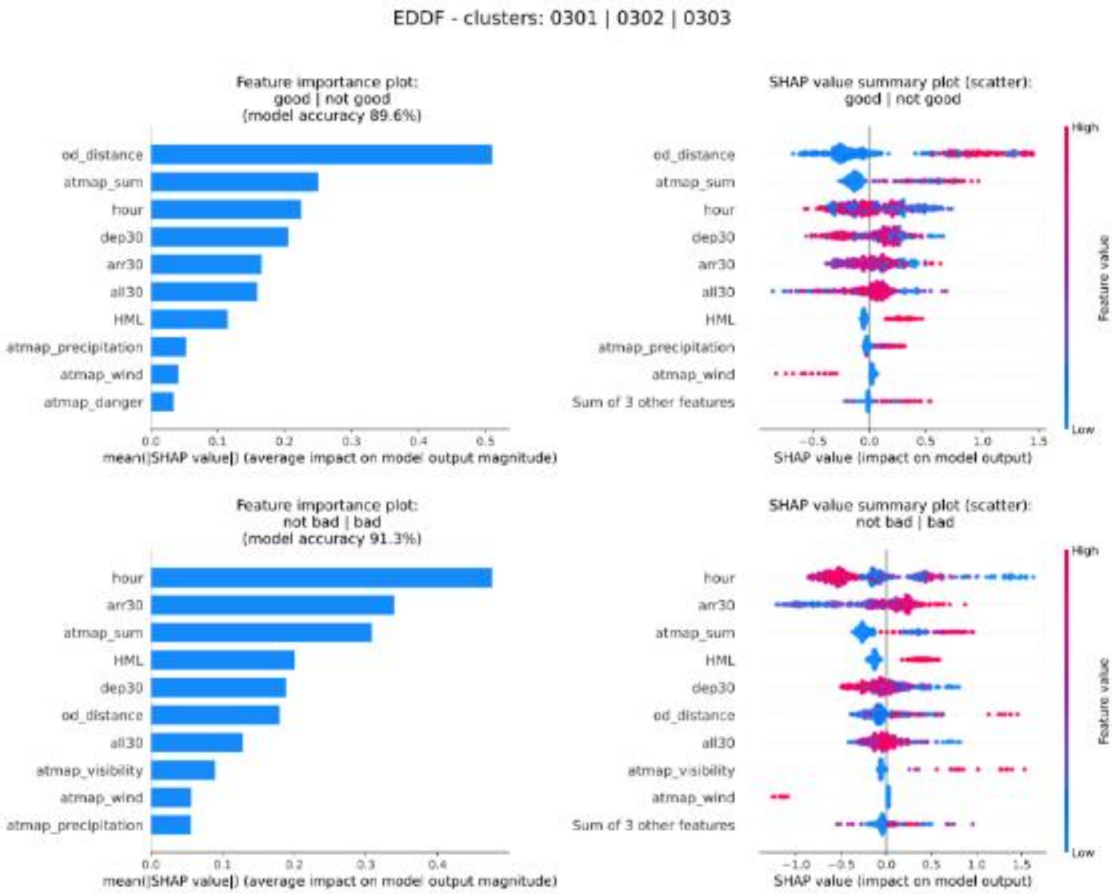


Figure 93: impact analysis of input vector importance

All plots are analyzed systematically and transferred into a table. One first analysis and results considering feature importance in FRA shows the following table.

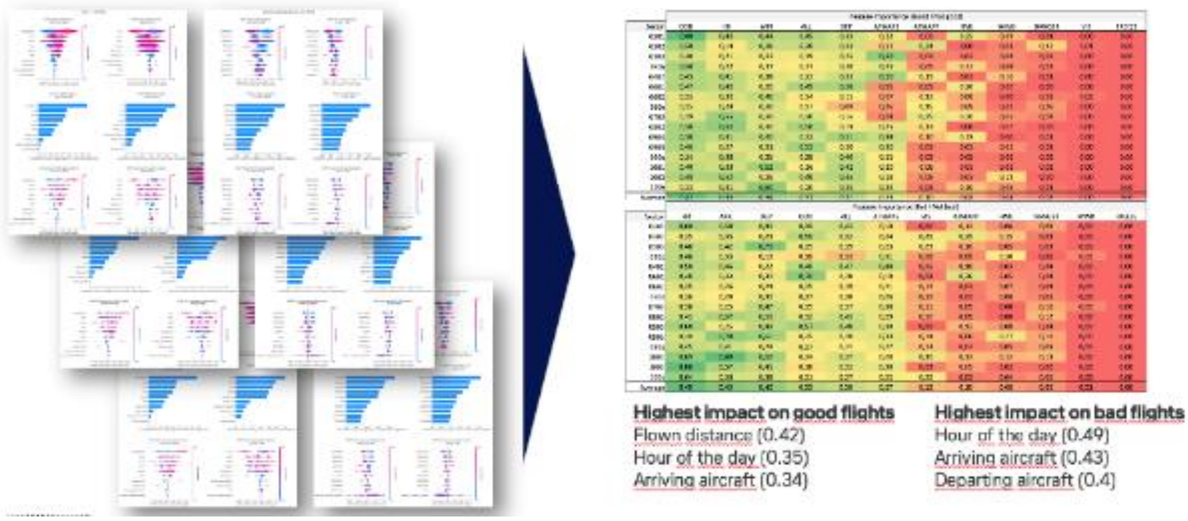
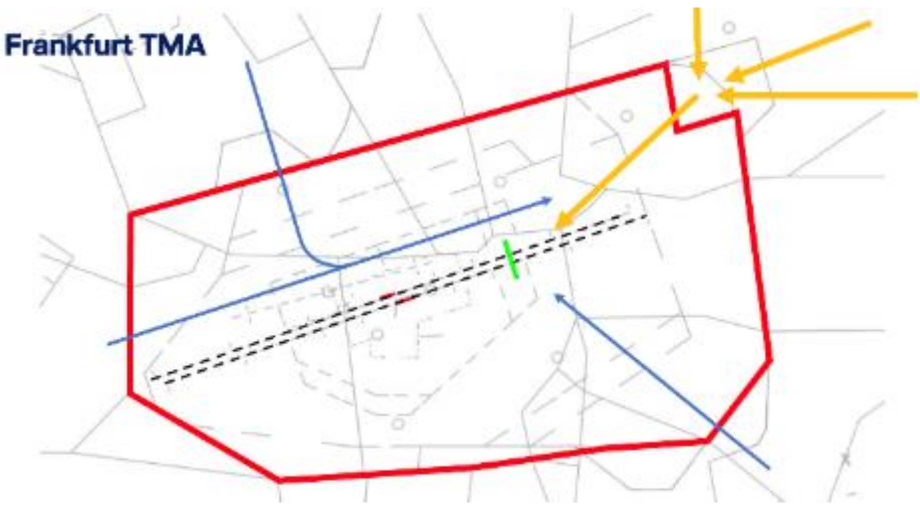


Figure 94: first analysis and results considering feature importance in FRA

The complete dataset of the analysis comprises 287 pages of plots. Due to the high complexity, the analysis is still ongoing.

Conclusions and Findings

Based on the findings of the vertical efficiency analysis, solutions for the FRA TMA have been developed and are currently under implementation review. Due to the complexity, we initially focused on optimization solutions for approaches from the northeast.



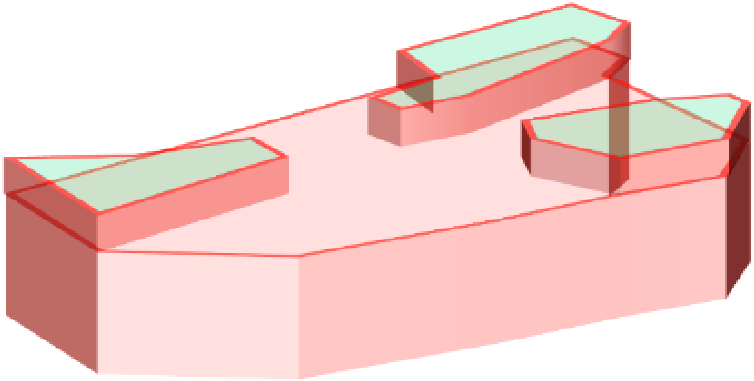


Figure 95: FRA approaches from the northeast

The solutions include

- a larger airspace for lateral sequencing and separation allows for more efficient vertical flight profiles
- individually (via AMAN System) coordinated higher transfer levels allow for a higher percentage of continuous descends
- flexible descend windows allow for optimal use of airspace considering the Runway in use.
- The flexible descent windows (green areas in the figure above) include:
    - Raise KERAX Transfer Level from 110 to 130
    - Potential higher Transfer Levels coordinated individually via AMAN
    - Installation of a "Descend Windows" for Landing Direction 07 and 25.

Demonstration Objective ID	Demonstration Objective Title	Success Criterion ID	Success Criterion	Sub-operating environment	Exercise Results	Demonstration Objective Status
OBJ-VLD-ALBATROSS-001	Demonstrate trajectories closer to the "optimum"	CRT_VLD_ALBATROSS_001	Identify factors leading to good or less good trajectories	TMA of CGN/DUS and FRA airports	several factors reliably identified	OK

Table 28: Exercise EXE-04 Demonstration Results

1. Results per KPA

The exercise focused on the "Environmental Efficiency" performance area.

Results are available in section D.3.1.

2. Results impacting regulation and standardisation initiatives

The results do not impact regulation or standardisation.

D.3.2 Analysis of Exercises Results per Demonstration objective

1. OBJ-VLD-ALBATROSS-001 Results

Results are available in section D.3.1.

D.3.3 Unexpected Behaviours/Results

The exercise consisted in post-ops data analysis. No unexpected results have been observed.

D.3.4 Confidence in the Demonstration Results

1. Level of significance/limitations of Demonstration Exercise Results

The level of significance is considered very high, since the analysis is based on a very high volume of actual flown trajectories and on state-of-the-art "ML/AI" methods of data analysis.

2. Quality of Demonstration Exercise Results

The quality of the results is considered very high.

3. Significance of Demonstration Exercises Results

The analysis and calculations of the suggested method apply specifically for an individual airport; in other words, extrapolation of the calculations to other locations is not relevant.

D.4 Conclusions

Overall, the ALBATROSS project demonstrated that machine learning methods can be applied to identify factors that can lead to more efficient flight trajectories in various traffic demand situations.

This can ultimately help optimize flights in the airport terminal area, improve the efficiency of airport operations, and enhance safety.

D.5 Recommendations

D.5.1 Recommendations for industrialization and deployment

The method first carried out for Frankfurt can be used in other airspace systems.

For the Frankfurt TMA, the solutions recognized to enable more efficient vertical flight profiles are considered for actual implementation (they include: improving lateral sequencing and separation by using a larger airspace; and flexible descend windows and raised transfer levels.)

D.5.2 Recommendations on regulation and standardisation initiatives

No specific recommendations for regulation and standardisation.

Appendix E Demonstration Exercise #05 Report

E.1 Summary of the Demonstration Exercise EXE-05A Plan

The goal of this exercise is to have PBN-to-ILS (CAT II/III) procedure for runway 29 at Vienna airport published in the Austrian AIP.

Project lead / coordination: Austro Control

Main Project Stakeholder: Austrian Airlines

E.1.1 Exercise description and scope

- Stakeholder coordination with local communities and governmental bodies at and around Vienna airport as part of the institutionalized "mediation": process successfully concluded July 2021
- Procedure design phase including multiple re-designs completed! (chart, coding and reports are finalized)

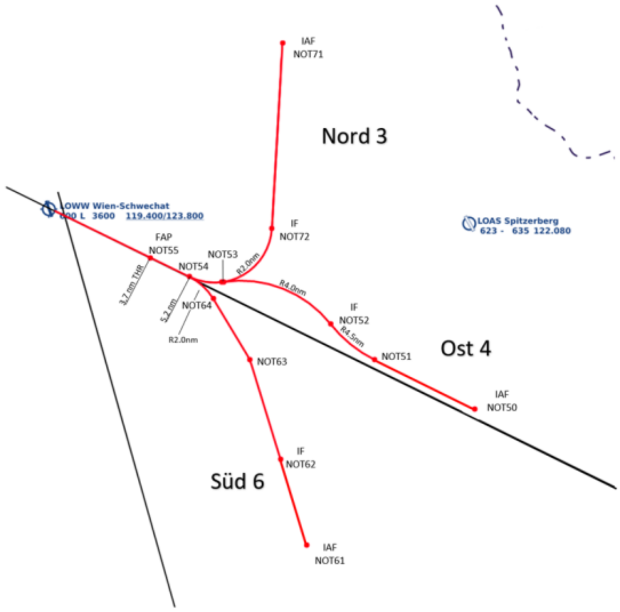


Figure 96: VIE PBN-to-ILS Procedure

- Safety Assessment prior the operational phase including all stakeholders (e.g., ATC, procedure designers, operators, airport,…) conducted and finalized

- Successful procedure evaluation using full-flight simulators (full motion, certified according to EASA CS-FSTD Level D)
    - Simulator trials from December 2021 till March 2022 (using a navigation test data base)
- Live-Trail flights in VMC conditions during February / March 2022 including very positive pilot feedback for all flight phases

Figure 97: Simulator / Deck

- Aircraft and FMS type used during simulations / flight trials:
    - Airbus A320 with a Honeywell FMS
    - Airbus A320 with a Thales FMS
    - Boeing B777 with a Honeywell FMS
    - Embraer E195 with a Honeywell FMS

Figure 98: Simulator

- ATC training finished till to end of October
- **Publication of the procedure in the Austrian AIP with AIRAC November 3rd, 2022**
- Implemented PBN-to-ILS RWY 29 will be usable by all project partner flights into Vienna(depending on traffic situation, only used in off-peak periods at the beginning, but active and available H24)

- Benefits assessment by Austro Control / Eurocontrol on the noise exposure / reduction, fuel burn and evaluating CO2 reductions from reduced track miles and improved flight efficiency (using AEDT / IMPACT)

E.1.2 Summary of Exercise EXE-05A Demonstration Objectives and success criteria

This exercise addresses objective OBJ-VLD-ALBATROSS-001 "Implement operational concepts that enabl trajectories closer to the optimum". The publication of a PBN-to-ILS procedure for runway 29 in VIenna (VIE/LOWW) in the AIP allows for any airline to be cleared to use it, with the associated reduction of fuel and emissions from reduced track miles and reduction of Noise impact.

E.1.3 Summary of Exercise EXE-05A Demonstration scenarios

The Solution Scenario for this exercise is that RNP to ILS Approach is implemented in order to minimize noise exposure, (CO_2) emissions, and improve flight Efficiency. This solution uses curved procedures (Radius-to-Fix) enabled by RNP to the interception of the final approach, based on ILS or LOC. This allows the aircraft to follow a new approach paths and thereby avoid noise sensitive / populated areas, reduce track miles, and yet be able to use ILS landing guidance.

For comparison, the Reference Scenario would be the currently published STAR / RNAV Transition 29 / ILS 29 procedures in the Austrian AIP.

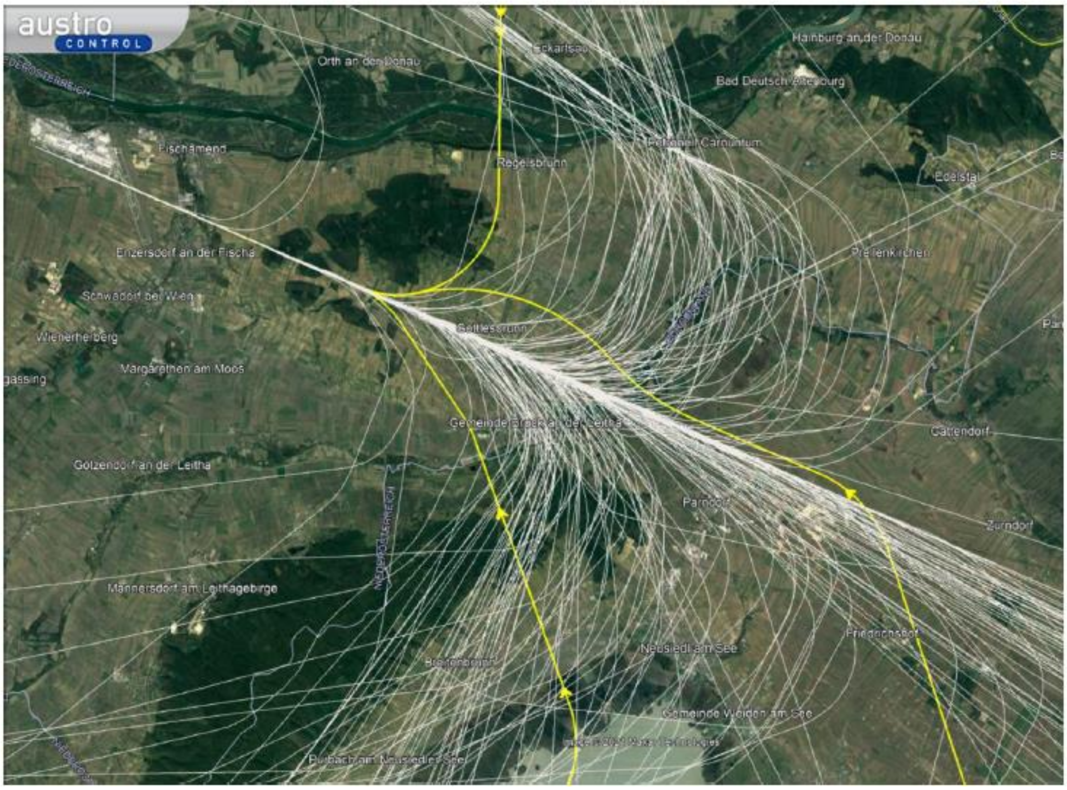


Figure 99: Arrivals RWY 29 radar tracks vs. planned PBN-to-ILS procedure for Vienna Airport

E.1.4 Summary of Exercise EXE-05A Assumptions

Identifier	Title	Type of Assumption	Description	Justification	Impact on Assessment

Table 29: Demonstration Assumptions overview

No assumptions were formally tracked.

E.2 Deviation from the planned activities

Apart from adjustments to the implementation dates, no deviation took place.

E.3 Demonstration Exercise EXE-05A Results

The full process that culminated with the permanent publication of the procedure has been successfully carried out : Coordination with local communities and governmental bodies at and around Vienna airport as part of the institutionalized "mediation"; Procedure design phase (multiple iterations); Safety Assessment including all stakeholders; Procedure evaluation using full-flight simulators and Live-Trail flights in VMC conditions (multiple Aircraft and FMS type); ATC training; Publication of the procedure in the Austrian AIP with AIRAC November 3rd, 2022.

Implemented PBN-to-ILS on RWY 29 will be usable by all flights into Vienna (depending on traffic situation, only used in off-peak periods at the beginning, but active and available H24)

The published Curved Procedure (radius-to-fix) enabled by RNP to the interception of the final approach (ILS CAT II/III or LOC) allows the aircraft to follow a new approach path and thereby avoid noise sensitive / populated areas, reduce track miles, and yet be able to use xLS landing guidance

E.3.1 Summary of Exercise EXE-05A Demonstration Results

Demonstration Objective ID	Demonstration Objective Title	Success Criterion ID	Success Criterion	Sub-operating environment	Exercise Results	Demonstration Objective Status
OBJ_VLD_ALBATROSS_001	Greener descents	CRT_VLD_ALBATROSS_001	Confirm reduction of CO2 emissions	Runway 29	Procedure published, that avoids noise-sensitive populated areas and reduces track miles	OK

Table 30: Exercise EXE-05A Demonstration Results

1. Results per KPA

See section E.3.

2. Results impacting regulation and standardisation initiatives

The implementation was performed according to existing regulation, so there no impact on further standardization.

E.3.2 Analysis of Exercises Results per Demonstration objective

1. EXE5B-OBJ-VLD-ALBATROSS-001 Results

See section E.3.

E.3.3 Unexpected Behaviours/Results

No unexpected behaviours or results are to be reported.

E.3.4 Confidence in the Demonstration Results

1. Level of significance/limitations of Demonstration Exercise Results

No limitations to be reported. The exercises fully completed the intended implementation.

2. Quality of Demonstration Exercise Results

The exercises fully completed the intended implementation.

3. Significance of Demonstration Exercises Results

The exercises fully completed the intended implementation.

E.4 Conclusions

The exercise has resulted in a successful deployment.

E.5 Summary of the Demonstration Exercise EXE-05B Plan

This exercise has been presented in the demonstration plan of the project Albatross. As described in A.1.1., it aims at demonstrating the environmental benefits of flight optimization solutions. Compared to the Demonstration Plan, the exercise contains some deviations, which are described in A.2. One of the main deviation is the concerned flight phases. The initial scope was supposed to cover the climb and the descent. However, due to a lack of maturity on the optimization function expected in Climb, the scope of the Exercise is finally focused on Descent.

E.5.1 Exercise description and scope

This exercise aims at demonstrating the environmental benefits of flight optimization solutions in descent phases. These solutions provided by NAVBLUE / AIRBUS have been used in real operations by Novair.

The proposed solutions are DPO and IFO. It aims at computing the most optimum descent, which consists in defining the optimal descent profile including the correct top of descent position, to minimize fuel consumption, CO_2 emissions and crew workload.

- DPO stands for Descent Profile Optimization. It is a fuel saving initiative updating FMS Performance Data Base (PDB) and reducing engine thrust margins allowing optimization of descent models. On every flight, top of descent is closer from the runway, and the portion of descent in idle is increased, leading to fuel savings and CO_2 emissions reduction. DPO is also a prerequisite for managed Continuous Descent Approaches (CDA) and an enabler for more accurate Idle factor computations.

- IFO stands for Idle Factor Optimizer. It is a solution that monitors the performance variation of individual aircraft through its lifecycle and fine tune the FMS descent trajectory thanks to the IDLE factor. IFO computes the optimized IDLE factor of each individual aircraft along its life by using in-flight recorded continuous data stream (QAR, DAR etc…).

Combining the IDLE Factor Optimizer with the Descent Profile Optimization:

- improves fuel efficiency and reduce CO_2 emissions
- brings operational benefits for pilots thanks to an optimized energy management in descent no matter the guidance mode selected.
- finally contributes at reducing both the thrust increases and airbrakes usage due to performance inconsistencies between FMS model and real aircraft, whatever its individual performance variation over time.

The application of these two solutions are independent from the operational context. As soon as the FMS performance data basis or Idle factor are updated, all the computed FMS descent profiles take benefits from the improvement.

These flight optimization solutions have been deployed and flown in standard operations by Novair. The complete fleet of Novair were already DPO equipped (2 A321 NEO) which is an enabler for IFO. The Idle factors have been computed thanks to IFO from NAVBLUE and applied in operations by Novair from the 17/08/2022 to the 13/10/2022, leading to more than 360 flights with the flight optimization solutions.

The objective of the exercise is to demonstrate the benefits on the management of the energy in descent and so the benefits on the reduction of the fuel / CO_2 emissions by the use of these flight optimization solutions in descent.

AIRBUS performed the analysis by using the flight data provided by Novair. For the fuel assessment, the method defined by the WP4 from ALBATROSS has been tried. The method recommends to compute an optimum trajectory for each flight and to apply a statistical analysis based on the Delta fuel instead of the total fuel consumption (more details in WP4 or in A.3.2). But some limitations with this method have been identified, leading to an analysis completed with simulations.

For the benefits on the energy management, the assessment method corresponds to a statistical analysis of parameters issued from the flight data.

E.5.2 Summary of Exercise EXE-05B Demonstration Objectives and success criteria

This exercise contributes to objective **OBJ_VLD_ALBATROSS_001** along three axes :

1. Demonstrate the reduction of CO_2 emissions and fuel consumption thanks to the use of DPO and IFO solutions in descent.

The success criteria is to demonstrate the reduction of CO_2 emissions and fuel consumption.

2. Demonstrate that the use of IFO allows maintaining the fuel benefits mainly obtained with DPO along the time. Indeed, DPO is an improvement of the accuracy of an aircraft type applying at the entry into service of the aircraft. IFO is an improvement of the accuracy by MSN all along the life of this aircraft.

