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THE ALBATROSS PROJECT – A EUROPEAN INITIATIVE TO REDUCE AVIATION'S CARBON DIOXIDE EMISSIONS IN LARGE SCALE

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Abstract

Aviation is seeking further ways to reduce its environmental footprint. To showcase currently still hidden potentials for fuel saving multiple European actors from different fields come together to implement a solution for the most efficient flight regarding state-of-the-art aircraft, airspace and ground infrastructure. Collaboration of all stakeholder is the key to seek benefits and make them permanent. Those acting parties are in particular Pilots, Air Navigation and Service Providers, Network Managers, Airport Operators, System Developers, Airlines and Airframers. This paper presents the approach of the ALBATROSS project. ALBATROSS is a 2-year very large scale SESAR[1] demonstration (VLD). The project participants work together to identify the potential for fuel savings and to demonstrate them in a large European-wide scale. The overall objective of the ALBATROSS project is to define and demonstrate operational solutions and processes allowing greener flights, minimising the environmental impact of aviation while maximising flight efficiency. This is done by a series of live trials and the comparison of the results with historical flight data. The feasibility of operating such flights in various operating environments, with fuel consumption as close as possible compared to the theoretical optimum and as low as possible compared to the average fuel consumption observed historically will be demonstrated. For the sake of comparability the investigations are conducted for similar aircraft types operating on the chosen city-pairs under similar operational conditions.

Keywords: emission reduction, efficient flight, fuel saving, very large demonstration, gate to gate

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[1] Single European Sky ATM Research Programme

1. Strategy of the Project

ALBATROSS inventories the sources of fuel/CO2 waste of the larger set of activities with a special focus on air traffic management (ATM) and air traffic control (ATC) related to the normal Gate-to-Gate operation of a flight, including predeparture, departure, climb-cruise-descent, arrival, ground operations for taxing and parking, and proposing adequate mitigations. Many solutions to improve fuel savings have been run through inventory, development and other tests before. ALBATROSS as a VLD is intended to be the occasion to show, that a soon and permanent implementation in specific portions of the European airspace is possible.

Many solutions will be put into practice parallelly to demonstrate the potential to minimise the environmental impact of aviation. Some selected examples include the following: New precision approach procedures (RNP-to-ILS, RNP-AR, etc.) will be implemented. Continuous climb and descent will be facilitated. Several novel data analytics-based tools will be introduced to assist pilots in identifying tactical in-flight trajectory optimization opportunities for improving fuel efficiency. Possibilities to relax and mitigate certain ATM constraints through airspace design by collaborative procedures and a certain degree of flexibility in the constraints will be tested. Improvements to taxiing operations will be investigated, in the form of single-engine taxiing. Moreover, a sustainable hybrid towing vehicle for taxi assistance ("taxibot") will be used in order to reduce emissions.

The project will examine how a resulting and adapted concept of operation could be permanently integrated into network operations. The biggest challenge lies in ensuring complementarity between already individually proofed solutions. These all have already demonstrated – in a given operational scenario and under specific circumstances – that they can improve flight efficiency and reduce fuel waste. The real challenge will be to determine how these solutions can work together in a real and operational environment and supported by existing multi-stakeholder processes.

1.1 Types of flights

The conceptual idea behind ALBATROSS is to investigate three types of flights which we are called:

- Baseline Flights (BF),
- Optimum Flights (OF) and
- Green Flights (GF).

The Baseline Flights (BF) are used to investigate the state-of-the-art air traffic situation and the statistically typical execution of intereuropean flights. Respectively they stand for the typical succession of recurrent flights between fixed city pairs. The according reference data for the baseline flights is derived from historical data involving aircraft types identical to those used during the demonstrations flying between the same pairs of airports, for similar weather conditions and operational conditions representative of peak seasonal periods of a normal traffic year. Possible sources for this flight data are historical Flight Data Recorder / Quick Access Recorder (FDR/QAR) data, Automatic Dependent Surveillance Broadcast (ADS-B) data, and flight plan data. Furthermore, historical data from actual flights are used to indicate current practices in congested airspaces (terminal maneuvering area around airports) to determine a minimum set of ATM constraints (including airspace, flow, capacity management and air traffic services).

In contrast to the Baseline Flights the Optimum Flights (OF) represent the bare optimum for a flight from A to B that can be achieved from a fuel saving perspective removing all constraints counteracting the optimal trajectory, except for constraints related to the aircraft envelope (e.g., maximum speed, maximum altitude etc.) or flight crew/airline procedures related to the safety of the flight. Since constraints from Air Traffic Control or other stakeholder will always be present in the real world the Optimum Flights are theoretical models. The 4D flight trajectory of each OF will be determined with OEMs performance modelling applications and mission virtual play using the avionics manufacturer Flight Management System (FMS), considering realistic atmospheric conditions and Actual Take-off Weight (ATOW), related to the demonstration flights. The OF trajectory will be defined taking aircraft envelope and commonly used flight crew procedures (Standard Operating Procedures – SOP) into consideration. Depending on these specific elements, several OF trajectories could exist between airport-pairs.

One main challenge in defining the OF is how to consider atmospheric conditions and in particular the effect of wind on the trajectory. Not considering atmospheric conditions would in many aspects simplify the definition of the trajectory, which then would be a simple great circle line between two points (origin and destination) and thereby provide a clear and recognisable reference for further comparison with live-trail flights. Considering atmospheric conditions will complicate the definition of the trajectory as all aspects of atmospheric conditions at any given point in space and time should be considered. Which, in the view of granularity, is very difficult to achieve at an appropriate and reasonable level given all the possible variants emerging. This means the trajectory, in the view of defining an OF, is not a set trajectory, specifically defined by geographical means (i.e., latitude, longitude and altitude) but variable depending on usage.

It is important to understand that the OF is an absolute and not a relative definition, with the aim of exploring one single set of requirements to define the optimum trajectory for a given