The success criteria is to demonstrate the maintaining of the reduction in fuel / CO_2 along the time.

3. Demonstrate an improvement in the management of the energy in descent.

- demonstrate the reduction of the airbrakes usage in descent;
- demonstrate the increase of the Idle thrust usage in descent;
- encourage the use of the FMS management mode in descent;

DPO and IFO allows having a FMS computed descent profile more aligned with the real aircraft performance leading to a more optimized top of descent and an increase capacity to respect the computed descent profile during the descent. This improvement is directly traduced by a reduction of the airbrakes use and an increase of the Idle thrust use in descent. This improvement increases the confidence of the pilot in the FMS computations and encourage the usage of the FMS managed mode. In the 4D context, with the use of ADS-C and EPP, this type of improvement will improve the representativeness of the EPP in descent for the controllers, corresponding to an increase of the predictability.

The success criteria is to demonstrate a reduction of the airbrakes use and / or an increase of the Idle thrust use.

E.5.3 Summary of Exercise EXE-05B Demonstration scenarios

The following table presents the configuration of the two Novair aircraft according to the time:

Scenario description	MSN	DPO active	IFO active	Idle Factor Level	Start date	End date
Initial configuration	SE-RKA	YES	NO	Initial	02/09/2021	24/03/2022
	SE-RKB	YES	NO	Initial	02/09/2021	22/03/2022
Reference	SE-RKA	YES	NO	0	25/03/2022	16/08/2022
	SE-RKB	YES	NO	0	23/03/2022	16/08/2022
Improved	SE-RKA	YES	YES	Optimized	17/08/2022	13/10/2022
	SE-RKA	YES	YES	Optimized	17/08/2022	13/10/2022

Table 31: Configuration of the two Novair aircraft

The exercise starts in March 2022. The first part of the exercise was dedicated to the reference scenario with flights where the Idle Factors have been reset to 0. The configuration was with DPO and with no Idle factor adjustment. This reference scenario started from the 25/03/2022 for the MSN SE-RKA and from 23/03/2022 for the SE-RKB, and went until the 16/08/2022 for the two MSNs.

The improved scenario with DPO and the computed Idle factors starts from the 17/08/2022 to the 13/10/2022. In this scenario, all the flights from Novair have been operated with the computed Idle Factors.

For the Idle factor computation, at least six months of historical data are required for each MSN. This is why, some historical data have been provided for the two MSNs from the 02/09/2021 in order to allow the computation of the updated Idle factors. These data allow capturing the evolution of the Idle thurst level along the time and they allow also to have some flights with the initial Idle Factor setting of Novair, which can be interesting for the analysis. This dataset corresponds to the Initial configuration scenario.

A reference scenario with flights without DPO would have been very helpful to evaluate the complete fuel reduction obtained by the use of the complete set of flight optimization solutions. Without this scenario, this complete assessment have been obtained thanks to simulations.

At the end, these different configurations contain the following number of flights:

Scenario Description	Initial configuration	Reference	Improved
Number of Flights	883 flights	834 Flights	362 Flights

E.5.4 Summary of Exercise EXE-05B Assumptions

Identifier	Title	Type of Assumption	Description	Justification	Impact on Assessment

Table 32: Demonstration Assumptions overview

No assumptions were formally tracked.

E.6 Deviation from the planned activities

Deviation 1: CPO not available

Initially, the use of a climb optimization function was also part of the scope. This function is CPO, Climb Performance Optimizer, and aims at computing the most optimum climb speeds which minimize fuel consumption and CO2 emissions. The optimization is mission centric and then considers additional climb conditions to the one considered by the FMS as for example the weather, the speeds constraints or the climb thrust setting. It is also a solution based on a tail centric aircraft performance model. This model is updated for each individual aircraft along its life by using the continuous data stream (QAR, DAR etc…) leading to a more accurate A/C performance model (digital twin).

Finally CPO was not enough mature to be part of the exercise. Some validations are still in progress.

Deviation 2: Collaboration with WIZZAIR

The initial exercise was planned with WIZZAIR, but due to their operational constraints, it was difficult to have a regular collaboration. The preparation of the exercise has been achieved in July 2022, leading to a reduced time for the execution and the analysis of the exercise. The required data for the computations have finally not been provided. Without data, the analysis of the exercise is not possible.

In order to ensure the exercise, it has been decided at beginning of 2022 to work also on an equivalent exercise with Novair.

The main interest for the exercise with WIZZAIR compared to Novair was the possibility to have a reference scenario without DPO, which would allow having an assessment of DPO based on flights instead of simulations.

Deviation 3: Opportunity to Fly PBN procedure at Vienna

Initially, combine a descent-approach with the flight optimization solutions and with the PBN procedure of Vienna from the EXE-05A was identified as an opportunity due to the flight network from WIZZAIR. But, this opportunity being connected to the WIZZAIR participation, the opportunity was dismissed.

Deviation 4: Removal of Objective OBJ_VLD_ALBATROSS_002 "Large scale implementation"

Given the smaller size of the fleet concerned by the deployment, it was considered that objective OBJ_VLD_ALBATROSS_002 "Large scale implementation" was not relevant; this objective has been has been removed from the scope of EXE-05B. The impact is considered minor, since DPO and IFO are standard products available on Airbus aircraft, and usage on a complete fleet does not create additional requirements than on some aircraft.

E.7 Demonstration Exercise EXE-05B Results

E.7.1 Summary of Exercise EXE-05B Demonstration Results

Demonstration Objective ID	Demonstration Objective Title	Success Criterion ID	Success Criterion	Sub-operating environment	Exercise Results	Demonstration Objective Status
OBJ_VLD_ALBATROSS_001	1. Greener descents		Confirm reduction of CO2 emissions		DPO/IFO allow reducing CO2 emissions	Partially OK (partially because based on theoretical simulations)
OBJ_VLD_ALBATROSS_001	2. Sustainable descents		Confirm maintaining of the reduction of C02 emissions over the time		Deviations to the reference aircraft level is confirmed (difference at ~16kg of CO2)	OK
OBJ_VLD_ALBATROSS_001	3. More predictable descents		Confirm a reduction of the airbrakes use and / or an increase of Idle thrust use.		A reduction of airbrakes use and an increase of Idle thrust use are confirmed	OK

Table 33: Exercise EXE-05B Demonstration Results

1. Results per KPA

The Main KPAs concerned by the Exercise are efficiency and predictability. The results about the efficiency are presented in the section A.3.2. and concerned the estimation of the fuel / CO2 reduction. The results about the predictability are presented in the section A.3.2.3 and are linked to the estimation of an increase in the use of the FMS managed mode.

In the scope of the exercise, no impact on the capacity, safety, security or others were expected and no impact have been observed or reported by the pilots.

No comparable solution on the improvement of the aircraft performance representativeness in descent is identified in the SESAR catalogue. The comparison with others results available for the SESAR solution is not possible.

2. Results impacting regulation and standardisation initiatives

Not applicable

E.7.2 Analysis of Exercises Results per Demonstration objective

1. EXE-05B OBJ-VLD-ALBATROSS-001 Results

This exercise contributes to objective OBJ_VLD_ALBATROSS_001 along three axes :

1. Axis of the Objective = Demonstrate the reduction of CO_2 emissions and fuel consumption thanks to the use of DPO and IFO solutions in descent.

The effect of DPO has been computed based on simulations. As explained above, the computation based on real data is not possible because there is no aircraft without DPO in the Novair fleet.

Based on several simulations realized on A321, the global benefit estimated by the introduction of DPO and IFO is around 50kg of fuel and 160kg of CO_2 by flight. This benefit is obtained by an improved identification of the idle thrust level associated to an optimization of the associated engine thrust margins.

All the recent NEO aircraft can take benefit from this improvement, which is the case for Novair on the A321NEO aircraft, explaining why the use of a reference situation without DPO was not possible.

2. Axis of the Objective = Demonstrate that the use of IFO allows maintaining the fuel benefits mainly obtained with DPO along the time.

The Idle factors have been computed for the two aircraft based on the 6 months of data from the initial configuration.

The following graphic presents the evolution of the Idle Factor according to the time for the period from 02/09/2021 to 01/03/2022 and for the MSN SE-RKA:

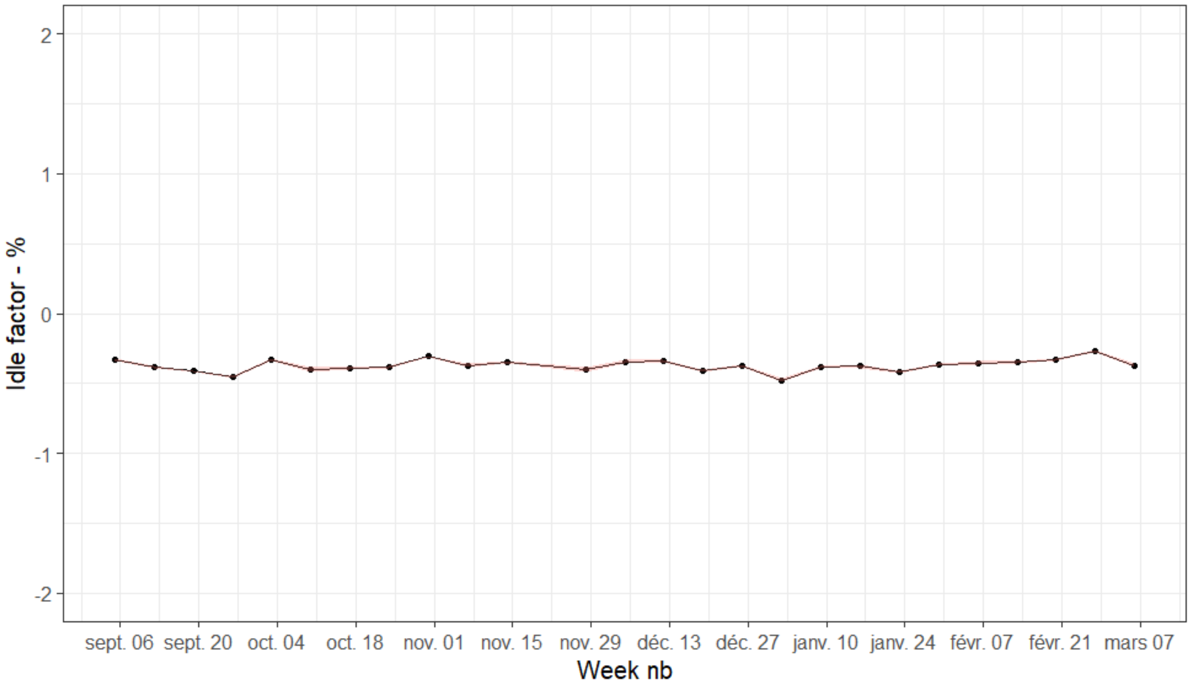


Figure 100: **Evolution of the idle factor on 6 months for MSN SE-RKA**

The following graphic presents the evolution of the Idle Factor according to the time for the period from 02/09/2021 to 01/03/2022 and for the MSN SE-RKB:

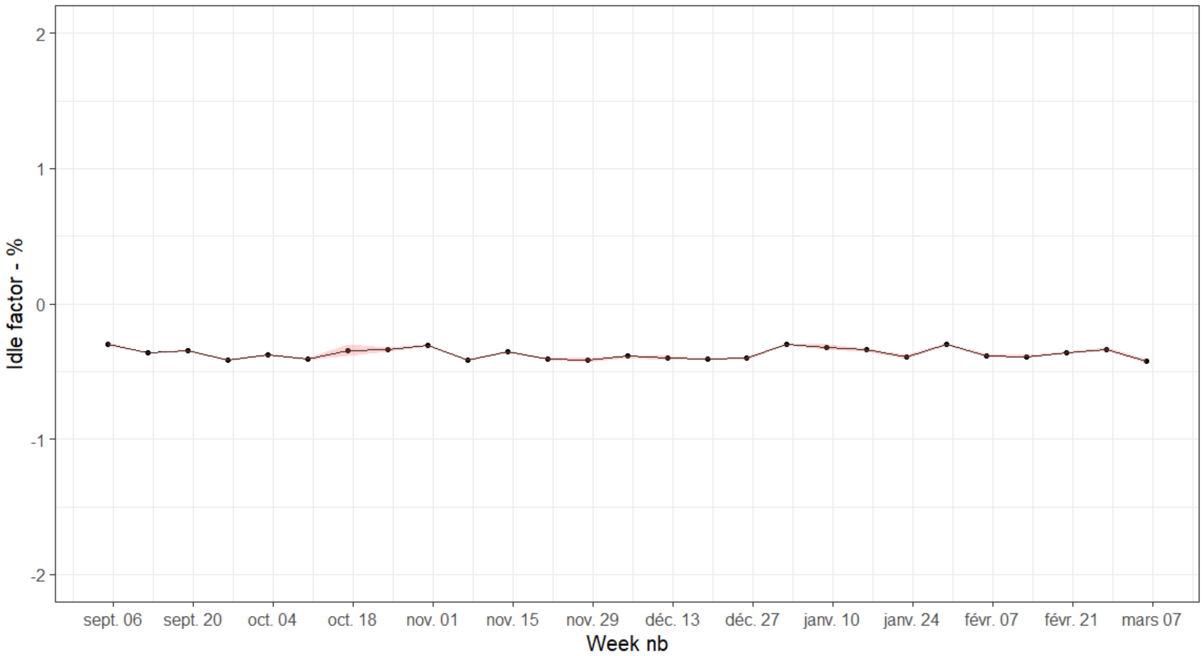


Figure 101: **Evolution of the idle factor on 6 months for MSN SE-RKB**

The evolution of the Idle factor corresponds to the variation of the Idle Thrust level along the time. These results demonstrate that the computed Idle Factor values are rather low for these two aircraft: around -0.3% / -0.4% compared to a reference at 0. These low values are in line with the age of the two aircraft, which are quite recent. The entry into service was mid of 2017. Indeed, for recent aircraft, the variation of the Idle thrust is expected to be low which is confirmed here with these results.

Note: The possible range for the Idle factor as entry in the FMS is [-9,99 : 9,99].

In terms of evolution in time, the Idle factor levels appear rather stable on the six months of data. This is why, only one adjustment by aircraft has been proposed to Novair during the period of the exercise.

Evaluation of the fuel / CO_2 benefits thanks to simulations:

AIRBUS has computed with simulations tools an estimation of the fuel reduction for the computed idle factors. The principle is to compare simulated descent trajectories at Idle Factor =0 versus simulated descent trajectories at the computed Idle Factor, covering the operational range in terms of Mass. The range of fuel difference is between 2kg to 7kg. In average, the estimated benefits can be considered at ~5kg in fuel and ~16kg in CO_2 by flight, which is coherent for almost non degraded aircraft.

Evaluation of the fuel / CO2 benefits thanks to real flights:

The objective with the assessment based on real data is to confirm the fuel / CO2 reduction computed with simulations. The assessment method corresponds to the method proposed by the WP4 and consists in a normalization of each flown descent by the optimum descent profile and a comparison between the normalized descents from the reference scenario versus the ones from the improved scenario.

The normalization of each descent consists in computing an optimized descent profile. This optimum descent profile corresponds to a descent with no constraints (no constraint from the STAR), starting from the real In-Flight point positioned at 200NM from the destination and going the most directly as possible to the destination.

The following graphic presents the principle of the method:

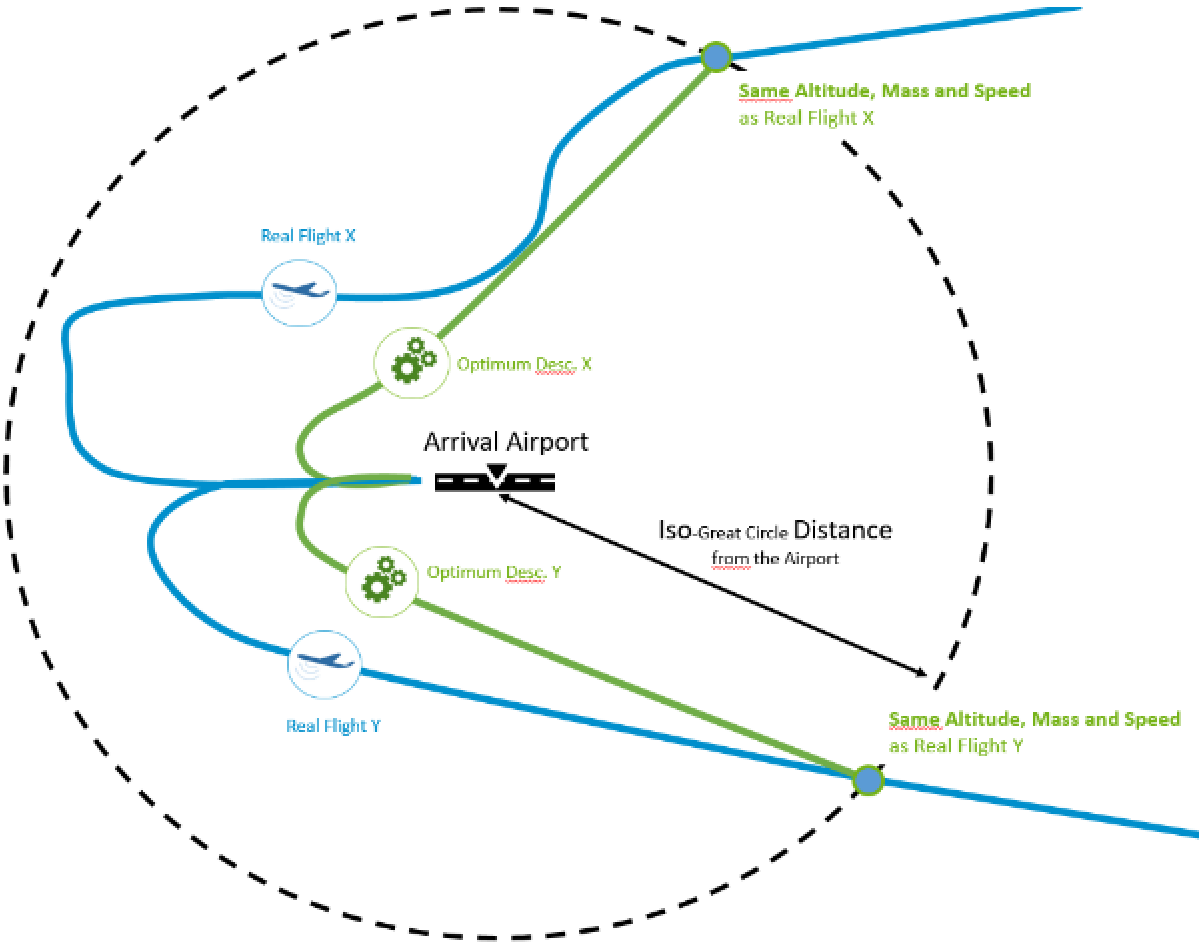


Figure 102: **Normalization of the real descent by its optimum**

The initial conditions from the optimum descent corresponds to the ones from the real flight in terms of mass, altitude and speed. The weather conditions correspond to the Global Forecast System analysis from NOAA at the flight time in order to be in similar weather conditions as the flight (mainly wind and temperature). In terms of aircraft performance, the selected aircraft type is the same as the real flight with the known corrections as performance factor and Idle factor.

For each flight, a difference in fuel consumption is computed between the real trajectory and the optimum descent. The optimum descent being computed in similar conditions in terms of mass, weather conditions and aircraft performance, the difference in fuel corresponds to a change of the descent published procedures, controllers tactical interventions and/or in-flight optimization.
This method allows comparing the flights all together independently from the flight conditions. In this exercise, the objective is to compute statistically the average delta fuel from the reference flights and from the improved flights, compare these two obtained delta fuel and compute the fuel / CO_2 difference.

At the end, this study does not allow to confirm the results based on simulations and was not conclusive. Indeed, the level of the expected difference in terms of fuel is rather low which tends to be inferior to the accuracy level of the method. Even if real flight data are used with this method, there are still some sources of error as for example the real mass of the aircraft or the weather model used in the optimum descent computation. These sources have to be identified with additional analysis in order to improve the level of accuracy.

The next part, corresponding to the statistical analysis of flight parameters, demonstrates the coherence between the idle level from the operational data and the computed fuel / CO_2 with simulations, giving confidence in these computed values.

3. Axis of the Objective = Demonstrate an improvement in the management of the energy in descent.
- demonstrate the reduction of the airbrakes usage in descent;
- demonstrate the reduction of the thrust increase in descent;
- encourage the use of the FMS management mode in descent;

For this objective, it has been decided to take benefits from the availability of the initial configuration scenario which was flown with a lower value of Idle Factor (-2), offering the possibility to see the impact of this configuration in terms of energy management.

The principle of the demonstration is based on a statistical analysis of different flights parameters according to the altitude. The average of the identified parameters is computed over an altitude range of 1000Ft. For each studied flight parameters, a comparison between the three scenarios is realised.
The studied flight parameters are mainly:

- The level of airbrakes use, which allows identifying over-energy situations. These situations correspond to an aircraft above the optimum descent profile (profile at minimum thrust / Idle), requiring to use additional drag. In terms of fuel consumption, this situation can be considered as a descent engagement after the optimum top of descent leading to an over-consumption due to the additional segment in cruise.
- The level of Idle thrust, which allows identifying under-energy situations. These situations correspond to an aircraft below the optimum descent profile (profile at minimum thrust / Idle), requiring to use additional thrust. In terms of fuel consumption, this situation can be

considered as a descent engagement before the optimum top of descent leading to an over consumption due to the additional thrust.

The results are not presented below 5000FT because it corresponds to the approach phase, which is very constrained (corresponding to the STAR procedure) and does allow capturing the effect from the idle factor.

Results for all the descents:

The following graphic presents the level of airbrakes according to the altitude and for the three levels of idle factor on all the descents from the studied dataset:

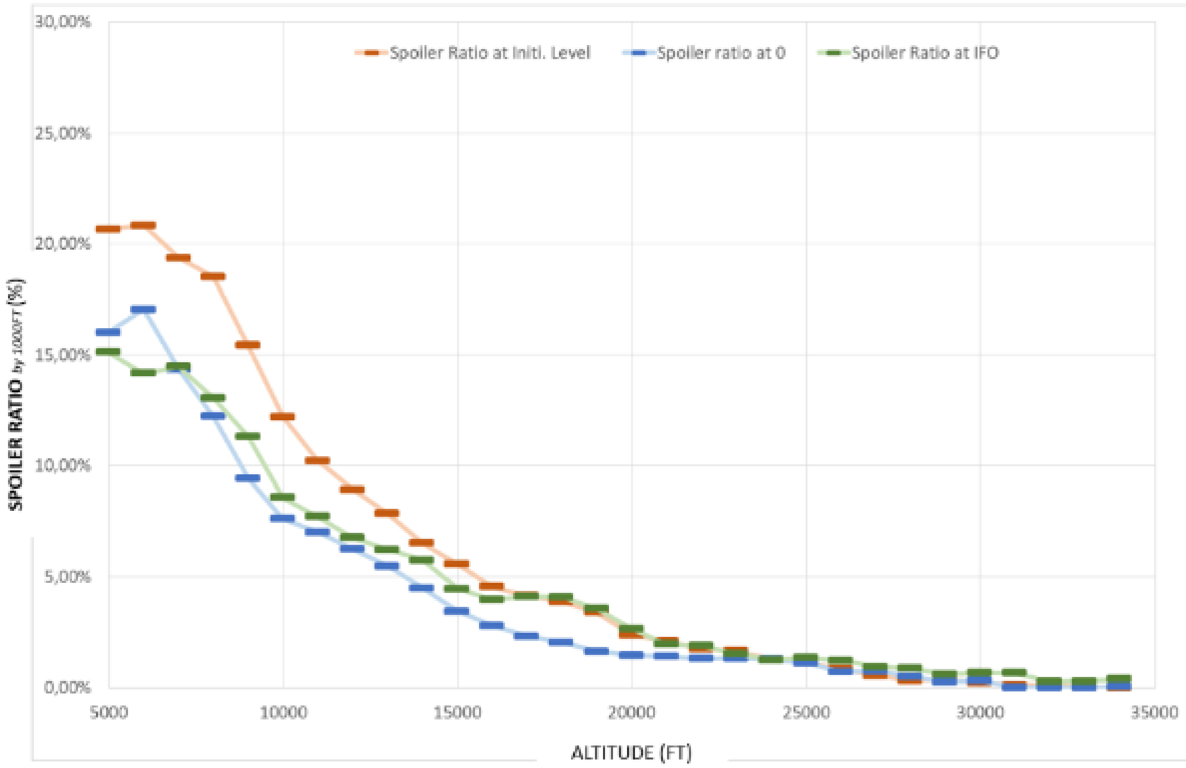


Figure 103: Spoiler ratio for all the descents

The level of airbrakes increases along the descent, which is logical because the energy management is more important when the aircraft becomes close to the first constraint of the approach.

The results demonstrate that the initial level of idle factor leads to a higher use of the airbrakes, especially below 15000Ft, where the use can be superior of until 7% compared to the two others levels.
Concerning IFO, despite the reduction of the idle factor, the level of airbrakes use stays equivalent to the level of use with the reference situation at idle factor equal to 0.

The following graphic presents the idle ratio according to the altitude and for the three levels of idle factors on all the descents from the studied dataset:

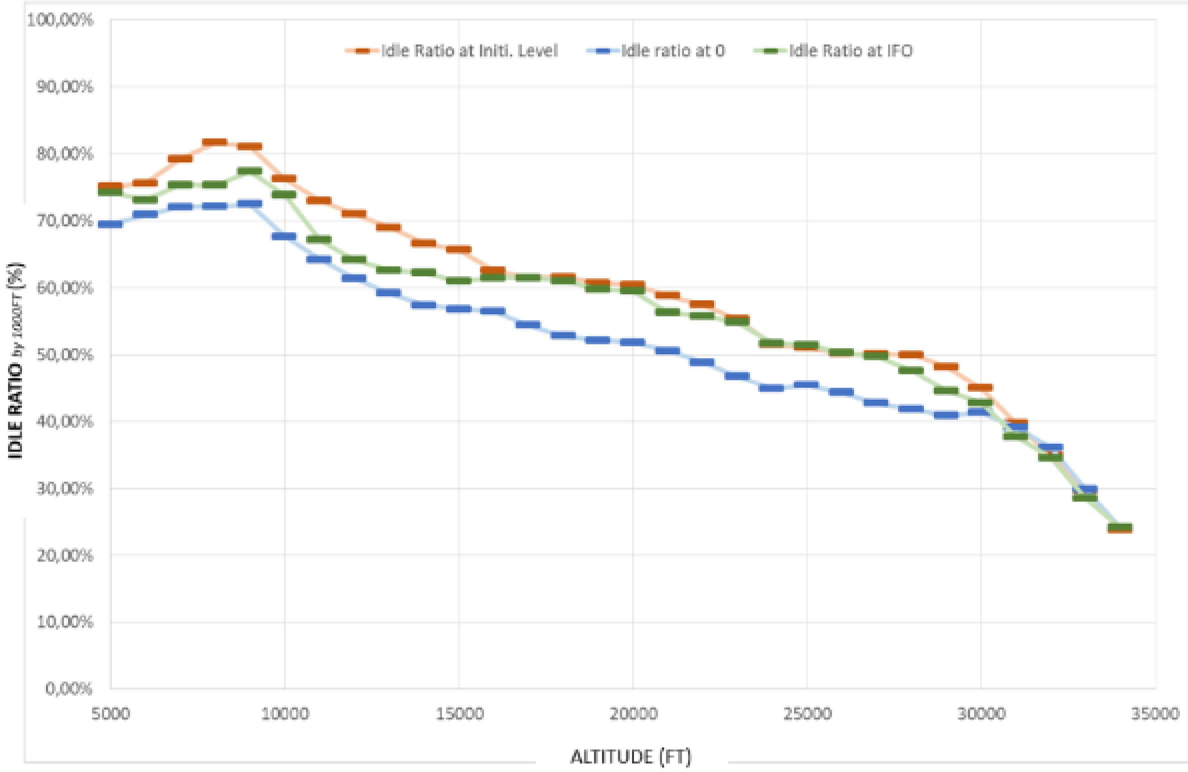


Figure 104: **Idle ratio for all the descents**

The minimum and the maximum idle ratio values are coherent from the minimum and maximum idle factor. The initial level of idle factor, being the smallest from the three, leads to the highest level and the reference level at 0, being the highest, leads to the lowest level. The difference between both is around 7% in average.

Concerning IFO, it is interesting to see that the level is always superior to the reference level and sometimes very close to the level obtained with the initial level. In average, with IFO, the Idle ratio is increased by 5% compared to the reference at 0.

<u>Results on Stockholm Arlanda</u>

In order to reduce the effect from the operational context, which can be different between the different datasets, only the descents on Arlanda, the most representative airport from the global dataset, have been selected for a second analysis. The filter leads to consider 205 flights with the initial idle factor level at -2, 164 flights with the reference idle factor at 0 and 71 flights with IFO.

The following graphic presents the level of airbrakes according to the altitude and for the three levels of idle factor on the descents to Arlanda:

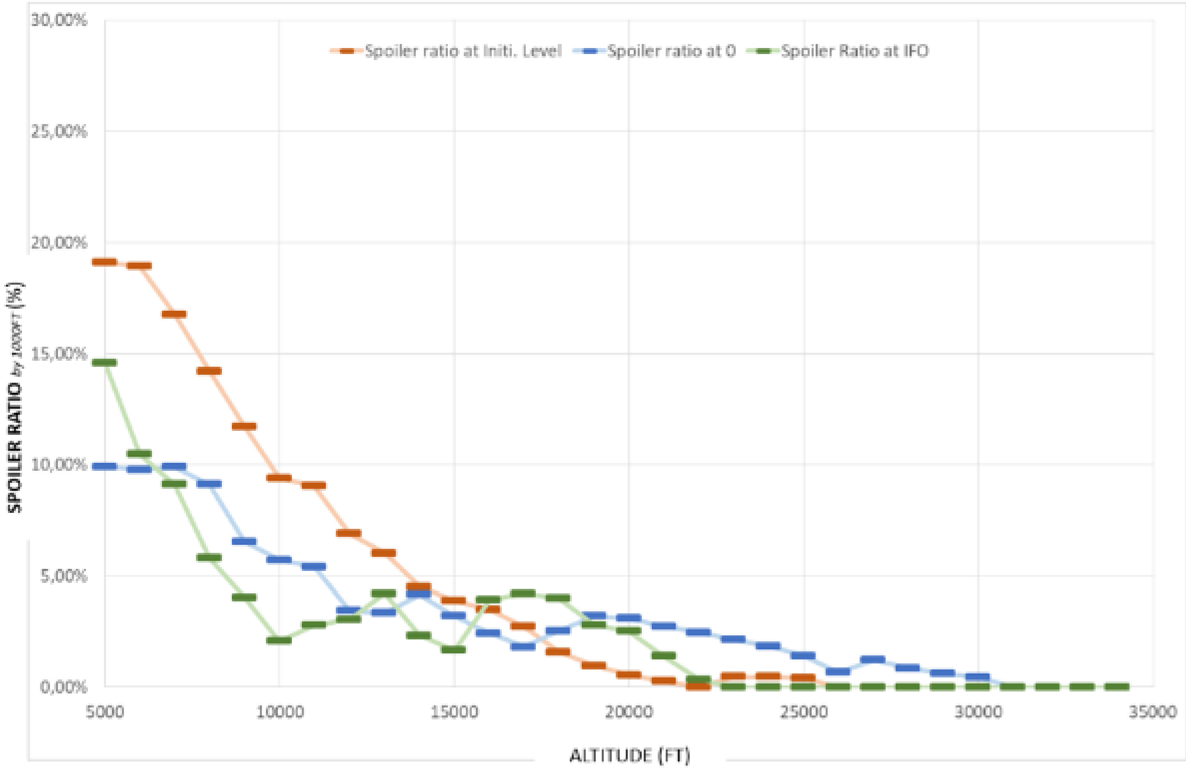


Figure 105: Spoiler ratio for descents on Arlanda

The results tend to confirm the ones obtained on all the descents. The initial level of idle factor increases the level of airbrakes use, while IFO is at a level similar to the reference idle factor at 0.

Note: Compared to the first results with all the descents, the curves have more variability. It can be explained by the reduced size of the dataset with the filtering on Arlanda. For example, the IFO dataset considers only 71 flights which tends to be the critical level for a statistical analysis on these parameters.

The following graphic presents the idle ratio according to the altitude and for the three levels of idle factor on the descents to Arlanda:

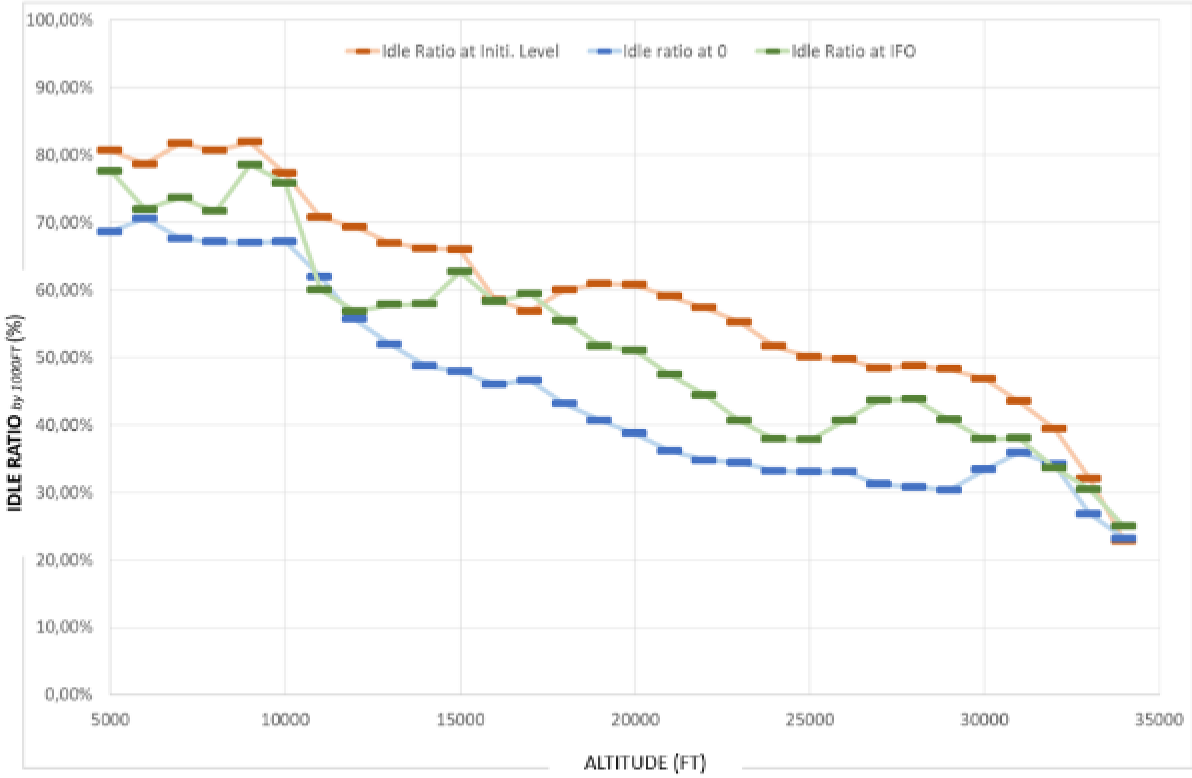


Figure 106: **Idle ratio for descents on Arlanda**

The results tend to confirm the ones obtained on all the descents. IFO leads to an Idle ratio between the reference at 0 and the initial level. Compared to the first results with all the descents, the difference are more important. The initial level leads to a superior idle use of around 14% compared to the reference situation. And IFO leads to a superior idle use of around 7%.
This difference of range on Arlanda demonstrates that the operational context can be a parameter to consider in the adjustment of the idle factor.

The combination of these graphics, Airbrakes (spoilers) and idle ratios, demonstrates that IFO leads to more optimized descents by increasing the level of idle use without increasing the level of airbrakes use.

Note: It would have been interesting to iterate around the IFO setting, with a more reduced idle factor, to find the optimum corresponding to an increase of the idle ratio without increasing the use of airbrakes. But this additional configuration was not in the initial plan of the exercise, and it was not possible to introduce it at the end.

The use of the FMS managed mode has also been analysed, but the results do not illustrate significant difference between the different levels of idle factor. Having a more optimized descent profile computed by the FMS is an element that can encourage the use of the managed mode in descent by the pilot, but it requires a more important exposure time in order to capture an effect.

E.7.3 Unexpected Behaviours/Results

The main change with the evaluated solutions concerned the management of the energy in descent for the pilot. Based on the feedback from Novair pilots, no unexpected behaviours have been observed in this exercise.

In addition, the analysis does not identify some unexpected results.

E.7.4 Confidence in the Demonstration Results

1. Level of significance/limitations of Demonstration Exercise Results

As computed in this exercise, the estimated benefits are around 50kg of fuel and 160kg of CO2 by descent on A321. However, these benefits depend on the aircraft type and the aircraft configuration. In this exercise, the Novair fleet is composed of two A321NEO, which are basically equipped with DPO. All new NEO AIRBUS aircraft are now basically equipped with DPO while on AIRBUS SA CEO aircraft, DPO is a modification. Having a mixed fleet between NEO and CEO in this exercise would have improved the significance of the results for DPO.

The benefits of DPO are fully available at the entry into service. But, with the time, the aircraft performance evolves and only a regular adjustment of the idle factor with a function as IFO will guarantee a maintain of the DPO benefits in the time. Extrapolation of the IFO benefits at higher level requires characterizing the evolution of the idle level, for an aircraft, along the time, which is only possible by having a mixed fleet in terms of aircraft ages. In this exercise, the two considered aircraft are rather recent and have an equivalent age. Having a mixed fleet in terms of aircraft age would have improved the significance of the results for IFO.

2. Quality of Demonstration Exercise Results

The main issue in terms of quality concerns the missing of a reference situation for the assessment of DPO. Due to this issue, the assessment is only based on simulations.

Concerning IFO, the fuel / CO2 assessment is based on simulations, but the analysis of the real flight data demonstrates that IFO leads to a more optimized descent profile by an order of magnitude which is coherent to the fuel / CO2 assessment.

3. Significance of Demonstration Exercises Results

DPO/IFO being applied on every flight, the significance of the results depends on the Novair fleet (for the aircraft) and the associated network (for the operational context).

E.8 Conclusions

This exercise, mainly focus on IFO due to the Novair fleet configuration, demonstrates that the use of solutions improving the accuracy of the aircraft performance model in descent allows the computation of a more optimized descent profile by the FMS aiming at flying more efficient descent.

The potential benefit brought by this type of solution on A321 NEO in case of both DPO and IFO is estimated at ~50kg of fuel and 160kg of CO_2 per descent. This exercise demonstrates a part of this improvement: the adjustment of the idle factor by IFO allowing maintaining the benefits along the time. The impact of IFO depends on the age of the aircraft, which are quite recent for the exercise.

In this exercise, **IFO was applied on 362 flights**. The estimated benefit by flight being of around 16kg of CO_2, the **total reduction of CO_2** obtained in this exercise **is at ~5792kg** (~6T).

In addition to the values, the demonstration of the capacity to optimize the descent profile computed by the FMS suggests that additional benefits can be expected by the combination of these functions with ATM solutions as for example: Continuous Descent Operations, Controlled Time of Arrival or by the use of the EPP, taking benefit of a potential improvement in terms of predictability.

E.9 Recommendations

E.9.1 Recommendations for industrialization and deployment

No recommendation for industrialization and deployment.

DPO is an update of the performance data-basis and requires no aircraft modification. It is already deployed.

For IFO, the adjustment of the Idle Factor is already available on-board, the main improvement being in the development of a capacity to regularly adjust the value.

E.9.2 Recommendations on regulation and standardisation initiatives

No recommendation on regulation and standardisation initiatives.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

Appendix F Demonstration Exercise #06 Report

F.1 Summary of the Demonstration Exercise EXE-06A Plan

The aim of this exercise was to undertake a detailed assessment of the environmental benefits brought by the deployment of "RNP1 to Final" procedures at Paris-CDG. In preparation of the general implementation of "continuous descent" procedures in the Paris area, DSNA has organized a campaign of live trials, to which Air France has contributed; the trials design and organization took place before ALBATROSS project, and these activities are not themselves part of this project. The part that is covered by ALBATROSS is the design of dedicated analysis methods that would allow to finely evaluate the benefits. The implementation by Air France and DSNA of the appropriate data processing tools to support the analysis methods was also done as part of ALBATROSS.

In the context of these trials, Air France has performed measurements of actual fuel usage during the descent phase and an evaluation of its reduction thanks to improved descent procedures.

DSNA has performed an evaluation of the noise and fuel reduction resulting from the arrivals being managed as continuous descents.

The methodology and tools implemented in EXE-06A have also been applied for the other parts of EXE-06, in particular EXE-06B.

F.1.1 Exercise description and scope

The "PBN-to-Final" Live Trials

In view of the future deployment of the continuous descent concept at Paris-CDG), DSNA has defined a set of RNP1 paths to the interception of the final approach axis, based on ILS or LOC or RNP APCH (performance-based navigation, using satellite positioning data). The purpose of this concept is to achieve operational (lateral and vertical) independence between aircraft flying simultaneously along the RNP1 segments connected to the final approach axes of the parallel runways in service, to allow continuous descent for both aircraft.

In order to prepare the demonstration of the target concept, an operational evaluation step has been scheduled from January to March 2021 to analyze and assess some components of the final system.

Full details of the procedures can be found in AIC Circular "A 01/21" published by DSNA in early 2021.

The illustration below sketches the simplified structure of the procedures (this is a conceptual schematic, not to scale).

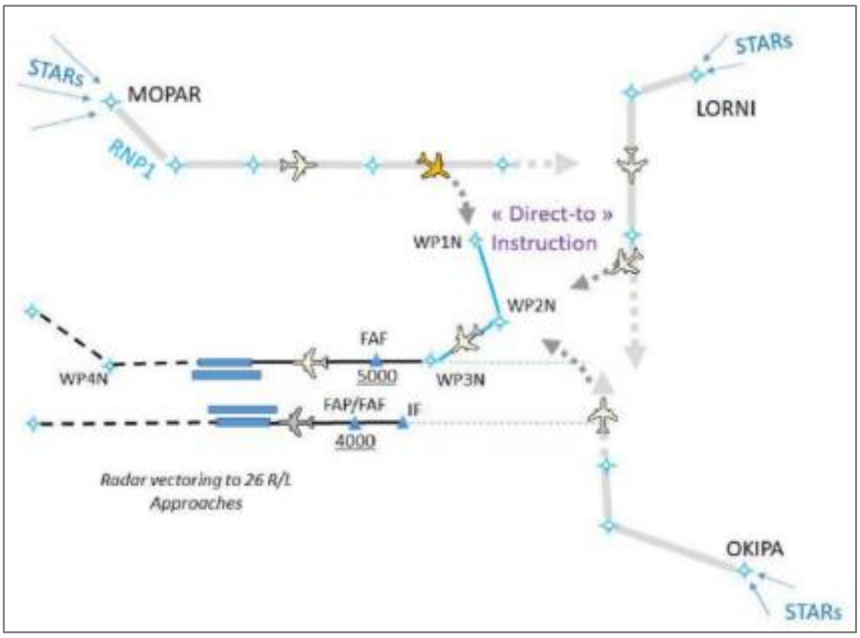


Figure 107 – PBN-to-Final in CDG: conceptual structure

A comparison between the standard (left) and improved (right) transition procedures is represented below.

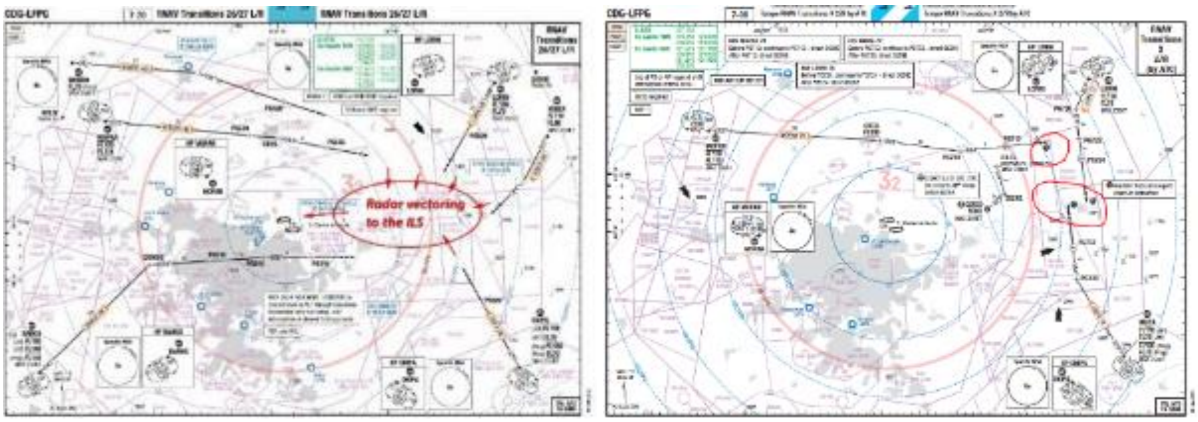


Figure 108 – Comparison of Arrival Transitions at CDG ("standard" and "PBN-to-Final")

The temporary system, subject of the evaluation, replaces by RNP 1 paths (only in specified time slots) the initial approach paths normally performed under radar vectoring. During the evaluation, in order to perform the ILS/LOC or RNP final approaches on runway 27R, the aircraft arriving from the north by IAFs MOPAR and LORNI and from the east by IAF OKIPA (in case of rerouting to the north runway) follow the new RNP 1 paths. These were published with identifiers "7X" (to ILS) and "7R" (to RNP).

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Co-funded by the European Union

Preceding the "RNP1 dogleg", each initial approach path resulting from an IAF (MOPAR, LORNI or OKIPA) is composed of several segments; the path is open, in order to allow controllers to sequence the traffic if necessary. Crews extend the last segment until a "direct-to WPxN" instruction is received from the ATC. The uncertainty from vectoring is very greatly reduced, compared to the standard transition procedures, since there is a guarantee of the availability of the subsequent points of the procedure at the end of the vectoring, and the interception of the 27R final axis is always guaranteed via the segments of the corresponding dogleg. During peak hours, the initial branch could be extended on average by (respectively) 5 NM, 3 NM, 5 NM past the last "upstream" waypoint of the arrivals (respectively WP PG712, PG724, PG732 for MOPAR, LORNI, OKIPA arrivals).

The implementation of these initial approaches does not modify the RNP 27R and ILS/LOC 27R final approaches that they feed.

The live trials were performed from the 18th of January to the 21st or April 2021.

The operating procedures during the live trials were the following:

The exact implementation time slots could vary from day to day, depending on the circumstances (traffic load upon arrival, weather conditions, availability of technical means, etc.) The activation time slot of the procedures was announced every day by the ATIS, between 1 hour and 40 minutes before they were actually implemented.

These approaches were used by all RNP 1 approved crews upon arrival from MOPAR, LORNI and for some RNP 1 approved crews from OKIPA. The controller would use the following phraseology when issuing the approach clearance: « [Call sign], cleared [MOPAR 7X or LORNI 7X or OKIPA 7X] approach, expect [ILS or LOC] 27R » (example for the ILS/LOC final approach case; the RNP final approach would say "7R"). Afterwards, as said above, at the proper time depending on the initial approach and the traffic organization, a «Direct to» instruction was given either to WP1N or WP2N of the "dogleg" segment.

In summary, five improved transitions from up to three of the four IAFs were used on one arrival axis during 3 to 4 hours a day, 5 days a week, during 3 months (3 PBN-to-ILS from 3 IAF, 2 PBN-to-RNP from 2 IAF, for arrivals facing West, on northern RWY: 27R)

The assessment methodology

For Air France:

The data analysis is performed in the SkyBreathe tool.

This platform facilitates the automation of the analysis of very large volumes of data records from multiple sources. In particular, flight or aircraft data from flight recorders, operational flight plans, datalink sources, etc. can be combined with information from the specific conditions surrounding each individual actual flight (weather, ATC constraints, etc.) The tool supports the tasks of raw data integration, data cleansing and quality control, computation of specific indicators, support for data analysis, exploration and presentation.

In the scope of ALBATROSS, Air France has devised a methodology for the fine-grained analysis of actual trajectories, specifically oriented to the fuel burn perspective. The evaluations are based on the actual flight data, as recorded by the flight data recorders (QAR or FDR): in particular, trajectories (in all 4D dimensions) and amount of fuel used.

Three samples of flights are have been used :
- "Experiment" sample: flights having flown the " PBN to Final" procedure; 262 flights in total
- "Standard" sample: flights from 2019 (full traffic conditions, standard procedures); 6802 flights total
- "Low traffic" sample: flights from low traffic periods of 2020 (Covid pandemic); 918 flights total

In the two reference samples ("Standard" and "Low traffic"), from the set of all available flights, only trajectories very close to the conditions of the exercise have been kept: ground distance of the approach segment within +/- 5% and less than 5 NM from the waypoint being studied.

The fuel burn is measured on specific segments, defined based on reference waypoints or reference altitudes (obviously specific to each arrival flow: from the West, with a "downwind" stretch; or from the East, straight-in).

The analysis has focused on the measurement of the following quantities:

- For the Horizontal profile: flight time, flight distance, fuel burn

- For the Vertical profile: identification of level-offs: time and distance flown, fuel burn; the horizontal and vertical speeds are used to classify the types of level-offs (deceleration level-offs, sequencing level-offs, etc.)

The method devised to assess descents is based on the calculation of the impact of the level-offs on the vertical profile. Referring to Figure 109, the dotted red trajectory is the actual flown trajectory of a certain flight; this is compared with an ideal descent trajectory, where from the last cruise altitude the flight descends directly to the runway, with the same rate of descent. The fuel consumption corresponding to the actual descent is known from the flight recorders; the fuel consumption corresponding to the optimum trajectory is estimated from the knowledge of the aircraft and flight parameters, applied to the new altitude, distance and time. The level-off impact of the trial sample is then compared to the level-off impact of the reference sample. (In this sense, the methodology is a variant of the "Delta fuel-burn" method described by ALBATROSS Work Package 4.)

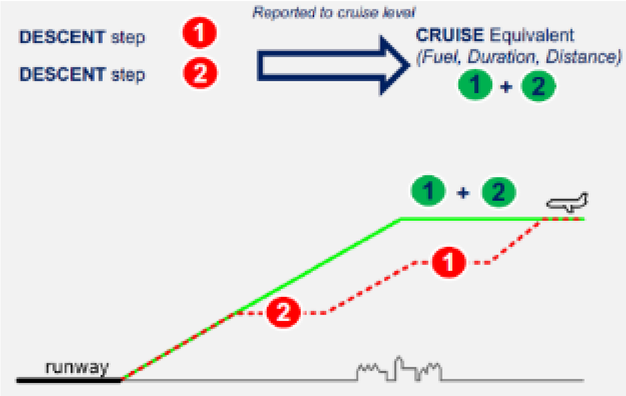

Figure 109 – Level-offs impact assessment

The outcomes are described in section C.3.1.

For DSNA :

DSNA performed the analysis of the environmental performance (visual / noise impacts / fuel consumption /CO_2 emissions / energy atypicity) of this evaluation.

The visual impact was studied using a DSNA model for calculating the density of overflights from the radar trajectories observed during the evaluation and in conventional situations (radar guidance).

To study the sound impact, a sound measurement campaign was carried out by the DSNA in collaboration with ADP and Bruitparif.

To analyze the impact on fuel consumption, CO_2 emissions, and energy atypicity, a Machine Learning model developed in collaboration between ENAC and the DGAC analyzing radar trajectories was used.

F.1.2 Summary of Demonstration Exercise EXE-06A Demonstration Objectives and success criteria

Two ALBATROSS objectives were addressed by EXE-06A :

OBJ_VLD_ALBATROSS_001: To enact operational procedures (applicable under specific operational circumstances) that achieve a reduction of CO2 and noise emissions during final approach.

Success criteria : Over the duration of the "PBN-to-FInal" live trials (Q1/2021) measure a reduction of noise and CO2 emissions on the production flights arriving to Paris CDG (the procedure was implemented on runway 27R).

OBJ_VLD_ALBATROSS_002: To apply on as many concerned flights as possible, during final approach, procedures (devised as part of objective n. 1) achieving a reduction of CO2 and noise emissions.

Success criteria: The trials have the purpose to confirm, in practice and on a significant scale, the feasibility of the concept: show that pilots and ATCOs correctly handle the procedures that have been designed, coded and published.

See sections below for the detailed description of the results.

F.1.3 Summary of Validation Exercise EXE-06A Demonstration scenarios

See in section C.1.1 the description of the "Assessment methodology":

The Solution scenario is: any flight using one of the "PBN to Final" procedures during the Live Trials period; 262 flights in total have been analyzed from this sample.

The Reference scenario is: flights arriving to runway 27R from the concerned IAFs (MOPAR, LORNI, OKIPA), outside the periods of activation of the "PBN to Final" procedures. Two different reference samples have been used for the analysis: flights from 2019, under "full traffic" conditions (6802 flights total) and flights from the low traffic periods of 2020 during the Covid pandemic (918 flights total).

F.1.4 Summary of Demonstration Exercise EXE-06A Demonstration Assumptions

Identifier	Title	Type of Assumption	Description	Justification	Impact on Assessment

Table 34: Demonstration Assumptions overview

No assumptions were formally tracked.

F.2 Deviation from the planned activities

No deviations took place.

F.3 Demonstration Exercise EXE-06A Results

F.3.1 Summary of Demonstration Exercise EXE-06A Demonstration Results

Objective ID	Title	Success Criterion ID	Success Criterion	Sub-operating environment	Exercise Results	Objective Status
OBJ_VLD_ALBATROSS_001	Greener trajectories	CRT_VLD_ALBATROSS_001	Perform optimized descents. Confirm measurable reduction of CO_2 emissions.		Average of 75 to 150 kg of CO_2 reduction per arrival (depending on a/c type and IAF) equivalent to 3-8% reduction on the arrival phase.	OK
OBJ_VLD_ALBATROSS_002	Greener collaborative procedures	CRT_VLD_ALBATROSS_002	Reduce constraints during specific time windows		Improved procedures published in AIP (conditional). Cleared to 750 flights (all operators)	OK

Table 35: Exercise EXE-06A Demonstration Results

1. Results per KPA

The exercise addressed the KPA "Environmental Efficiency".

An average reduction of 75 to 150 kg of CO_2 per arrival (depending on a/c type and IAF) has been measured, equivalent to 3-8% reduction on the arrival phase.

2. Results impacting regulation and standardisation initiatives

No impact on standardisation and regulation initiatives.

F.3.2 Analysis of Exercises Results per Demonstration objective

OBJ_VLD_ALBATROSS_001 Results

The analysis was performed at first on the entire sample of live trial flights, that is calculating the fuel differences over all flights from all IAF points and for all aircraft types.

However, the number of different a/c-types over the IAFs is very different, and distributed differently in the different samples. For example, flights on A320 family represented 81% of the "Standard" sample (6% over CRL, 68% over DEVIM, 7% over OKIPA) whereas they were 41% in the "Trial" sample (9% over CRL, 13% over DEVIM, 19% over OKIPA).

Therefore, in order to have more representative results, the analysis has been performed by grouping a/c-type and IAF.

The outcomes for the groups having a significant number of flights are the following:

- Average fuel burn during final descent:

Waypoint / a/c type	Average fuel burn Trial vs Standard	Average fuel burn Trial vs COVID
DEVIM LORNI / A320	-8.45 %	-1.81 %
MOPAR CRL / B777	-3.11 %	-7.79 %
OKIPA / A320	-5.57 %	-3.87 %

The trial sample has a lower fuel burn than both reference samples.

Level-offs : Proportion of level-offs performed at low altitude (FL130-FL50)

Waypoint / a/c type	Standard	COVID	Trial
DEVIM LORNI / A320	38 %	34 %	7 %
MOPAR CRL / B777	22 %	16 %	11 %
OKIPA / A320	53 %	30 %	42 %

There is a clear reduction of the low altitude level offs in two flows out of three.

<u>**DSNA assessment**</u>

(Detailed results are in DSNA's Report in reference [24])

The number of flights during the evaluation was limited. This number is further reduced after CDO identification according to Eurocontrol requirements (vertical speed analysis). Consequently, the performance results of the PBN to ILS device deduced from the analysis of the Live Trials evaluation recalled below are to be considered in knowledge of these limitations.

1. Potential visual impact reductions:
   - The reduction of visual impact in Live Trials compared to a radar guidance situation is strongly conditioned by the realization of CDOs on the one hand and the proportion of trajectories converging towards the PBN branches on the other hand.
   -
2. Potential reductions in noise :
   - In northern doublet: the noise reductions under trajectory by the improvement of vertical profiles (CDO) thanks to the PBN to ILS device compared to current profiles are low (from **[-1 to -2 dB(A)]** depending on the position relative to the runway threshold and the aircraft type).
   -
   - In southern doublet: noise reductions by improving vertical profiles (CDO) should be stronger: up to maximum values ranging from **[-2 and -4 dB(A)]** on BANOX and **[-3 and -5.5 dB(A)]** on OKIPA depending on the position relative to the runway threshold and the aircraft type.
   -
3. Potential fuel consumption reductions and CO2 emissions:
   - In order to estimate the gain on fuel consumption and CO_2 emissions, the Live Trials results were used by considering operational assumptions (assumptions defined by the Environment Mission) in order to correct the pandemic effect when comparing with the baseline 2019 status quo situation.
   -
   - In northern doublet: fuel consumption reductions (and gaseous emissions) are estimated at:
     1. MOPAR in the study area (CRL/THR27 or 46 NM on average in Live Trials):
        1. **[-6 to -8%]** in a highly regulated situation,
        2. **[-13 to -15%]** in a weakly regulated situation,
     2. LORNI in the study area (DEVIM/THR27 or 52 NM on average in Live Trials):
        1. **[-3 to -4%]** in highly regulated situation
        2. **[-8 to -9%]** in weakly regulated situation.
   -

The method of analysis of fuel consumption (and CO_2 emissions) used in this study is based on the study of radar trajectories, only the northern doublet was studied.

OBJ_VLD_ALBATROSS_002 Results

DSNA :
During the live trials, the percentage of flights with a CDO profile below 8 000 ft was 37% ;

from 20 000ft, it was 26,3%. These results are not what is expected from the project. The live trials highlighted the need to reinforce sensibilization, training, and study of an adapted phraseology.

Air France Qualitative Feedback

- The rate of application of the procedure seemed relatively low; crews did not optimize the vertical profiles upstream from the improved procedures as much as was felt possible. This can be explained with the fact that the trial took place at a time when activity was just restarting after the big slowdown of the covid pandemic: crews had a tendency to apply conservative practices, due to limited practice;
- Intermediate level-offs were performed at the beginning or end of the procedure, but were not eliminated as much as expected.

No safety events linked to the trials have been identified.

F.3.3 Unexpected Behaviours/Results

No unexpected behaviours or results have been observed.

F.3.4 Confidence in the Demonstration Results

1. Level of significance/limitations of Demonstration Exercise Results

The results are considered of good significance.

The new operating method was applied on one runway-end, out of the eight available in CDG.

The methods of quantitative analysis put in place for the exercise were of high significance and could be reused for other exercises.

2. Quality of Demonstration Exercise Results

The demonstration results are of high quality.

3. Significance of Demonstration Exercises Results

The significance of the exercise results are moderately high.

The measured quantities are consistent between the Air France and the DSNA evaluations.

However, the traffic levels during the live trials were low because of the covid crisis, so the operational circumstances may have been not fully representative.

F.4 Conclusions

The PBN-toFinal live trials by DSNA allowed Air France to develop a reliable method to assess the fuel/CO2 benefit on the basis of data from the flight recorders. This methid, as well as the evakuations calculated by DSNA on the basis of flown trajectories (hortrizontal and vertical profiles) show a reduction of CO2 emissions thanks to the PBN-to-Final procedures.

A reduction of noise emissions could be assessed, but is of relatively small magnitude.

F.5 Recommendations

F.5.1 Recommendations for industrialization and deployment

The exercise recommends to pursue the deployment of PBN-to-FInal procedures.

F.5.2 Recommendations on regulation and standardisation initiatives

No specific recommendations are to be made, since PBN procedures are standardized.

F.6 Summary of the Demonstration Exercise EXE-06B Plan

The aim of this exercise was to demonstrate the possibility to enable optimized descents in the Paris area, when possible in specific traffic conditions, by "relaxed" interfaces between control centers; less stringent constraints in delivering traffic are expected to enable: less or shorter level-offs, performed a higher flight levels; flights starting to descend (ToD) later than in current operation or closer to preferred ToD; flights able to better manage their energy in the vertical profile also in terms of speed.

F.6.1 Exercise description and scope

Keeping an aircraft at higher altitudes for as long as possible reduces or eliminates the time and distance of level-offs during descent; any level-off during descent is obviously penalizing for fuel consumption (and therefore CO2 emissions), since it requires thrust to be applied and it interrupts the ideal management of the aircraft potential energy (idle descent).

Completely eliminating level-offs is not possible. Besides the necessary deceleration level-offs, some altitude constraints are necessary (in particular in the structure of the Paris TMA airspace) to separate intersecting traffic flows (departures and arrivals of multiple airports) and to ensure the necessary interfaces between control centers (Paris-ACC and the Approach Controls).

However, when traffic density is not at its peak, Paris-ACC and CDG-Approach are able to coordinate in order to reduce the necessary vertical constraints on the descents. During the strong traffic reduction that happened with the covid pandemic for several months of 2020, French ATC would often be able, with the very low traffic volumes, to allow flights to descend towards Paris-CDG intercepting the Initial Approach Fixes (IAF) at a higher altitude than published.

Based on these precedents, a wider and semi-permanent deployment of these "coordination procedures to allow for conditionally relaxed constraints" was studied as part of the ALBATROSS project (by DSNA in cooperation with Air France and other airlines).

It must be pointed out that although Air France worked closely on the preparation and performed a detailed quantitative analysis, the improvement implemented by DSNA has been available to all flights arriving in CDG, by any airline. The achieved benefits are therefore larger than what reported below (which is based on the measurements by Air France for its flights only).

Multiple instances of "raised altitudes at the IAFs" exercises took place :

1. On the BANOX and OKIPA IAFs, November 2020 until April 2021

2. On all 4 Paris IAFs April until June 2021

3. With an AIP-SUP publication February until July 2022

Two studies of "Further descent optimization from ToD" have also been performed: the improvements made possible at the intermediate altitudes of the TMA (interface between Paris-ACC and CDH Approach) were pushed further upstream, to the interface between the Upper Area Centers and the "extended TMA" (Brest and Bordeaux ACC to Paris ACC) :

4. CDO coordination Brest-ACC, Paris-ACC, CDG-APCH April 2021

5. Study of the PEPAX flow (coordination Bordeaux-ACC, Paris-ACC, CDG-APCH) Q2-Q4/2022

Although these two explorations resulted in a limited number of flight trials (at least during ALBATROSS – later implementation is being considered), they are excellent examples of the approach put forward by ALBATROSS : Examine in detail the constraints of a certain airspace portion; Analyze the reasons that make those constraints necessary; Evaluate whether under specific conditions (eg. certain hours in the day, or certain traffic levels or configurations) the constraints can be relaxed; Define the coordination procedures (ATC/ATC, ATC/Airlines) that must be followed in order to activate the "greener" airspace.

The quantitative analysis of this Demo Report focuses on instances 1. and 2.

Instance 3. is a very-large-scale quasi-permanent generalization.

Operational Setup

Instance 1. BANOX and OKIPA IAFs, November 2020 until April 2021

Paris-ACC and CDG-Approach would coordinate to select the time slots when to apply the improvement.

The improvement would apply to the two southern IAFs BANOX and OKIPA and only for arrivals performing a downwind segment (arrivals BANOX in West-facing configuration and arrivals OKIPA in East-facing configuration).

Under these circumstances, flights would be tactically authorized to fly over these waypoints at respectively FL180 ou FL190 instead of the FL150 published in the STARs. (These are the "Not above" altitudes).

Air France issued an internal communication to pilots, instructing to respect the allowed altitude and to perform the descent as smooth as possible.

Instance 2. All 4 Paris IAFs April until June 2021

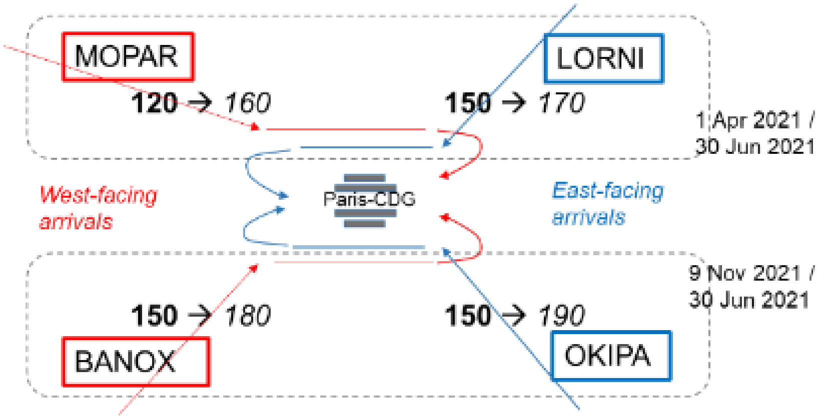

Figure 110 – Overview of EXE-06B implementation on all Paris-CDG IAFs

Same as Instance 1. : Tactical clearance.

Improvement extended to all four IAFs (for arrivals performing a downwind segment).

Activation decided tactically by Paris-ACC and CDG-Approach.

Instance 3. AIP-SUP publication February until July 2022

(Note: the AIP-SUP was eventually extended until the end of 2022)

This instance was a very large scale semi-permanent implementation, that made the improved airspace structure available over almost six months.

It was realized that the traffic conditions allowing for the improved procedures did not need to be decided dynamically, and could instead be activated in specific time slots, only based on runway configuration. This resulted in the publication of an AIP-SUP (nb. 008/22) that described the procedure.

The procedures would be available every day between 13h30 and 17h00 UTC (during winter; one hour earlier during the summer season) as well as in the night between 23h30 - 04h00 (summer: -1 hr).

If conditions allowed, Paris-ACC and CDG-APP could expand the time limits of the evaluation. However, any difficulty encountered in traffic management (adverse weather conditions, accident or incident, unpredicted workload, etc.) was a potential reason to suspend the evaluation.

The optimized descent profiles were restricted to LFPG arrivals operating STAR and downwind initial approach (INA) procedures and active runway configuration in Paris-CDG according to the following combinations:

- West-facing configuration (RWY 27R/L and 26L/R): Western IAFs MOPAR and BANOX

- East-facing configuration (RWY 09L/R and 08R/L): Eastern IAFs LORNI and OKIPA

Based on the experience from the previous instances (with tactical clearance only of an altitude) a work of refinement of the phraseology and additional description of the expected aircraft behaviour was undertaken between Air France and DSNA. It resulted in the detailed conditions of phraseology and provisions of altitudes, speeds and descent ratios all along the descent that have been published in the AIP-SUP.

Instance 4. CDO coordination Brest-ACC, Paris-ACC, CDG-APCH April 2021

In early 2022, when the PBN-to-Final live trials were still active (EXE-06A) an attempt was made to implement full optimized descents from ToD to final approach.

Since EXE-06A concerned the Northern East-facing runway (27R), the EXE-06B variant of interest was the one on the MOPAR IAF. Arrival flows from the North-Atlantic were selected as candidates. For these flights, the Top-of-Descent takes place in the airspace of Brest-ACC. The arrival flows may interact with crossing departure flows from the London area: therefore, appropriate altitude constraints are put in place to ensure separation.

The exercise sought to identify timeframes when the absence of crossing flows would enable Brest-ACC to allow for relaxed altitude and speed constraints.

To fully exploit the combination of relaxed constraints at initial descent, across the IAF, and PBN final the advanced energy-management capabilities of the Airbus A350 were particularly promising. To demonstrate these optimized descent possibilities to ATC controllers, a session on A350 simulators was organized. All altitude and speed constraints were cleared, and CDA descent was applied.

A simple coordination procedure was designed , and the live trial execution was planned during one week in April 2022, involving a few early morning North-Atlantic arrivals as candidates.

Unfortunately, during the entire week the runway configuration in CDG was west-facing, so that neither the PBN-to-FInal procedure, not the MOPAR "Green descents" were used. The exercise could not be activated.

Only one flight, used in fact as a dry run, was able to obtain the optimized descent. For this flight the crew estimated a reduction of 200 kg of fuel burn, or more than 600 kg of CO_2 emissions, on the entire descent (equivalent to approximately 5%).

Despite the disappointing quantitative outcome, the preparation process was very positive, done in cooperation between three control centers and the airline.

This experiment will be further investigated as part of the HERON project.

Instance 5. Study of the PEPAX flow (coordination Bordeaux-ACC, Paris-ACC, CDG-APCH) Q3/2022

NB: For this case, only the analysis of the flights and airspace will be reported, as an illustration of the "ALBATROSS approach"; but no quantitative work has been done in the scope of ALBATROSS.

For the flows arriving into CDG from the South-West quadrant, the structure of the airspace

To avoid entering the airspace of Brest-ACC, from Bordeaux-ACC after waypoint PEPAX above FL300 (which would require a new transfer to the underlying Paris-ACC only minutes later), a RAD is in place (corresponding to the Letters of Agreement between the concerned Centers), that anticipates the descent to FL300, so that Bordeaux-ACC transfers directly to Paris-ACC.

In situation of low traffic, typically at night, the coordination between Bordeaux, Brest and Paris can become feasible, and therefore allow a much more optimized descent profile, as represented in the diagram below. The potential benefit from this improved profile is estimated at 150 to 900 kg of CO_2 (50 to 300 kg of fuel) depending on the aircraft type. It should be noted that several long-haul arrivals (higher benefit potential) from South-America transit in this area at times of low traffic.

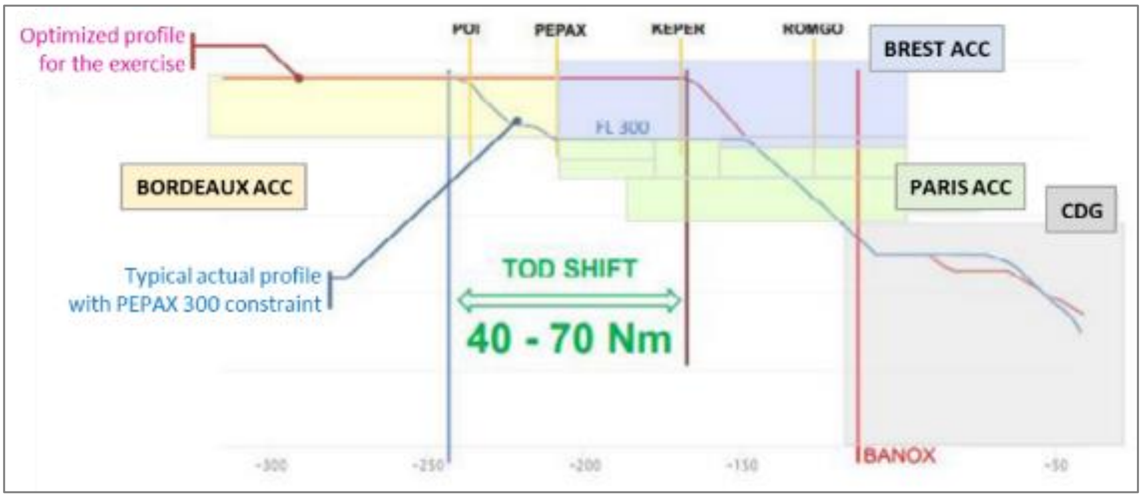

Figure 111: Optimized descents from ToD / UAC

Here again, the improvement in the upper part of the descent can be combined with the raised altitude at the IAF, to further optimize the descent profile.

Furthermore, the French Control Centers are getting equipped with the capability to receive ADS-C EPP messages, by which the actual ToD calculated by the aircraft can be shared with ATC.

This use case illustrates again a detailed collaborative analysis of the specifics of a portion of airspace, from which possible improvements have been identified. The use case will be further investigated in the HERON project.

F.6.2 Summary of Demonstration Exercise EXE-06B Demonstration Objectives and success criteria

The objective is to enact operational procedures (temporary and limited in space) that allow to achieve more efficient descent profiles, resulting in less fuel burn and hence ower CO2 emissions. The target is to apply those procedures on as many flights as possible (ie. whenever the traffic conditions allow for relaxed constraints).

Two ALBATROSS objectives were addressed by EXE-06B :

OBJ_VLD_ALBATROSS_001: To demonstrate that trajectories closer to the "optimum" can be executed or planned-and-executed. This implies: i. being able to identify potential improvements on flights (any process); ii. designing a concrete solution to materialize those benefits; iii. operating under the improved conditions as part of daily operations.

Success criteria : Over the duration of the project (2021-2022) measure a reduction of CO2 emissions (and optionally other gaseous emission and noise emissions) on one-thousand revenue/production flights (i.e. not "test-flights" set up on purpose).

OBJ_VLD_ALBATROSS_002: To demonstrate that certain ATM processes, confirmed to enable greener trajectories (at least when specific conditions are met, typically low density or complexity), can be activated as often as possible and are used by the operators on a significant portion of eligible flights.

Success criteria: Reduction in the extent (locations and time windows) when ATM constraints causing inefficient trajectories need to be active. High rate of uptake by operators when the constraints are relaxed.

See sections below for the detailed description of the results.

F.6.3 Summary of Validation Exercise EXE-06B Demonstration scenarios

The Reference scenarios was made of Air France flights from 2019, performing standard (non-improved) arrivals into Paris-CDG.

The Solution scenario was made of Air France flights that benefited of the improved arrivals into Paris-CDG, ie. passing at higher altitudes on the IAF points. Two IAFs were particularly analyzed: OKIPA and BANOX.

The analysis has been performed per IAF-point and per aircraft-type.

F.6.4 Summary of Demonstration Exercise EXE-06B Demonstration Assumptions

Identifier	Title	Type of Assumption	Description	Justification	Impact on Assessment

Table 36: Demonstration Assumptions overview

No assumptions were formally tracked.

F.7 Deviation from the planned activities

Rather than a deviation from the Demo Plan, many ALBATROSS exercises rather needed a refinement of the detailed planning and definition. In fact, the ALBATROSS Proposal and to some extent also the Demo Plan were prepared while the limitations imposed by the covid pandemic were still having a string impact: short-term work by most teams and uncertainty about the feasibility of innovative concepts (either because of a return of high traffic volumes, or on the contrary because the low level of activity would reduce the reactivity of the operational actors and discourage any experiment).

After all, for EXE-06B the implemented scope has been much larger than initially expected : All IAFs were covered (DemoP = only two), the procedure was semi-permanent (DemoP = tactical), via the AIP-SUP publication; the total time scope was very long.

F.8 Demonstration Exercise EXE-06B Results

F.8.1 Summary of Demonstration Exercise EXE-06B Demonstration Results

The results from this exercise are considered extremely positive.

The CO_2 benefits from the improvement have been largely confirmed. The operational applicability has been confirmed. The activation times of the concept were gradually extended, until it became a semi-permanent implementation.

It is estimated that in 2022 at least 5 000 flights from all operators have benefited from the increased altitudes at the IAF. It can be said that this initiatives resulted in a "permanently greener" portion of airspace at CDG.

Objective ID	Title	Success Criterion ID	Success Criterion	Sub-operating environment	Exercise Results	Objective Status
OBJ_VLD_ALBATROSS_001	Greener trajectories	CRT_VLD_ALBATROSS_001	Perform optimized descents. Confirm measurable reduction of CO_2 emissions.	All four IAF of the Paris-CDG Arrivals, altitudes raised by 2000-4000 ft	Quantitative analysis of ~1700 AF "greener" flights : 250-300 kg CO_2 reduction per descent (7-12%).	OK
OBJ_VLD_ALBATROSS_002	Greener collaborative procedures	CRT_VLD_ALBATROSS_002	Reduce constraints during specific time windows	Procedure active in "downwind" configuration, during specific hours	Procedure active for 5 months, accessible to all Aircraft Operators.	OK

Table 37: Exercise EXE-06B Demonstration Results

1. Results per KPA

The exercise addressed the KPA "Environmental Efficiency".

The results are available in Table 37.

2. Results impacting regulation and standardisation initiatives

The concept brought forward by the exercise was published in several editions of AIP-SUP documents; in the first edition it was observed that different airlines made different interpretations of the document, highlighting the importance of simple and well expressed procedures. These initial difficulties were completely overcome in the subsequent editions. (The improved arrival procedures have in fact ben eventually incorporated in the STARs and Transitions published in the AIP.)

F.8.2 Analysis of Exercises Results per Demonstration objective

OBJ_VLD_ALBATROSS_001 Results

For illustration, Figure 112 shows the vertical profile of one "Green" flight that benefited from the improvement, compared to another flight that did not.

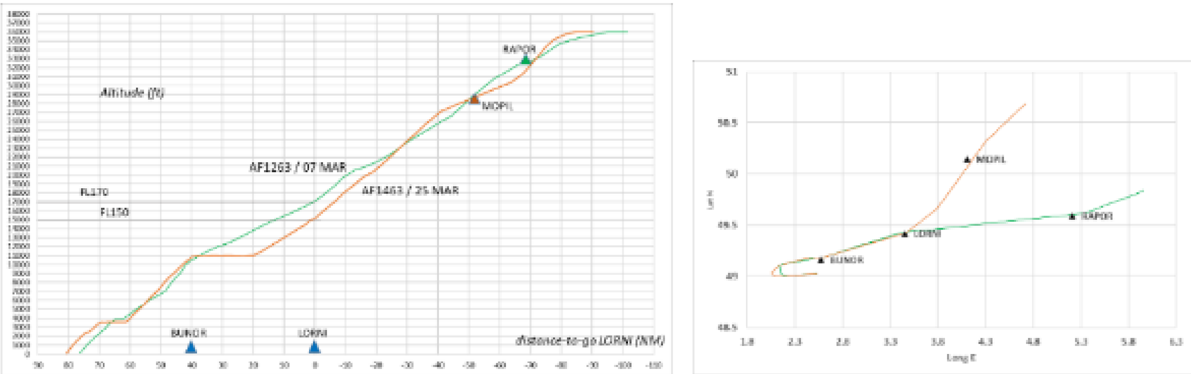

Figure 112 Vertical and Horizontal profiles of a "Green" and a "Baseline" flights (the diagrams should be read "right to left": they reproduce the geographical position of the flights Stockholm to CDG, arriving East to West)

Quantitative results

Multiple runs of the analysis have been performed by Air France.

The following sample is selected as the most representative of the exercise results, in terms of number of flights that could be evaluated. The other runs have produced results consistent with these (or better).

- Period : November 2020 until June 2021 (Instances 1. and 2.)

- Reference for the comparison : Flights from 2019

- Measured segment : TOD to landing

- Figures : comparison of average CO_2 emission (fuel-burn) per single descent and distance+time spent in level-off

CO2	OKIPA				BANOX			
Fleet	Nb. flights	Fuel burn	CO2	%	Nb. flights	Fuel burn	CO2	%
A320	529	94 kg	296 kg	-12%	897	87 kg	274 kg	-9%
B777	107	162 kg	511 kg	-9%	100	164 kg	517 kg	-7%

[The usual factor of 3,15 fuel to CO2 is used]

Level offs	OKIPA				BANOX			
Fleet	Distance	% dist.	Time	% time	Distance	% dist.	Time	% time
A320	18 NM	-53%	214 min	-50%	41 NM	-28%	439 min	-28%
B777	16 NM	-57%	205 min	-53%	39 NM	-40%	390 min	-41%

OBJ_VLD_ALBATROSS_002 Results

The exercise was implemented via AIP-SUP documents published by DSNA.

The application rate on eligible flights (ie. the number of flights for which the improvement was accessible, and did actually take advantage of it) was measured by DSNA at above 30% (variable on the various IAFs, higher on the western points).

For Air France, the application rate is considered high. For example, in one sample of the "gate-to-gate" exercise, out of 19 Air France flights operating in the time window of the improvement, 13 did actually pass the IAF at the raised altitude.

F.8.3 Unexpected Behaviours/Results

No unexpected behaviours or results have been observed.

F.8.4 Confidence in the Demonstration Results

1. Level of significance/limitations of Demonstration Exercise Results

The results are considered of very high significance. The concept was applied over a very long period of time and was eventually deployed permanently.

2. Quality of Demonstration Exercise Results

The demonstration results are of very high quality.

3. Significance of Demonstration Exercises Results

The demonstration results are of very high significance, for Paris-CDG.

The implemented concept is inherently linked to the structure of Paris-CDG arrivals.

F.9 Conclusions

The exercise was very successful, in identifying the opportunity for an easy-to-implement improvement on Paris-CDG arrivals. The implementation was carried out over several incremental steps, until it became permanently part of the published procedures. Although applied during only a few hours a day, to half of the arrival flows (depending on runway configuration) the CO2 reduction brought by the raised altitudes systematically accumulates over each flight that benefits from it.

F.10 Recommendations

F.10.1 Recommendations for industrialization and deployment

Deployment has in fact been achieved.

F.10.2 Recommendations on regulation and standardisation initiatives

The concept was based on entirely standard processes, so no recommendations need to be made.

F.11 Summary of the Demonstration Exercise EXE-06C Plan

The concept demonstrated in EXE-06C addresses one of the factors identified in the works of the "CCO/CDO task Force" in the document "European Action Plan for Continuous Climb and Descent Operations (CCO AND CDO)": the calculation of "*a flight profile optimised to the operating capability of the aircraft*".

That document points out that the variables affecting an aircraft's behaviour are multiple, and include aircraft aerodynamic characteristics, aircraft mass, weather, the specific structure of the airspace, airline business choices, and more. Therefore, each flight has its own specific optimum trajectory and profile, that should be calculated taking all the specific detailed input parameters. The optimum vertical profile will typically be a continuous profile, with fine grained and continuous adjustments of position, altitude, speed and acceleration.

The target would be to have the aircraft FMS be able to calculate and then exactly execute the specific optimum profile of the flight. However, available FMS systems that include this capability are still very few.

In the short term, it is possible to dissociate the calculation of the optimum profile from its automatic execution : although very detailed optimizations based on very large input sets are not yet feasible in embedded airborne systems, standalone tools on ground, possibly also connected to EFB devices, can readily perform these calculations and provide the results to the crew. The tactical execution of the optimum profile can be left to the pilot's skills, who achieves it by inputing the suggested parameters into the aircraft FMS, according to the capabilities of the avionics.

In line with the ALBATROSS target to demonstrate large-scale implementations of the improvements, and not simply one lucky example of a perfect flight, the exercise also focused on the impact caused to ATC from having each flight profile optimized individually, and therefore potentially too much variability or unpredictability in the behaviour of the flights.

F.11.1 Exercise description and scope

OptiClimb

Principle of operation

The FMS normally uses the same speed ("ECON") whatever the flight conditions are.

Instead, the OptiClimb profile is unique per aircraft, and is based on a machine-learning algorithm that takes in consideration the specific aircraft performance model and the latest weather parameters.

The calculation is performed before departure. The crew receives the following parameters, to be inserted in the FMS ("CLB" page) :

First climb speed, Acceleration altitude, Second climb speed, Transition altitude, Climb Mach until TOC

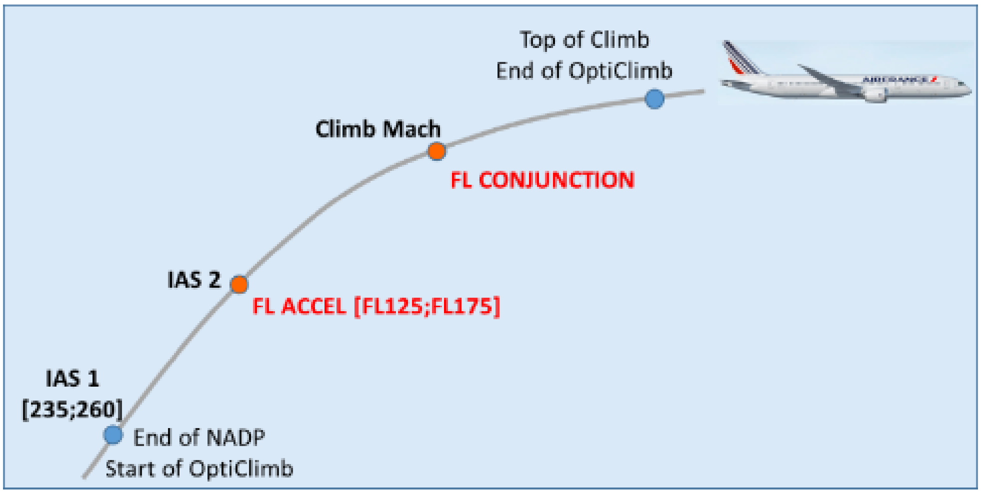

Figure 113 – OptiClimb Principle of Operations

Implementation in the Air France Boeing long-haul fleet (B777, B787)

A technical study about speed management in the various aircraft types brouhgt to the conclusion that Boeing long-haul aircraft, ie. B777 and B787, were the best candidates for the first stage. The corresponding safety study was also conducted.

A group of about 50 "key users" in the pilot community were trained in the first stage. This would result in very few (3 to 5) departures applying the concept every day.

Given the successful outcome of the first stage, a full deployment to the entire population has been carried out, starting Q2/2022.

Agreements with ATC

As of the forst stage conducted by the reduced group of "key users", several meetings tool place with CDG controllers, to explain the concept and identify any requirements from ATC.

The finding, unexpected to ATC, was that the variability of speeds over different flights resulting from the OptiClimb calculation was of the same order pf magnitude of the natural differences that can be normally observed (for example, due to different aircraft performances or cost-indexes).

It was nevertheless agreed that flights applying a speed profile calculated via OptiClimb would announce this fact at departure over the radio (simply stating the word "OptiClimb").

Obviously, any clearance from ATC would prevail over the OptiClimb suggested profile.

F.11.2 Summary of Demonstration Exercise EXE-06C Demonstration Objectives and success criteria

EXE-06C addresses one ALBATROSS objective:

OBJ_VLD_ALBATROSS_001: Implement the tools of the "OptiFlight" ("OptiClimb") suit to assist pilots in the calculation of an optimum flight profile and achieve a reduction of CO_2 (during climb). Use the tool on as many flights as possible.

Success criteria : Over the duration of the live trials, identify a measurable reduction of CO_2 emissions.

F.11.3 Summary of Validation Exercise EXE-06C Demonstration scenarios

The Solution scenario is: B777/B787 Flights departing CDG, using precisely calculated speed profile during climb. Period : January-March 2022.

The Reference scenario is: Departures using the standard departure speed ("ECON").

F.11.4 Summary of Demonstration Exercise EXE-06C Demonstration Assumptions

Identifier	Title	Type of Assumption	Description	Justification	Impact on Assessment

Table 38: Demonstration Assumptions overview

No assumptions were formally tracked.

F.12 Deviation from the planned activities

The OptiFlight solution includes multiple modules, for the optimization of different phases of flight (climb, cruise, descent, speed). Instead of a limited evaluation of multiple modules ("horizontal") it has been decided to proceed with a wide implementation of a single module ("vertical").

F.13 Demonstration Exercise EXE-06C Results

F.13.1 Summary of Demonstration Exercise EXE-06C Demonstration Results

After the successful experimentation by a group of key users, with no negative impact on ATC, Air France extended the usage of OptiClimb to the entire Boeing long haul fleet. Extension to Airbus fets, both long-haul (A330, A350) and medium haul (A320 family) will be considered, but out of the scope of ALBATROSS. (Note: Air France does not operate Beoing medium-haul aircraft).

As a result of this exrcise, carbon emissions related to departures are clearly reduced, without modifications to the airspace structure and while preserving capacity. This was made possible by the cooperation of Air Traffic Control and the airlines.

Objective ID	Title	Success Criterion ID	Success Criterion	Sub-operating environment	Exercise Results	Objective Status
OBJ_VLD_ALBATROSS_001	Greener trajectories	CRT_VLD_ALBATROSS_001	Calculate and execute optimized vertical profiles (climb). Confirm measurable reduction of CO2 emissions.	Departures from CDG, Air France Boeing long-haul fleet (B777, B787)	Between 400 and 500 kg of CO2 reduction per departure. Application rate of 60-70% of B777 and B787 departures (~40 per day).	OK

Table 39: Exercise EXE-06C Demonstration Results

1. Results per KPA

The exercise addressed the KPA "Environmental Efficiency".

The results are visible in Table 39.

2. Results impacting regulation and standardisation initiatives

No impacts on standardisation and regulation have been identified in the scope of the demonstration as executed.

F.13.2 Analysis of Exercises Results per Demonstration objective

OBJ_VLD_ALBATROSS_001 Results

The fuel reduction measured on average is equivalent to 400-500 kg of CO2 reduction per departure.

Very positive cooperation from ATC (CDG and Paris-ACC):

- Only 10-15% of departures were asked to not apply the variable climb profile.

- Of all departures allowed to use OptiClimb, 80% applied the entire profile

- The overall rate of application (Boeing fleet) was above 60%, which is very positive

F.13.3 Unexpected Behaviours/Results

No unexpected behaviour was observed.

F.13.4 Confidence in the Demonstration Results

1. Level of significance/limitations of Demonstration Exercise Results

The exercise demonstrated the concept on Boeing aircraft and specifically for Paris-CDG departures.

Extension to other airports and to other aircraft types requires further study.

2. Quality of Demonstration Exercise Results

The quality of the demonstration results is very high.

3. Significance of Demonstration Exercises Results

The exercises results are statistically very significant, being based on a very large sample (many hundreds of flights).

The results are however specific to the Paris-CDG airport and to t eaircraft type on which the tool was deployed (B777 and B787).

F.14 Conclusions

The exercise was very successful, in deploying improvement on Paris-CDG departures, in a relatively easy-to-implement fashion. The implementation was carried out incrementally, until it was fully deployed on the Air France long-haul Boeing leet. The CO2 reduction brought by "customized" climb profiles systematically accumulates over each flight that benefits from it, while not introducing adverse effects for ATC in Paris-CDG.

F.15 Recommendations

F.15.1 Recommendations for industrialization and deployment

In case of deployment in other terrains, it is recommended to keep ATC informed, in order to anticipate possible unexpected effects from climb profiles (speeds, altitudes) out of the habits.

F.15.2 Recommendations on regulation and standardisation initiatives

No specific recommendations for regulation and standardisation are issued for the calculation of the customized climb profiles.

An information loop towards ATC, to inform of the usage of customized climb profiles and of the corresponding values of speed and altitudes may be beneficial or required to ATC, at specific airports. If this were the case, the information loop will need to be standardized.

F.16 Summary of the Demonstration Exercise EXE-06D Plan

The target of this exercise was to explore the possibility to increase the rate of usage of single-engine taxiing on departures, by Air France medium-haul flights.

"Single-engine taxiing" indicates the practice of using only one of the two aircraft engines during ground movements, if the taxiing and flight conditions are such that the power of one engine is sufficient to move the aircraft safely.

F.16.1 Exercise description and scope

Flight statistics at Air France (in particular at the main base, Paris-CDG) show that the rate of application of single-engine-taxiing ("SET") is very high on arrival: the vast majority of those flights for which the operational conditions allow for SET do actually apply it; on the other hand, the rate of application on departure is considered much lower than possible (less flights are "eligible" on departure, because of more preconditions necessary and in particular linked to a longer engine startup required for cold engines; it is the rate of SET on the eligible flights, that is of interest, not the absolute number of SET departures).

At the onset of the project, it was thought that one key aspect that would encourage crews to opt for SET at departure was to have a reliable estimate of the taxi time: how many minutes are available so that engine warmup times are respected and that all other tasks at departure can be performed with serenity and being ready to depart as cleared by ATC.

Several circumstances led to a rescoping of this exercise

- Operational conditions during 2022 were tense, with a faster-than-expected (although welcome) ramp up of traffic after the covid crisis. This required a focus on flight safety, because high volume operations were triggering a worrisome number of "early alerts": a ban on procedure modifications was issued at Air France.

- Detailed verification of the information flows showed that the taxi times provided in the Operational Flight Plans are in fact of very high accuracy. Actual taxi times are collected continuously and feed a database where the average observed time in specific a operational context (combination of aircraft-type, gate, runway, time-of-day, etc.) are stored. At flight briefing time, the value for the specific flight conditions is then provided to the crew. This estimated taxi time does not include the instantaneous runway waiting time, but is precise enough to allow crews to achieve a large portion of taxiing on one engine (to fix the ideas, on a taxi route with an average time of, say, 13 minutes, for a minimum engine warmup time of 5 minutes, saving 8 minutes on one engine would be a decent improvement, not requiring additional complex information feeds).

For these reasons, the activities of EXE-06D were eventually reduced to a more in-depth study of the conditions that could increase the application rate and on the safety barriers that would improve this process.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

Synergy with the AEON project proved fruitful.

F.16.2 Summary of Demonstration Exercise EXE-06D Demonstration Objectives and success criteria

This exercise had the objective to measure an increase in the rate of application of SET at departure for Air France medium-haul flights (A320 family). This was linked to ALBATROSS objective OBJ_VLD_ALBATROSS_001.

Since the exercise was rescoped, the objective had to be dropped.

F.16.3 Summary of Validation Exercise EXE-06D Demonstration scenarios

The activities were limited to a study of the safety barriers that could improve SET at departure.

F.16.4 Summary of Demonstration Exercise EXE-06D Demonstration Assumptions

Identifier	Title	Type of Assumption	Description	Justification	Impact on Assessment

Table 40: Demonstration Assumptions overview

No assumptions were formally tracked.

F.17 Deviation from the planned activities

The original scope included the analysis, and possibly the implementation, of a way to provide to the crew the exact taxi time for each departure.

The analysis concluded that the taxi time is currently already known to a sufficient level of detail, so fetching exact taxi times was not relevant. On the other hand, any modification of the current procedure (eg. the provision of other information to support decision about SET) was rules out because of the growing traffic.

For these reasons, the exercise scope was reduced to an analysis of the safety barriers.

The ALBATROSS project was member of the "Advisory Board" of the AEON project. As part of its analysis work, the team of EXE-06D participated in a few discussions in the frame of AEON. Several of the concepts described in the AEON Concept of Operations can be applied for the scope of EXE-06D, in particular the notion of "engine startup locations" along the taxi route.

F.18 Demonstration Exercise EXE-06D Results

F.18.1 Summary of Demonstration Exercise EXE-06D Demonstration Results

The exercise did not produce any quantitative results.

Demonstration Objective ID	Demonstration Objective Title	Success Criterion ID	Success Criterion	Sub-operating environment	Exercise Results	Demonstration Objective Status
OBJ_VLD_ALBATROSS_001	Measure a reduction of CO_2	CRT_VLD_ALBATROSS_001	Increase the rate of SET at departure		NOK	

Table 41: Exercise EXE-06D Demonstration Results

1. Results per KPA

Because of the rescoping, this section is not relevant.

2. Results impacting regulation and standardisation initiatives

It is recommended that any approach to encouraging application of single-engine taxiing is performed in compliance with applicable regulation and within the operating procedures provided by the aircraft manufacturer.

F.18.2 Analysis of Exercises Results per Demonstration objective

1. EX1-OBJ-VLD-XX-UUU Results

Because of the rescoping, this section is not relevant.

F.18.3 Unexpected Behaviours/Results

Not applicable, given the scope reduction.

F.18.4 Confidence in the Demonstration Results

1. Level of significance/limitations of Demonstration Exercise Results

Not applicable, given the scope reduction.

2. Quality of Demonstration Exercise Results

Not applicable, given the scope reduction.

3. Significance of Demonstration Exercises Results

Not applicable, given the scope reduction.

F.19 Conclusions

The subject of this exercise must be pursued after the end of ALBATROSS.

There is the intention to explore the usage of the Airport Moving Map ("AMM") as a tool to support crew decision making during departure:

- Usage of the AMM in the navigation display on the A220
- Integration of hints for decision making and safety barriers in the AMM display

F.20 Recommendations

F.20.1 Recommendations for industrialization and deployment

Not applicable, given the scope reduction.

F.20.2 Recommendations on regulation and standardisation initiatives

It is recommended that any approach to encouraging application of single-engine taxiing is performed in compliance with applicable regulation and within the operating procedures provided by the aircraft manufacturer.

F.21 Summary of the Demonstration Exercise EXE-06E Plan

Before the ALBATROSS project, DSNA has already installed a full station onto an isolated site: a radio antenna near Bordeaux. The electrical supply combines hydrogen system (fuel cell and electrolyser) and photovoltaic panels to locally produce green electricity and green hydrogen. This green energy is used for the air-ground radio transmission equipment instead of using directly the supply from the power grid.

This initiative is called "SEPHER" ("*Secours Electrique basé sur une Pile à Hydrogène et des Energies Renouvelables*" in French) and contributes to the goal of reducing overall CO2 emissions. **In the frame of ALBATROSS project**, the aim of this exercise was to experiment this innovative solution to provide back-up energy to the airport ground equipment for ATC.

This experiment took place into Paris-CDG airport platform to supply the Mesnil-Amelot primary and secondary radar. DSNA industrial partners have supplied an electro-hydrogen generator associated with a gaseous hydrogen stacked in cylinders. Indeed, for this experiment, the green hydrogen was produced on other sites and deliver to the DSNA.

Usually, DSNA ground equipment uses a diesel generator to provide emergency power in case of failure of the electricity main grid. However, such diesel generator is the origin of GHG emission and pollution. In addition, even if they are not solicited, periodic maintenance is required on these old generators and consumes a lot of fuel.

F.21.1 Exercise description and scope

This exercise took place onto the Paris-CDG platform. The aim was to provide electricity to the Mesnil-Amelot primary and secondary radar. The radar is used in a real operational context providing air traffic management. This ground equipment is supplied with electricity grid (primary energy source) and a classic diesel generator (emergency energy source).

In the frame of ALBATROSS project, the goal was to replace the diesel generator with an electro-hydrogen generator to demonstrate the feasibility in real operations of such type of power supply. It was necessary to install an electro-hydrogen generator associated with green hydrogen stored into cylinders. The electrical connexion was made in coordination with the Paris-CDG operational team.

DSNA conducted this installation with the help of industrial partners. This exercise was only a demonstration during a short-term period in order to demonstrate the feasibility and the usefulness of this technology.

Experiment #1 conducted with EODev and ENERIA

EODev (Energy Observer Developments) is a start-up which wants to provide hydrogen technologies based on the Energy Observer demonstration boat. EODev is associated with ENERIA (specialist on diesel generator technologies) to provide an electro-hydrogen generator called “GEH2” (white box into the picture hereafter). The GEH2 from EODev use hydrogen into a fuel cell to supply electricity. As a result, GEH2 is a zero-emission system: only water is rejected by the generator.

The hydrogen was provided by MESSER into cylinder racks (red cylinders onto the picture hereafter).

Figure 114: Experimentation #1 – GEH2 system from EODev and ENERIA

Experiment #2 conducted with POWIDIAN and BOUYGUES Energies & Services

DSNA also conducted a second experimentation with the “M110” electro-hydrogen system proposed by POWIDIAN and Bouygues Energies & Services. The installation was similar with green hydrogen supplied by Linde.

Figure 115: Experimentation #2 – M110 system from POWIDIAN and BOUYGUES Energies & Services

F.21.2 Summary of Exercise EXE-06E Demonstration Objectives and success criteria

SEPHER joined the ALBATROSS project to demonstrate the feasibility of back-up energy solution using hydrogen. To provide backup power to the radar, the CO2 emitting fuel generator was replaced with a fuel cell system using only hydrogen (zero CO2 emission).

The demonstration objectives were to:

- Replace the classic diesel generator by an electro-hydrogen generator, during a short-term period, without any impact on ATM operations (quality of service as the same level),
- Reduce at least by 40% the GHG emission with the use of green hydrogen in comparison to fossil fuel.
- Test the supervision of such systems to connect to the air traffic control system.

As a result, the success criteria were principally qualitative (success of operation in real conditions) and partially quantitative in terms of GHG reduction (40%).

F.21.3 Summary of Exercise EXE-06E Demonstration scenarios

The **Reference scenario** is the use of a diesel generator to provide back-up energy to a DSNA ground equipment (Mesnil-Amelot “P+S” radar on the Paris-CDG airport platform) during a period of 4 days (96 hours). The diesel generator is associated to a fuel tank onsite. The fuel is provided from the nearest refinery.

The **Solution scenario** is the use of an electro-hydrogen generator for the same function, during the same time. The solution scenario is realized with two installations form 2 DSNA industrial partners

The scenarios will be compared in terms of carbon footprint (reduction of CO2 and GHG emission) which should consider the hydrogen origin and transport.

Concerning the solution scenario, 2 operational tests were successfully carried out in collaboration with DSNA industrial partners:

- **Experiment #1:** The “GEH2” system proposed by **EODev** and **ENERIA** was tested from 30th may till 4 June 2022
- **Experiment #2:** In collaboration with **Powidian** and **Bouygues Energies & Services**, a second experimentation was made using the “M110” system from 20th June till 24th June 2022.

F.21.4 Summary of Exercise EXE-06E Assumptions

The main assumption related to this exercise concerns the carbon footprint and its calculation.

To evaluate the carbon footprint, following assumptions have been taken.

Experiment #2 :

Diesel carbon footprint in terms of onsite consumption:

- Total energy delivered : **1160 kwh** (average active power = 15,572 kw)
- *Fuel consumption with a diesel generator ~* ***0,45 l/kwh***

  → *Total of fuel consumption =* ***522 l***

- Diesel carbon footprint (for consumption) = **3,10 kgCO2e/l** (source: ADEME carbon base)

  → *Total of diesel carbon footprint in terms of onsite consumption =* ***1618,20 kgCO2e***

Diesel carbon footprint in terms of transport:

- *Origin of diesel : Grandpuits refinery located to* ***77 kms*** *from Paris-CDG airport platform.*
- Diesel volumic mass = **0,84 kgs/l**
- Diesel carbon footprint (for transport) = **0,378 kgCO2/t.km** (source: ADEME carbon base)

  → *Total of diesel carbon footprint in terms of transport =* ***12,76 kgCO2e***

Total diesel carbon footprint: 1630,96 kgCO2e

Notice: For the **experiment #1**, the assumptions can be quite similar, excepted the test duration.

F.22 Deviation from the planned activities

The only deviation from the planned activities which could mentioned concerns the test duration.

Normally, each experiment was planned to operate for 96 hours (4 days of 24h).

Actually, due to different technical and operational restrictions, the experiment durations were, respectively, 90h30mins for experiment #1, and 73h37mins for experiment #2.

F.23 Demonstration Exercise EXE-06E Results

F.23.1 Summary of Exercise EXE-06E Demonstration Results

In terms of quality of service, the demonstration is only a partial success.

During the experiment #1, maintenance agents from DSNA were obliged to come onto the site to switch between the different hydrogen racks. This process is not acceptable for a long-term use of such technological solution.

In the opposite, during the experiment #2, a specific **supervision** solution has allowed to switch automatically between the hydrogen racks. This technical solution is a guarantee of autonomy and allow to install electro-hydrogen generator on isolated sites where DSNA agents could not act quickly. Moreover, the supervision solution provided a supervision to monitor the system by distance.

In addition, as described previously, some technical problems during each experiment led to a partial duration of each experiment:

- Experiment#1: duration of 90h30mins with a 4h30mins interruption due to the impossibility to switch from the 1st hydrogen rack to the second one.
- Experiment#2: A problem on electrical connection led to postpone the experiment start. Finally, the start of the experiment was only on the day'2 which led to an experiment duration of 73h37mins.

In terms of **quantitative results**, the demonstration is a success as the criterion have been exceeded:

<u>Experiment #2 :</u>

→ Total of H2 consumption = **78 kgs H2** during the experiment

- *Carbon footprint due to green hydrogen production = **1,59 kgCO2/kgH2** (*)*
- *Additional carbon footprint due to compression @200 Bars = **0,1 kgCO2/kgH2** (*)*
- *Additional carbon footprint due to H2 transport = 1,12 kgCO2/kgH2/100kms (*)*
- Hydrogen was delivered from a production site located at 59 kms from Paris-CDG airport → **0,66 kgCO2/kgH2** for this experiment

→ *Total of hydrogen carbon footprint = **2,35 kgCO2/kgH2***

(*) source: ADEME carbon base

	96 kgs H2 provided onsite	78 kgs H2 really consumed
Total H2 carbon footprint	225,6 kgCO2	183,3 kgCO2

In both cases, the carbon footprint by using an electro-hydrogen generator is less than the one calculated with a diesel generator. Considering the worst case, the carbon footprint is reduced from more than 85%. It must be underlined that the hydrogen used in the installations was either "green" or had its CO_2 impact compensated for; therefore this is the net CO_2 reduction (no CO_2 penalty from hydrogen production needs to be counted).

Total carbon footprint reduction: 1405,36 kgCO2e

Notice : For the **experiment #1**, the carbon footprint reduction is similar considering a test duration of 90,5 hours and a total of H2 consumption of **91,1 kgs H2** during the experiment (1,007 kgH2/hour).

F.23.2 Analysis of Exercises Results per Demonstration objective

The main exercise results are satisfactory in terms of carbon emission reduction. The carbon footprint reduction is around **1,5 tCO2e for a 4-day duration experiment**. This amount is like a normal car consumption for a year.

With a real system using a hydrogen storage, the result could be more significant.

The average consumption of hydrogen by the electro-hydrogen generator are in conformity with the constructor data.

F.23.3 Unexpected Behaviours/Results

As described previously, some unexpected behaviours have been observed.

For the experiment #1, the impossibility to switch between the hydrogen racks was problematic. In addition, the lack of supervision was also a difficulty.

For both experiments, some unexpected behaviours have also been noticed as short service interruption of the electro-hydrogen generator during operation. This interruption has no consequences as batteries are available to take relay. However, the generator providers should explain this unexpected behaviour in more details to avoid such disagreement in the future.

F.23.4 Confidence in the Demonstration Results

As the demonstration has been conducted in real conditions with an operational ground equipment, the quality and the significance of the results are fully satisfactory.

The only point that needs to be addressed is the origin and mode of production of hydrogen. If the hydrogen is not produced locally (for example by solar panels and an electrolyser), it must be delivered to the site by a large gas company after being produced from renewable energies to be "green". At present, the "hydrogen ecosystem" does not seem ready to offer "green hydrogen" for emergency use. Large companies (Linde, Air Liquide, etc.) prefer to deliver hydrogen for occasional use (worksites, events, etc.) and regularly renew the storage.

However, DSNA's industrial partners have proposed technical and logistical solutions that seem satisfactory to resolve this difficulty.

F.24 Conclusions

To conclude, the possibility to use an electro-hydrogen generator associated to a local hydrogen storage has been demonstrated. Such system can replace a classic diesel generator use as emergency power supply in case of normal electricity grid failure.

Using green hydrogen allows to reduce GHG and CO2 emission around 85%!

The return of investment is not yet guaranteed and the green hydrogen delivery around the French territory is not yet mature.

However, investment in such technology appears to be a necessary way to prepare the future: climatic crisis, lack of fossil energies, and energy cost increase.

Another possibility could be to locally produce green hydrogen by solar panel installation near airport platforms.

F.25 Recommendations

F.25.1 Recommendations for industrialization and deployment

For industrialization and deployment, DSNA recommends associating major companies to create a virtuous ecosystem with green hydrogen produced in few different centres, a logistic organization to deliver this hydrogen on the small and isolated sites if necessary, and a technical harmonisation for the hydrogen storage.

F.25.2 Recommendations on regulation and standardisation initiatives

The use of hydrogen and its standardisation is tricky and should be considered by ANSPs or aerospace industry in general.

For example, the gaseous hydrogen storage could be standardized to make its use easier on airport platforms (storage pressure, type of connectors, security aspects, …).

In the same way, more and more airport platforms are looking to install photovoltaic panels near the runways to enhance their unused spaces. Such installation must also consider the risk of disturbance of the radio emission/reception (decrease of the EM field) or the risk of visual discomfort for the pilots (reflection on the panels).

Figure 116: EXE-06E partners

Appendix G Demonstration Exercise #07 Report

G.1 Summary of the Demonstration Exercise 07 Plan

This Exercise aimed to create a better understanding of the aspects of Sustainable Taxiing operation based on trials using TaxiBot vehicles to taxi aircraft from Runway-to-Gate and Gate-to-Runway. The goal was to learn by demonstrating taxi-out and taxi-in as environmentally friendly and efficiently as possible during the ground operation. Using the TaxiBot ensures that aircraft engines are not used during the taxi phase. Several trials would take place, aimed to demonstrate the feasibility of sustainable taxiing from gate to runway (vv.) under several weather conditions and peak hours/days for narrow body planes (A320) and (B737) integrated in normal operation.

G.1.1 Exercise description and scope

Building on previous experiences over the last few years, this Exercise aimed to further investigate the feasibility of Sustainable Taxiing from gate to runway (vv.) by carrying out live TaxiBot missions/demonstrations in the following conditions:

- Operation in several (adverse) weather conditions
- Operation during operational peak hours/days
- Simultaneous operation of two TaxiBots
- Operation with more airlines / handlers than the first trial, including operation with additional aircraft types.

These activities were to take place as part of standard ground operation, at the airside of Amsterdam Airport Schiphol, both in the non-manoeuvring and the manoeuvring area. They require the use of TaxiBot vehicles.

The TaxiBot is a unique Smart Airport Systems vehicle, which is the only certified sustainable taxiing sustainable solution available today. It is certified for the most common narrow-body types of aircraft (Boeing 737 and Airbus A320). It is currently powered by a hybrid combination of electric traction system and diesel engines and consumes 95% less fuel when taxiing than aircraft engines would normally use. Schiphol expects to achieve a total savings of 50-85% on fuel consumption during taxiing because engines need to warm-up for a few minutes before departure.

During Sustainable Taxiing operations (TaxiBotting), the control of the convoy lies with the Pilot in Command of the aircraft. He/she is able to steer the aircraft using the regular controls inside the cockpit. Since the bypass pin has been left out of the nose landing gear (NLG) of the aircraft, the nosewheel will turn, allowing these inputs to be received by the cradle of the TaxiBot. The vehicle will mirror these inputs and replicate the desired aircraft behaviour using its four-wheel steering system. The TaxiBot is able to accelerate the aircraft up to 22 knots by itself. Braking takes place using the aircraft's main landing gear, with the TaxiBot responding to the resulting drag. In this way, the aircraft's NLG doesn't experience high loads or fatigue events and stays within design parameters.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

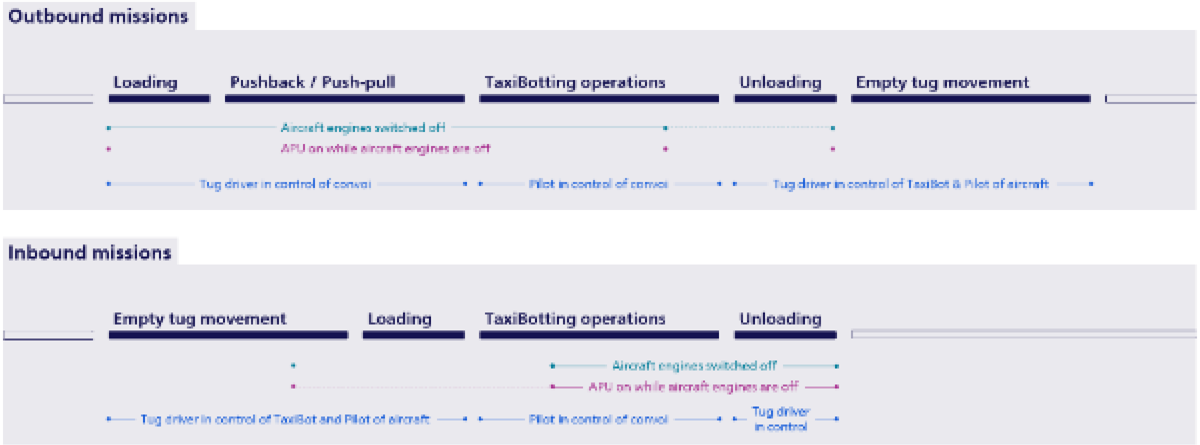

Figure 117: schematic overview of Sustainable Taxiing phases using the TaxiBot

At the start of the project, the B737 was already certified for this solution. However, for the desired operational planning and use it was required to acquire a B737 MAX certification/NTO as well. For the A320 family, an aircraft modification (aircraft SB) was (and still is) required, a first version of which was also readily available. A new and simpler modification was expected to be certified by Airbus in time for the trials, after which it could be integrated by the Aircraft Operators. This new SB version has faced several delays and has now been confirmed to be certified and market available in November 2023. This new SB will also be available on a fleet forward option.

Figure 118: overview stakeholders in trials at Schiphol

1. Operational scope in terms of actors and processes

To be able to perform the Sustainable Taxiing operations in any form, various stakeholders at the airport must be engaged. Notably the airport, airlines, ground handlers and ATCO were be involved in a working group preparing and carrying out the exercise. During any operational trials as part of this Exercise, the group evaluated results and tried to mitigate any unexpected occurrences. The trial was open to any airline who wants to try this sustainable solution with a certified plane, under the condition that their respective ground handler could operate the TaxiBot.

2. Key demonstration objectives and scenarios

The key Exercise objective was to demonstrate & validate Polderbaan operations by addressing high-risk barriers to standardisation. We aimed to gauge feasibility of Sustainable Taxiing operations at Amsterdam Airport Schiphol by demonstrating TaxiBot operations using new procedures under the following circumstances:

- Two Taxibots to test simultaneity in operations
- Carry out outbound (departure) and inbound (arrival) missions from the Polderbaan (18R / 36L)
- Test impact of Sustainable Taxiing in busy operations (goal of original test)
- Test the effect of changing (adverse) weather conditions within operations
- Test the impact of more participating airlines, aircraft types and ground handlers within operations

As a result, the live trials were meant to be a step up to a possible subsequent standard implementation and should be as close to standardised operations as feasible. The demonstrations were aimed to help us gain knowledge & experience and the testing of many hypotheses to study the concept's effects and solve specific conditions.

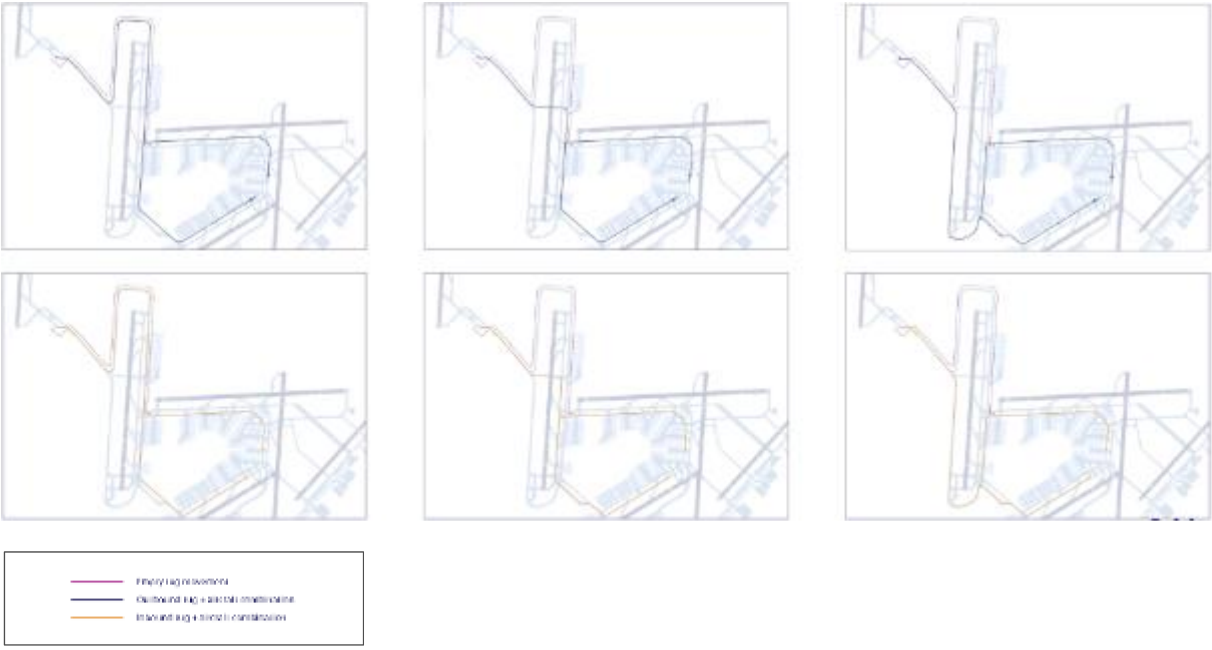

Figure 119: overview of planned Sustainable Taxiing routes to and from the Polderbaan (RWY 18R / 36L)

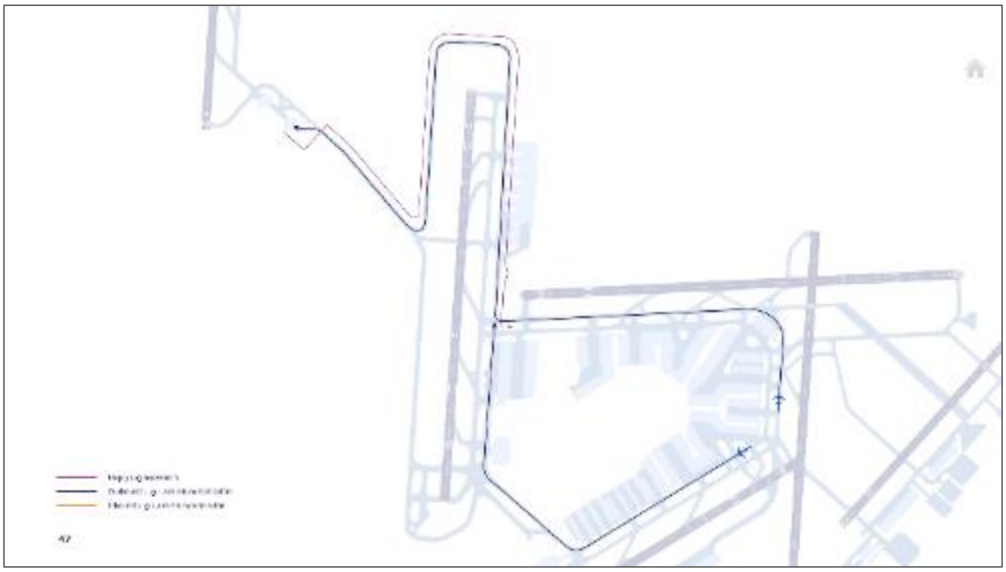

Figure 120: detailed view of an outbound route to the Polderbaan (RWY 18R / 36L) using North-bound path

Main effects to be studied during the Exercise:

- Emission reductions
  - Fuel savings and related reductions of CO2, NOx etc, calculated through engine-off time during demonstrations and comparison to average engine-on times of similar regular operations.
  - Reduction of UFP levels in working areas, measured if possible.

- Safety: estimation of overall safety through registration of number of incidents, the possible elimination of hazards, and the actual & perceived safety per process actor through post-mission evaluations with involved stakeholders.
- Workload: the (perceived) complexity and intensity of the workload per actor through analysis of the required procedures and post-mission evaluations with involved stakeholders.
- On-time performance, as an estimate based on two factors:
    - Capacity
      Estimated total number of possible movements per year and per runway configuration, modelled based on the process times encountered during the demonstrations.
    - Flow
      The overall flow, flow per area and process times per actor, modelled based on the process times encountered during the demonstrations.

Most important conditions to solve and validate

- Right of way: How to differentiate between sustainable taxiing and (dispatch or maintenance) towing in order to judge right of way?
- Engine start-up and shutdown on the move: Can we safely start the engines during outbound missions and shut them down during inbound missions to save precious minutes of standstill in the manoeuvring area? And how to define the engine start positions to maximize the emissions reductions and minimize the time on ground?
- Docking procedures: Can aircraft pilots still dock at the gates themselves? Do all gates have the right VDGS and enough room for this?
- Safe and visible all clear positions & (un)coupling spots: Can the truck driver and pilot safely interact with each other across weather and lighting conditions?
- Incident procedures: Which airside procedures do we need to update to support Sustainable Taxiing in case of incidents and emergencies?

3. Exercise activities

We judged following activities needed to take place for the Exercise to achieve its goals[6].

Demonstration preparation

- Setting up role division between stakeholders.
    - For project management and steering.
    - For actual demonstrations/operation (part of procedures, see next bullet).
- Identifying and developing necessary procedure and procedural changes with sector partners; writing CONOPS (Concept of Operations) document.
    - Procedures for outbound missions (departure) under nominal conditions.

[6] This overview is an update from the list in the Demo Plan, based on actual progress and insights over time.

    - Procedures for inbound missions (arrival) under nominal conditions.
    - Procedures for non-nominal conditions.
    - Emergency procedures.

- Carrying out safety assessments required as part of the Management of Change (MOC) process.
    - Individual (internal) safety assessments per stakeholder.
    - Safety Assessment by the Integral Safety Management Schiphol (ISMS).
- Setting up & signing legal & financial agreements, including insurances.
    - Collaboration agreement local sector partners.
    - User agreement TaxiBots.
- Developing hypothesis list for all envisioned circumstances, to check and validate the desirability, viability and operational feasibility of the concept with regards to, amongst others, the weather circumstances, time of day, aircraft type, amount of airside traffic (i.e. seasonal peak or downtime operations). This also includes developing the right metrics for each hypothesis.
- Developing initial mission list.
    - Detailing involved parties (airline/handler) per mission.
    - Desired hypotheses to be (in)validated and/or learnings to be gathered based on the mission parameters.
- Training of involved stakeholders: tug drivers, aircraft pilots (and possibly ATCOs).
    - Developing updated training procedures for TaxiBot operation.
    - Developing updated training protocol for operation in the manoeuvring areas.
    - Training of involved stakeholders.
- Adapting airside infrastructure to facilitate TaxiBot operations:
    - Adding bays to service roads to allow vehicles to pass one another.
    - Adding specific markings to service roads.
    - Adding signage to service roads.
    - Adding markings to (un)loading locations on Taxiway.
- Acquiring and preparing the necessary equipment.
    - Facilitating the arrival of equipment (and preparing for use) The trials will involve two TaxiBots which will have to be at the airport and prepared for operation.
- Preparing promotion materials and public affairs approach.

Carrying out and managing the demonstration project and demonstration missions on airside

- Managing overall demonstration
- Gathering baseline data
- Monitoring and refining hypothesis list and research questions

- Carrying out missions
    - Planning individual mission(s) with specific airline, handler and other relevant stakeholders
    - Running mission(s)
    - Debrief with all involved stakeholders
    - Collecting data throughout the mission stages
- Ongoing troubleshooting and adapting PoC / future mission list

Drawing up demonstration conclusions

- Analysing quantitative data
- Analysing qualitative data
- Writing final report / publication, including a popular scientific publication
- Communicating learnings

G.1.2 Summary of Exercise 07 Demonstration Objectives and success criteria

[OBJ]

Identifier	OBJ-VLD-ALBATROSS-003
Objective	Showcase aviation decarbonisation initiatives
Title	Other decarbonisation initiatives
Category	<performance>, <operational feasibility>, <acceptability>
Key environment conditions	Nominal conditions

[OBJ Suc]

Identifier	Success Criterion
CRT-VLD-ALBATROSS-003	The selected decarbonisation initiatives can be effectively performed (i.e. "do produce an effect") by the relevant Aviation/ATM/ATC actors.

Demonstration Objective (as in section 4.5)	Demonstration Success criteria (as in section 4.5)	Coverage and comments on the coverage of	Demonstration Exercise 7 Objectives	Demonstration Exercise 7 Success criteria

		Demonstration objectives (as in section 4.5)		
OBJ_VLD_ALBATROSS_003	CRT_VLD_ALBATROSS_003	Partial	Operation during several (adverse) weather conditions	At least 5 missions during adverse weather conditions.
		Partial	Operation during operational peak hours / days	At least 5 missions during operational peak moments.
		Partial	Simultaneous operation of two TaxiBots	At least 10 missions with concurrent operation of TaxiBots (i.e. 5 instances).
		Partial	Operation with more airlines	At least one additional airline part of one or more live missions.
		Partial	Operation with more handlers than the first trial	At least one additional handler part of one or more live missions.
		Partial	Operation with additional aircraft types.	At least 3 missions with an Airbus A320 (If Airbus SB is brought out in time and if a Schiphol based carrier has embodied this SB onto its fleet.)

G.1.3 Summary of Exercise 07 Demonstration scenarios

1. Reference Scenario

Baseline flights. Reference scenario will be based on historical data of Airbus A320 and Boeing 737 family aircraft while taxiing at Amsterdam Airport as usual. The data attributes, such as sample size, runway configurations, contributing airlines, time scope, are to be established during the project in collaboration with consortium partners and non-consortium contributors to the trial.

The above reference scenario data was to be collected after a large enough number of live trials were performed to create a valid comparison. As described in G.2 below, circumstances led to a new Exercise reality, and ultimately the reference scenario data was not collected or analysed within ALBATROSS.

2. Solution Scenario

The initial plan was to perform full-scale operational Sustainable Taxiing operations Runway-to-Gate and Gate-to-Runway. Using the TaxiBot ensures that aircraft engines are not used during the taxi phase. Several runs allow us to demonstrate the feasibility of sustainable taxiing from gate to runway (vv.) under several weather conditions and peak hours/days for narrow body planes (A320) and (B737) integrated in normal operation.

As detailed in G.2, due to deviations from the planned activities, a number of updated solution scenarios were created to allow demonstrations to take place within this Exercise:

- Training runs for tug drivers
- Field checks to verify the infrastructure compatibility
- One or more full-scale TaxiBotting showcases
- Pushback missions
- Towing missions
- P10 missions – outbound holding with limited use of TaxiBotting procedures

In the end, due to time constraints resulting from the adaptations as detailed in G.2, the latter three activities will take place outside of the ALBATROSS timeframe, and are scheduled to be part of the actions in HERON.

G.1.4 Summary of Exercise 07 Assumptions

A list of over 200 hypotheses (/assumptions) and sub-hypotheses and in excess of 180 research questions was devised as part of the live trial preparations. An overview of the main hypotheses is listed found below.

Identifier	Title	Type of Assumption	Description	Justification	Impact on Assessment
			The overall concept of Sustainable Taxiing is desirable, feasible and viable.		

			The overall concept of Sustainable Taxiing is safe.	Safety levels must be maintained or increased, as compared to the current situation.	
			All actors can work safely during ST operations	Pilots/drivers/ground crew/cabin crew/passengers	
			Sustainable Taxiing operations does not have a negative impact on the flow of ground movements at Amsterdam Airport Schiphol.		
			The On-Time-Performance at Amsterdam Airport Schiphol will not be negatively influenced by the implementation of ST operations [O1]-[O4]		
			The overall concept of Sustainable Taxiing has an acceptable workload, in terms of intensity and complexity, for every individual actor at all times.	Pilots/drivers/ATC	
			Sustainable Taxiing operations has no negative effect on the total number of possible aircraft movements at Amsterdam Airport Schiphol.		
			Sustainable Taxiing operations has no negative effect on the total number of possible aircraft movements to and from RWY 18R / 36L (Polderbaan).		
			A full-scale Sustainable Taxiing operation at Amsterdam Airport Schiphol would result in a minimum of 50% reduction of taxiing-related fuel consumption. [O1]-[Ox]		
			A full-scale Sustainable Taxiing operation at Amsterdam Airport Schiphol would result in a significant reduction of taxiing-related emissions.		
			Sustainable Taxiing operations contributes to reducing noise levels on airside.		
			Sustainable Taxiing will contribute to reductions in emission of UFP near the gates/bays, which will positively affect the health and working environment of the ground crew.		
			The right of way for aircraft performing Sustainable Taxiing operations is clear to all involved stakeholders on airside.		

			D0 ST operations planning can take into account adverse weather conditions.		
			We can create a fair allocation system for Sustainable Taxiing operations for all involved stakeholders		
			Every actor is able to provide the required resources the planning/allocation of Sustainable Taxiing operations takes into account [O1]-[O4].		

Table 42: Demonstration Assumptions overview

G.2 Deviation from the planned activities

1. Deviation of planned activities

The Exercise was adapted from the original plan to demonstrate several dozens of live flights using TaxiBots on arriving and departing flights. There are several reasons for this, all of which lie beyond our reasonable sphere of influence or control.

- First, the trials were pushed due to later than anticipated delivery of the TaxiBots, which were caused by supply chain shortages caused by the Covid-19 pandemic, combined with a pending commitment from SNBV to purchase the first 2 TaxiBots following changes to the project approach.
- This coincided with the rough scale-up period at our airport and most local stakeholders facing staff shortages and large, impeding, operational constraints after Covid-19.
- A demonstration with the A320 became infeasible for 2 reasons:
    - The new SB certification kept being pushed back, despite the ongoing and productive talks between SNBV, SAS and Airbus.
    - No A320 carriers showed interest to integrate the current SB to enable a participation in our trials, despite talks on possible integration with various airlines as part of our ongoing mitigative actions.
- And finally, we have had to alter trial plans due to a large-scale and ongoing capacity shortage at LVNL (our local ATC/ANSP), which is in opposition of their initial commitment.
    - They were unable to deliver the operational expertise required to finalize the draft CONOPS and join the Management of Change procedure (which includes individual safety assessments by all local partners, as well as an Integral Safety Management Schiphol decision). These steps must of course precede any operational implementation of new procedures.
    - Their limited involvement in the demonstration preparations, which even included a period of several months where they withdrew all collaboration efforts, both limited our ability to work on the required cultural and operational changes necessary for the demonstrations and the future standard operations and slowed down the overall development of procedures and demonstration preparations.

These deviations were largely the result of risks identified in the Demo Plan, and for which mitigative measures were taken. This overview can be found below.

Risks	Impact	Probability	Mitigation Actions	Occurrence
Congestion during live operations making trial missions impossible for a certain period of time	4	2	Shared coordination of missions and plans between stakeholders, both in advance and in the day(s)/hour(s) before a mission. Leave time in overall mission schedule for back-up moments/missions.	Yes, linked to unavailability of ANSP
Safety and/or security risks making trial missions impossible	5	2	Start necessary safety & risk assessment procedures early on and in close coordination between relevant stakeholders. Collaborate to take away remaining concerns, if present.	Yes, linked to unavailability of ANSP
Lack of different (adverse) weather types	3	3	Planned trial over various seasons, with a possibility to lengthen the trial if absolutely necessary,	Yes, linked to unavailability of ANSP
TaxiBots not present at the airport due to manufacturing problems / supply chain constraints	5	3	Close coordination between supplier, operators and other stakeholders to keep planning up to date and identify and deal with any delay(s) early on.	Yes, mitigated
No availability of TaxiBots for certain planned missions	2	1	Shared coordination of missions and plans between stakeholders, both in advance and in the day(s)/hour(s) before a mission. Part of overall stakeholder meetings.	No
No availability of crew for certain planned missions	3	3	Shared coordination of missions and plans between stakeholders, both in advance and in the day(s)/hour(s) before a mission. Part of overall stakeholder meetings.	No
No availability of aircraft for certain planned missions	3	2	Overplanning of missions Back-up plans	No
No availability of modified A320 aircraft for planned missions	3	4	Set up talks with OEM, airlines and SAS to coordinate swift upgrade of one or more A320 aircraft of participating airlines.	Yes
Malfunctions / technical incidents / maintenance of TaxiBots	3	2	Close coordination between supplier, maintenance provider and other stakeholders to quickly resolve any issues.	Yes, mitigated
Damaging aircraft or other GSE / vehicles on airside	5	1	Good training and use of experienced personnel.	No
No training facilities available for crew	4	1	Training has already been carried out last year, knowledge is still present with a number of drivers.	No

Risks	Impact	Probability	Mitigation Actions	Occurrence
			Also supplier is on hand to provide further training.	
Coordination between stakeholders lacking	3	2	Make collaborations part of larger Sustainable Taxiing programme and governance structure.	No
No availability of ANSP (and other stakeholders)	4	4	Scheduling of operation initially to take place off peak and then slowly roll out into busier periods of the day.	Yes
Operational stop at airport (heavy weather, terrorist attack, fuel shortage etc.)	4	1	Very small chance of this happening so will have a small impact on the trial. Heavy weather might even bring opportunities to show what it can do to improve flow during challenging conditions.	No

2. Overall mitigative actions and continuation of Exercise

Local exercise partners and sector continued their collaboration and pushed hard to make operational use of the TaxiBot possible in other forms. We pivoted our plans to make use of the TaxiBots at Schiphol in as many ways as possible (as described in G.1.3 above), including a plan to operate within existing procedures, outside of ATC domains. While smaller in scope and number, partners were able to book meaningful progress on some of the main hypotheses, gain some of the envisioned learnings and further enrich/validate the draft CONOPS. These steps are crucial to further utilize and demonstrate under the umbrella of HERON. The pivoted approach to TaxiBot utilization we developed consists of:

- A full-scale TaxiBotting showcase, testing as much of the draft CONOPS as possible with special support from the local ATC.
- Advanced training for push back drivers of the implicated handlers.
- Pushback missions, using the TaxiBots to carry out regular pushback and push-pull manoeuvres to allow crew to further familiarize themselves with the vehicle, test its operational characteristics, ensure infrastructure across the airport supports the vehicle and log relevant procedural datapoints.
- Towing missions, using the TaxiBots to carry out regular (maintenance) towing manoeuvres over various distances to allow crew to further familiarize themselves with the vehicle, test its operational characteristics, ensure infrastructure across the airport supports the vehicle and log relevant procedural datapoints.
- P10 missions, using the TaxiBots to carry out outbound Sustainable Taxiing manoeuvres to a specific location at Amsterdam Airport Schiphol outside of ATC's domain of responsibility. On top of the learnings above, this will also allow partners to validate many of the CONOPS building blocks, as it includes the Pilot Control Mode operation of the TaxiBot, where the PiC is in control of the convoy. Apart from a number of specific clearances, this procedure is an identical, though abbreviated, mission to the previously planned TaxiBot live trials and therefore also includes some of the associated fuel and emission savings.

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As mentioned before in G.1.3 above, the Exercise ultimately concluded with the full-scale showcase, while the sector continues to work on the other utilizations and is preparing for these activities to take place in 2023 as part of the actions in HERON.

3. Consequences for Exercise results

The (operational) use of the TaxiBots was restricted to training runs for tug drivers, field checks to verify the infrastructure compatibility and a full-scale TaxiBotting showcase. As a result of the low number of (operational) movements, very limited data was collected. The data to compare performance in terms of fuel usage and emission savings was too limited and therefore, the necessary data exchange contracts (with the airline) were not negotiated. The limited data set would not allow us to analyse and prove the KPI beyond the currently available knowledge. As detailed below, various other concrete deliverables were created, and the massive preparation and mitigation efforts have resulted in a host of learnings regarding the underlying hypotheses and research questions for this Exercise.

An additional consequence is that the objective OBJ_VLD_ALBATROSS_002 "Large scale implementation" has been removed from the scope of exercise EXE-07.

G.3 Demonstration Exercise 07 Results

G.3.1 Summary of Exercise 07 Demonstration Results

Ultimately, preparation for both the original Exercise demonstrations and the pivoted/revised Exercise demonstrations were largely completed. The number of demonstrations fell short of the planned ‘several dozens’ of missions.

Demonstration Objective ID	Demonstration Objective Title	Success Criterion ID	Success Criterion	Sub-operating environment	Exercise Results	Demonstration Objective Status
OBJ-VLD-ALBATROSS-001	Showcase aviation decarbonisation initiatives	CRT-VLD-ALBATROSS-003	The selected decarbonisation initiatives can be effectively performed (i.e. "do produce an effect") by the relevant Aviation/ATM/ATC actors.		Due to impediments, a low number of trials was performed and data relevant to measure decarbonisation effect wasn’t collected. All efforts do reaffirm the earlier belief that Sustainable Taxiing can significantly increase the sustainability of the taxiing phase.	POK

1. Results per KPA

Firstly, since the Exercise comprises an activity that doesn't yet constitute a SESAR solution, no reference performance results are available.

1. Fuel consumption

A Key Performance Area that the Exercise aimed to evaluate was "fuel consumption", as a direct way to assess CO2 emissions. Given the adjustments we've had to make to the overall project, it hasn't been possible to directly measure the fuel consumption improvements within this Exercise.

2. Other KPAs

As part of the preparations for the initially planned live trials, as well as the pivoted objectives, many assumptions were identified and documented relating to other KPAs, such as capacity and safety, in the form of new and existing hypotheses and research questions.

3. Results impacting regulation and standardisation initiatives

We worked with local sector partners to expand the Supplemental Type Certificate for the use of TaxiBots with the Boeing 737 MAX. Progress was made, but the final steps will be completed in the follow-up of ALBATROSS as part of the preparations for HERON.

We collaborated with Airbus to achieve a certification for the updated Airbus A320 modifications. Progress was made, but the final steps will be completed outside of ALBATROSS as part of the preparations for HERON.

Results impacting regulation and standardisation are expected through our efforts and collaboration in many other efforts. Schiphol through our TULIPS project and various local sector partners were in contact with other European stakeholders, such as Brussels Airport as part of StarGate, and ADP as part of OLGA to share our knowledge, approach and lessons learned where possible. These efforts are supplemented with our involvement in EUROCONTROL STX TF, as detailed in G.5.2 below, though no concrete results can be shared yet.

G.3.2 Analysis of Exercises Results per Demonstration objective

1. OBJ-VLD-ALBATROSS-001 Results

1. Concrete deliverables

The efforts in ALBATROSS have resulted in a number of concrete deliverables, contributing to the possibility to perform the demonstration and aviation decarbonisation initiative both within ALBATROSS and future endeavours:

- A draft CONOPS for standard Sustainable Taxiing operations with narrow body aircraft at Amsterdam Airport Schiphol.

- The iterative development of the procedures and the CONOPS document contribute to the objective to further investigate the feasibility of ST operations, and the CONOPS takes into account the specific situations, such as adverse weather conditions, scoped in the demo plan.
- We believe it can be referenced in D2.4 FINAL CONOPS or included as an appendix – as our latest F2F meeting has highlighted the difficulties of incorporating a ground based process in an already mature deliverable focused on in-flight procedures.
- Coinciding with our efforts in ALBATROSS, we already presented the key content of this document with the EUROCONTROL STX TF, which is currently working on a set of considerations and recommendations on various forms of Sustainable Taxiing for European aviation stakeholders.

- The Sustainable Taxiing showcase on December 6th 2022
  - Actual use of TaxiBot FG on airside of Amsterdam Airport Schiphol under normal operational conditions, which consisted of:
    - Pilot control mode test of new TaxiBot with B737 aircraft
    - Outbound and inbound return movement using TaxiBotting procedures as close to newly developed CONOPS as possible, with route depicted in below image.

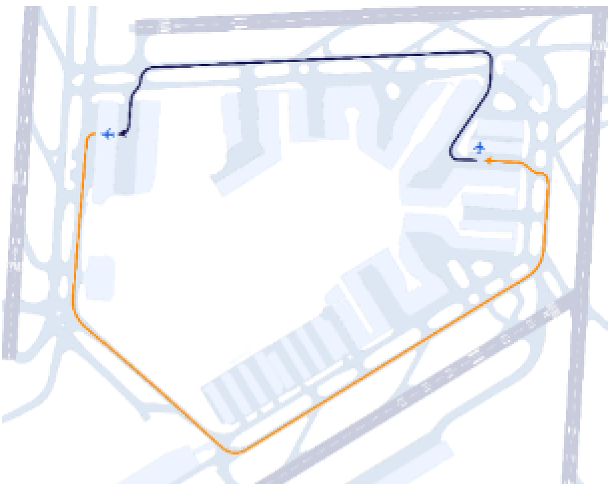

Figure 121: Showcase outbound route (blue) and inbound route (orange)

  - Showcase report, detailing the process from preparations to lessons learned.

- Progress on the TaxiBot certification of the B737 MAX.
  - In collaboration with partner SAS, we have facilitated contact between TUI fly and Boeing to acquire an NTO for further testing at Schiphol in the period to come.
  - The current (and final) step is dependent on the Dutch government organization IL&T (Human Environment & Transport Inspectorate). Approval and clearance by the authorities to make operational use is pending. It is unclear if the clearance process is finalized ahead of the closure of ALBATROSS.
  - SAS have indicated this will allow them to carry out the remainder of the checks required for full certification of the B737 MAX.

- An updated design of the TaxiBot, including relevant subsystems:
    - Slight changes to vehicle frame and cab interior based on trials, which improves overall vehicle dimensions and the comfort and visibility of the operator.
    - Iterative development and implementation of new communication systems to allow the TaxiBot to carry out various procedures on airside, requiring specific VHF and UHF communication protocols.
    - Iterative development and implementation of new lighting systems to allow better identification by others to distinguish between various operational statuses of the TaxiBot like towing and TaxiBotting, to improve overall safety and create an initial approach to the ‘right of way’ question related to aircraft-based Sustainable Taxiing solutions.
    - Reduction of the overall width of TaxiBot to ease driving on the service roads.

- Actual training of stakeholders and improved training materials:
    - Assistance to SAS in the development of updated tug driver training for TaxiBot operations.
    - Development of new trainings procedures for the certification of tug drivers to drive on Schiphol airside under passive control, including the development of a certification database.
    - Subsequent training of 8-10 tug drivers under both programmes, which included several training runs with the TaxiBots on Schiphol airside under regular operational conditions.
    - Training of airline pilots through CBT (computer based training) with the following feedback from pilots:
        - Easy to learn – adequate CBT.
        - Step forward in term of sustainability.
        - Experience of Taxiing with the TaxiBot is similar than without .
        - Speed (lower acceleration) and agility are different but is easily accomodable after one round of practice.
        - Deceleration: small time delay with the TaxiBot but no impact to the Taxiing – small adjustment in the way of working.
        - Adequate communication between the TaxiBot and the cockpit.

- Investigation of an alternative approach to Sustainable Taxiing at Amsterdam Airport Schiphol with a focus on centralized scale-up to maximize short-term uptake within current operational and procedural boundaries.
    - Combined existing procedures to allow for new ‘P10 TaxiBotting operations’, as detailed below.
    - A follow-up risk assessment to the 2020 TaxiBot safety assessment was prepared, where some risks and mitigation tasks were identified. The finalisation of this process is currently underway, pending ATC availability. More information can be found in Part II Safety.
    - Plan to investigate the possible effects of such utilization on ultra-fine particle emissions at airside.

- Development and realization of several infrastructural modifications to allow for TaxiBotting operations to and from the Polderbaan, including:
    - Additional markings for (un)loading locations and service roads
    - Bypass bays to allow for two-way traffic on service roads with TaxiBot operations
    - Signage to optimize certain locations for TaxiBot operations.
- Promotion materials, such as blogs and a movie[i] on the operational showcase, related to ALBATROSS and several presentations. For more information, see the communication, dissemination and exploitation report.

2. Results related to effects & conditions

Main effects to be studied

- Emission reductions: insufficient data available yet.
- Safety: required safety assessments carried out/updated as part of Exercise activities, as detailed in Part II.
- Workload:
    - The overall workload of the concept varies for different stakeholders. Especially in case of the tug drivers (handler companies) the overall workforce required is higher, due to the longer allocation required per task.
    - Mission-related workload during operations
- On-time performance: insufficient data available yet.

Most important conditions to validate

- Right of way: possible solution described in draft CONOPS, using distinguishing lights on convoy. This preliminary approach was built into the TaxiBots delivered to Amsterdam Airport Schiphol. To be further detailed in next phase with collaboration of local ATC.
- Engine start-up and shutdown on the move: discussed required procedures with airline partners. Some of the involved airlines have similar procedures in place for single engine taxiing. To be further detailed in next phase, as some of the airlines remain concerned about possible increase in pilot workload, depending on the aircraft type involved in the mission.
- Docking procedures: tested 1 of 3 systems operational at the airport, which did not (yet) support ST operations. Other systems to be tested in later phases.
- Safe and visible all clear positions & (un)coupling spots: (un)coupling spots at P6/P7 were given correct markings as part of the infrastructural adaptations and new (un)coupling spots were identified for central (un)loading procedures as part of the P10-procedures written in the pivot plan. No extensive empirical assessment of these position through operations has taken place with the TaxiBots yet.
- Incident procedures: incident procedures were defined as part of the draft CONOPS, with procedures and recommended actions identified for various possible incidents.

G.3.3 Unexpected Behaviours/Results

Due to the low number of demonstrations, no unexpected behaviours or results were identified in relation to the Solution.

G.3.4 Confidence in the Demonstration Results

1. Level of significance/limitations of Demonstration Exercise Results

Firstly, the limitations mentioned in the Demo plan still hold true for the originally planned demonstration exercise. These limitations can be found below, where limitations in italic didn't apply to the operational showcase performed under this exercise in ALBATROSS, but will still apply if/when operations on such a scale are demonstrated in the near future, e.g. as part of HERON.

Limitations mentioned in Demo plan:

- *Focus on trialling during peak operations; lessons learned might not be transferrable 1-on-1 to less busy times at the airport (where less stress on the processes of all stakeholders might make things easier).*
- TaxiBot number limitations: *2,* unsure if lessons can be extrapolated 1-on-1 to larger roll-out.
- Not all A/C, *but covered the largest fleet.*
- Not all runways, *but covered the furthest and busiest runway (so high significance and high local impact).*
- *Runway in question (18R/36L) isn't very representative of a typical runway on other European airports, due to the long distance from the gates. Unsure if all lessons are replicable or transferable to other place.*
- Solution isn't zero-emission yet, but retrofittable – this has impact on the (future) concept of operations, which might depend on charging and/or (hydrogen) fuelling.
- Trial has a smaller crew of familiar stakeholders; whereas standard operations are carried out by the entire population of operational crew. Differences might occur because of this, since the larger population might not work with a test mindset / future-thinking culture.

As described below (under G.3.43) results related to the actual operational demonstration within the exercise might be quite limited in significance. However, many of the findings/results related to the research and preparation phases of this operational demonstration are believed to be significantly representative of such an effort in a similar European medium-large sized airport.

As a result of the long-term impediments at the local ATC, the exercise did not receive sufficient representation from ATC to carry out initial plan and full-scale operations, and no large number of operations in the actual environment. Thus, this hampered the preparation and execution of the Exercise, thereby limiting the demonstration results. The difficulty in bringing all sector stakeholders together, however, is a valuable observation/result in and of itself. These struggles and lessons learned are surely representative of any medium to large airport wishing to demonstrate or implement this upcoming Solution in the future. We believe the preparation process is therefore very significant and sufficiently representative to the upcoming Solution.

2. Quality of Demonstration Exercise Results

Given the widespread collaboration between sector partners, we believe the quality of the process and subsequent deliverables to be fairly high. Most, if not all, deliverables and preparatory processes/documents are of good quality and can be used by the local sector partners in next steps, as well as be inspiration material for other European actors wishing to explore Sustainable Taxiing operations at their airports.

The two limiting factors in our confidence in the results is:

- The partial absence of our local ATC, and more specifically their operational experts. While partly mitigated by the presence of other ATC personnel and other domain experts, this absence led to a significant deviation in our plans. The number of operational demonstrations was cut drastically, and the associated CONOPS now only reaching a draft version, pending final input and approval from ATC. Given the input from all other stakeholders, we are quite confident in the maturity and validity of this concept of operations, and expect only minor adjustments need to be made during future stages.

- As a result of the low number of (operational) movements, no data was collected to compare performance in terms of fuel usage and emission savings. While the empirical data supports the assumptions on the significant decrease in fuel consumption and emissions, no significantly updated results can be provided as of now.

3. Significance of Demonstration Exercises Results

1. Statistical significance

Given the qualitative nature of most of the preparatory work and deliverables, the statistical significance of our results is limited, due to low number of operational demonstrations and the aforementioned lack of quantitative data.

2. Operational significance

Despite the necessary deviations from the plan, the operational significance of the Exercise results remain high. In fact, all decisions surrounding the continuation of the Exercise heavily relied on the understanding that the operational significance of the efforts shouldn't and couldn't be diminished.

- We delivered a draft CONOPS applicable to medium to large size airports, pending final adjustments from ATC.
- Various forms of TaxiBot utilization took place in the regular operational environment of the airport. Little special or temporary circumstances were created in order to facilitate TaxiBot operations.
- We continued to make progress on the TaxiBot certification of the B737 MAX, with the final steps now clear and underway.

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- An updated design of the TaxiBot, including relevant subsystems was created, manufactured and delivered to Schiphol.
- As part of the preparatory efforts, the actual training of stakeholders (tug drivers, airline pilots) took place. These trainings and certifications were based on improved training materials and procedures, which were developed as part of ALBATROSS but will remain relevant for all upcoming efforts.
- Development and realization of several infrastructural modifications to allow for TaxiBotting operations to and from the Polderbaan; these were created based on the original demonstration plan and remain relevant for upcoming activities, e.g. within HERON.
- Investigation of an alternative approach to Sustainable Taxiing at Amsterdam Airport Schiphol with a focus on centralized scale-up to maximize short-term uptake within current operational and procedural boundaries. This alternate approach to scaling is currently being explored further and will remain in scope for the utilization of TaxiBots at our airport in the coming years.

G.4 Conclusions

The implementation of new operational procedures requiring new concepts that interact in multiple domains are very strenuous and are mostly of non-technical nature – but touch on culture and adaptability. Especially complicating is the Pandemic and the challenging period following the Pandemic, when the uptake of operational business at airports impacted resources in many ways. The combination of both makes it very challenging.

Partners have put in a lot of effort to progress with the concept of Sustainable Taxiing / TaxiBot operations at Amsterdam Airport Schiphol, but the amount of changes and both innovation and operational challenges that we have faced show that the need for timely testing and demonstrating concepts are necessary to progress the goals of SES. Steps may seem small and the demonstrations results may not meet our own, SJU's or the communities expectations. A key take-out of the entire effort is the importance of ongoing support and collaboration from all sector partners, which must be carefully maintained and continuously coordinated. At the same time, we believe our efforts show multiple lessons learned and deliverables obtained serve as a crucial base for any and all subsequent steps. Finally, we believe the proposed SESAR solution utilizing Sustainable Taxiing based on a Taxibot is still the most progressed solution of all other European efforts, and will continue to collaborate with potential partners looking for guidance and advice, both within the HERON consortium, the EUROCONTROL Sustainable Taxiing Taskforce and through other collaborative efforts.

G.5 Recommendations

Please note that the below recommendations are already slated for follow-up as part of SNBV's possible actions within HERON and the ongoing contact with the EUROCONTROL Sustainable Taxiing Taskforce.

G.5.1 Recommendations for industrialization and deployment

- Make sure to secure ongoing support and collaboration from all sector partners by continuously investigating the various future benefits of the solution (Sustainable Taxiing / TaxiBotting) from the perspective of each individual partner.

    - Try to pre-emptively find mitigative actions in case on or more stakeholders are unable or unwilling to dedicate the required resources to the project.

- In order to quickly resume operations according to the initial plan, we recommend finalizing the draft CONOPS with help and contribution of ATC/ANSP as soon as possible.

- On the one hand we recommend to continue exploring alternative approaches to hypothesis-driven demonstrations by continuously evaluating the minimum required circumstances to learn certain aspects of the operation, like we proceeded to do with the pivoted approach to TaxiBot utilization.
  At the same time, we recommend to carry out a larger number of full-scale live trials in standard operations, building on the preparatory work and lessons learned in ALBATROSS, in the following conditions:

    - Operation in several (adverse) weather conditions
    - Operation during operational peak hours/days
    - Simultaneous operation of two (and) or more TaxiBots
    - Operation with more airlines / handlers than the first trial, including operation with additional aircraft types.

- To better understand the ultimate potential of the Sustainable Taxiing / TaxiBot solution, it is important to focus on the gathering of actual fuel data to further validate fuel saving predictions. Fuel data is sensitive information which needs careful consideration and tailormade NDA's with involved airlines. This must be an integral part of the project execution. To achieve satisfactory data and information, we also recommend determining the relevant fleet mix for comparison to the TaxiBot operations, which may be based on historical data, but may also be specific to current and future changes to the airport operations.

- We recommend looking at the desired ownership/operating model(s) for Sustainable Taxiing operations with the TaxiBot in various medium to large scale European airports, including the investigation of legal and financial aspects of such models.

- We recommend the exploration of the ability for Sustainable Taxiing with the TaxiBot to address additional aircraft types (including the wide body fleet), pending various certification and/or modification options.

- We recommend continuing to exchange with other airports regarding our mutual Sustainable Taxiing approach deploying the TaxiBot to share our roadmap and lesson learned.

G.5.2 Recommendations on regulation and standardisation initiatives

- A key question to be dealt with regarding Sustainable Taxiing operations with aircraft-based solutions, like the TaxiBot, is the ability for stakeholders to distinct between regular taxiing operations, towing operations and Sustainable Taxiing / TaxiBotting operations. This is particularly relevant, since Right of Way status differs per movement classification. We recommend to further test our initial solution, and to collaborate with European and Global stakeholders to come to international standards.

- We recommend continuing our work with EUROCONTROL STX TF to create a set of considerations, development and implementation guidelines for medium to large European airports considering various forms of Sustainable Taxiing (SET, airport-based approaches and aircraft-based approaches).
- We aim to work with our local governmental agencies (ministry of Infrastructure & Water Management) and Inspection Living Environment and Transport to assess future implementation of operational building blocks at the airport.

Appendix H Demonstration Exercise #08 Report

H.1 Summary of the Demonstration Exercise #08 Plan

H.1.1 Exercise description and scope

Why SAF within Albatross?

Aiming at deploying the concept called "Book & Claim"

1. Challenge

- Limited Sustainable Aviation Fuel supply in few physical locations
- Access limited to carriers in a few hubs with limit on offtake levels
- Cost and emissions of transporting SAF to customers
- Lack of ability of a corporate customer to claim GHG emission reductions

2. Book & Claim solution - as proposed by the RSB organization

- Allows SAF purchase without a physical connection to the supply site
- No matter where SAF is purchased the net environmental effect is the same
- Enables the attribution of GHG emission reductions through SAF use to corporates to reduce their scope 3 emissions
- RSB provides assurance that transactions are credible, traceable and don't lead to double counting

3. What is the RSB - Roundtable for Sustainable Biomaterials?

- RSB is a global, multi stakeholders, independent organization driving the development of a bio-based & circular economy on a global scale through sustainability solutions, certification & collaborative partnerships.
- In 2021, the RSB has launched a book & claim pilot project.
- The Albatross project was the opportunity to benefit from this pilot and support the feasibility of such a concept.
- The RSB has also agreed to support the B&C process description and to support the communication initiatives to the external audience.

Main activities at the start of the project

1. Main objective of the exercise

- Demonstrate feasibility of a dematerialized concept called “Book & Claim” to use Sustainable Aviation Fuel within the European Union, reduce CO2 emissions on the whole life cycle

2. Preparation of the Very Large Demonstrator early 2020

- Evaluating Airbus participation in the open VLD
- Initiating the promotion of Sustainable Aviation Fuels use to the partnering Airlines: Apr-20
- Starting assumptions to budget Sustainable Fuels: Jun-20
- Evaluating EU project possible interactions to complete the claiming process: Oct-20
- Grant Agreement preparation: Oct-20

3. Launch of the project

- Albatross kick-off Meeting: Jan-21
- Construction of the “Demo Plan” for SAF deployment: Mar-21 to Jun-21
- Presentation to RSB (Roundtable for Sustainable Biomaterials) & role within Albatross: Jul-21
- Identification of roles and responsibilities of potential stakeholders (Partnering Airlines, Airbus, Roundtable for Sustainable Biomaterials, regulatory bodies)
- Procurement: presentation to get their involvement: Aug-21
- Re-activating & arguing Airlines to use SAF in Albatross: Sep-21

What has been developed

1. Explanation of the Book & Claim concept at different levels to push for its deployment

- Fuel Economy & Emissions Reduction Forum in Toulouse: presentation of Albatross by Airbus/Eurocontrol: Oct-21
- Face to face workshop in Toulouse with Albatross partners: presenting SAF Book & Claim concept: Nov-21
- RSB subcontracted work: development of specification + Purchase Order: Nov-21
- Work specification review & alignment with Procurement for PO & RSB contract: Nov/Dec-21
- Hypothesis refined + letter sent to Airlines to get their positioning on their contribution: Jan/Feb-22
- Identification of eligible flights & assumptions: Feb-22
- Albatross Demonstrator for the Book & Claim concept - Kick off meeting with RSB, assumptions refined & confirm retroactivity if applicable: Mar-22
- Legal and Ethics & Compliance risks review (step when contacting potential suppliers):Mar/Jun-22

- 1st awareness session held by RSB to explain Book & Claim concept to Albatross partners: Mar-22
- Recurring coordination meetings with RSB
- Book & Claim related activities being refined with the RSB (their Pilot project being adapted to Albatross demonstrator) + process mapping: May-22

2. Looking for incentives & promoting Book & Claim concept

- Connecting with European Union, preliminary investigation: Jun-22
- 1st draft modelization of the Albatross Book & Claim process (with/without Schiphol airport incentives scheme)
- Meeting with Schiphol airport to investigate the optional use of SAF incentives
- Identifying Albatross candidate airlines part of Schiphol program to clarify engagement
- World ATM Congress in Madrid, participation of Albatross: Jun-22
- First attempt for RSB training with invitation to partnering Airlines, extended to SAF representatives: Aug-22
- Workshop in Amsterdam, remote presentation of status: Oct-22
- Second attempt for RSB training performed with video conference: Nov-22
- Purpose of this awareness:
    - Explain detailed mechanisms and advantages of the concept
    - For Airlines: explain their actions to implement
    - For Legislator: explain integration into the regulatory framework
    - Targeted audience: Albatross partners, EASA or EU Commission, Airbus
    - 1h30 webinar, recorded, GMeet, interactions between participants & RSB speaker

3. Investigating for potential fuel suppliers

- SAF Supply: 1st contact with eligible SAF supplier, volumes difficult to secure due to high demand vs availability
- Final Book & Claim process to be refined accordingly
- Investigating & selecting supplier(s)/airport(s) for collaboration with RSB & project stakeholders
- Very few stakeholders eligible to the RSB Book & Claim process
- Contact with various SAF suppliers: plans to investigate with potential additional eligible supplier(s)
- Start of contact with first eligible supplier (#1 supplier - under NDA) on the B&C topic: May/Jul-22
- Supplier not able to answer to the request despite the various scenarios (3) considered
- Start of contact with another potential supplier (#2 supplier - under NDA): Jul-22
- Supplier not able to answer to the request as not eligible to the RSB B&C registry
- Attending RSB conference & review of the RSB Book & Claim manual version 3: Aug-22
- Start of contact with another potential supplier (#3 supplier) - dedicated NDA submitted and signed: Jul/Dec-22
- Supplier not able to answer to the request despite several scenarios (5) considered

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- Start of contact with another potential supplier (#4 supplier - under NDA): Dec-22
- Last supplier not able to answer to the request despite exchanges

Conclusion

1. A challenging context

- "Sustainable Aviation Fuel" was not identified as a key building block of the Albatross SESAR initiative from the start, thus it has integrated the project while already running and while budget & resources allocation were already defined
- Book & Claim concept may represent a risk for key producers/suppliers (especially when well established as it increases competition risks)
- Limited volumes (50 to 100T) is not interesting for SAF suppliers/producers, it may even represents an issue logistically wise
- High risk of competition due to other similar Book & Claim initiatives are running in parallel worldwide
- The RSB Book & Claim registry requires the suppliers to be certified (sustainability wise) but also to be accredited (or enrolled in the accreditation process) of the Book & Claim registry which drastically limits the eligible stakeholders
- Risks of confusing communications for some project's stakeholders (eg. key Airlines promoting their SAF roadmap) leading to very limited interest in getting involved in the SAF initiative of the Albatross project => link with Schiphol incentivisation initiative that was launched in parallel
- Impossible to renegotiate existing contracts either from a Supply or a Demand side. Such contracts are likely to have been negotiated for months

2. Lessons learnt from this experiment

- The initiative to push the Book & Claim through the Albatross project was the opportunity to explore its feasibility, the needs and expectations for such a concept
- It was an opportunity to de-risk different aspects of the concept, test stakeholders' understanding and appetite, capitalize lessons learnt from successes and failures and get experience for future work on the topic.

H.1.2 Summary of Demonstration Exercise #08 Demonstration Objectives and success criteria

This Exercise addresses objective OBJ-VLD-ALBATROSS-003 of the VLD : to showcase additional decarbonation initiatives, not directly coming from the core processes of Air Traffic Management and Flight Operations.

The success criteria is to demonstrate that the selected decarbonisation initiative, SAF in this case, can be adopted by the relevant Aviation actors and can in fact produce an effect. The concerned actors are in this case mainly airlines (and the fuel supply chain). ATM and ATC actors are not concerned, to the extent that the foreseen blends of SAF fuel do not impact the operational performance or the behaviour of the aircraft and therefore do not change the processes.

H.1.3 Summary of Validation Exercise #08 Demonstration scenarios

The exercises targeted the usage of the "SAF Book & Claim" solution proposed by the RSB organization.

More detail can be found in section H.1.1.

H.1.4 Summary of Demonstration Exercise #08 Demonstration Assumptions

Identifier	Title	Type of Assumption	Description	Justification	Impact on Assessment

Table 44: Demonstration Assumptions overview

Assumptions were not formally tracked.

H.2 Deviation from the planned activities

The exercise did not succeed in actually making use of the Book & Claim mechanism. More detail about the reasons of this deviation can be found in section H.1.1 (in particular under the subtitle "Conclusions").

H.3 Demonstration Exercise #08 Results

H.3.1 Summary of Demonstration Exercise #08 Demonstration Results

Demonstration Objective ID	Demonstration Objective Title	Success Criterion ID	Success Criterion	Sub-operating environment	Exercise Results	Demonstration Objective Status
OBJ-VLD-ALBATROSS-003	Showcase aviation "other" decarbonisation initiatives	CRT-VLD-ALBATROSS-003	Effective implementation of SAF B&C.	*N.A.*	The B&C could not be actually used.	Partailly OK

Table 45: Exercise 8 Demonstration Results

1. Results per KPA

No measurement was taken by the exercise.

Nevertheless, the initiative to push the Book & Claim through the Albatross project was the opportunity to explore its feasibility, the needs and expectations for such a concept and its complexity.

More detail can be found in section H.1.1.

2. Results impacting regulation and standardisation initiatives

The exercise did not produce results that could feed regulation or standardisation initiatives.

H.3.2 Analysis of Exercises Results per Demonstration objective

1. EXE8-OBJ-VLD-003 Results

The exercise did not succeed in actually making use of the Book & Claim mechanism.

Nevertheless, the initiative to push the Book & Claim through the Albatross project was the opportunity to explore its feasibility, the needs and expectations for such a concept and its complexity.

More detail can be found in section H.1.1.

H.3.3 Unexpected Behaviours/Results

The exercise did not succeed in actually making use of the Book & Claim mechanism. More detail about the reasons of this deviation can be found in section H.1.1 (in particular under the subtitle "Conclusions").

H.3.4 Confidence in the Demonstration Results

1. Level of significance/limitations of Demonstration Exercise Results

Not applicable.

2. Quality of Demonstration Exercise Results

Not applicable.

3. Significance of Demonstration Exercises Results

Not applicable.

H.4 Conclusions

The main purpose of the exercise was to highlight the current Sustainable Aviation Fuel challenges. Because we have limited Sustainable Aviation Fuel supply in a few physical locations. The access is limited to carriers in a few hubs with limits on offtake levels. Cost and emissions of transporting SAF to customers have to be considered. The complexity for corporate clients to claim GHG emission reductions is demonstrated. Intention through this exercise was to demonstrate the feasibility of a dematerialized concept called “Book & Claim” to use Sustainable Aviation Fuel within the European Union, thus reducing CO2 emissions on the whole life cycle. The “Book & Claim” solution allows SAF purchase without a physical connection to the supply site. No matter where SAF is purchased the net environmental effect is the same. It enables the attribution of GHG emission reductions through SAF use to corporate customers to reduce their scope 3 emissions. Within the projected process the identified partner was able to provide assurance that transactions were credible, traceable and didn’t lead to double counting.

A step by step approach was followed. First by arguing the importance of SAF deployment to the Albatross participants. We identified roles and responsibilities of potential stakeholders (Partnering Airlines, Airbus, Roundtable for Sustainable Biomaterials, regulatory bodies). We explained the concept to convince potential contributors at all occasions, through training sessions with different levels of details. The partnership with RSB (Roundtable for Sustainable Biomaterials) was established to develop specifications, using one of their pilot projects. In parallel we proceeded with a risk review of the Legal, Ethics & Compliance aspects. Additional SAF incentives (Schiphol airport proposal) were envisaged to stimulate the proposal. Preliminary assessment was performed by connecting with the European Union. Finally the complete investigation for potential fuel suppliers, airports was made to initiate potential collaboration with identified stakeholders.

A very challenging context was experienced all along the duration of this project. Book & Claim was not identified as the key building block on SAF from the start, it was integrated while the project was already running and budget/resources allocation already defined. The Book & Claim concept increases competition risks for key producers, other initiatives could run in parallel. Limited volume (50-100 tons) expected for the exercise was not attractive for suppliers, and required logistics. The RSB Book & Claim registry requires the suppliers to be certified and accredited, reducing the number of eligible stakeholders. A risk of confusing communications could appear for some project’s stakeholders (eg. key Airlines promoting their SAF roadmap) leading to very limited interest in getting involved in the SAF initiative of the Albatross project (referring to the Schiphol incentivisation initiative that was launched in parallel). It was Impossible to renegotiate some existing contracts either from a Supply or a Demand side, negotiated for months.

H.5 Recommendations

H.5.1 Recommendations for industrialization and deployment

The main lessons learnt from this experiment are the following. The initiative to push the Book & Claim through the Albatross project was the opportunity to explore its feasibility, the needs and expectations for such a concept and its complexity. It was an opportunity to de-risk different aspects of this solution, test stakeholders' understanding and appetite. As a final result we capitalized lessons learnt from successes and failures and got experience for future similar work.

H.5.2 Recommendations on regulation and standardisation initiatives

Several training sessions with different levels of details, in partnership with RSB (Roundtable for Sustainable Biomaterials), addressed the identification of roles and responsibilities of potential stakeholders (Partnering Airlines, Airbus, Roundtable for Sustainable Biomaterials, regulatory bodies) and a risk review of the Legal, Ethics & Compliance aspects. However, the exercise did not issue explicit recommendations on this subject.

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[i] https://www.youtube.com/watch?v=2mO0wrP8_ac

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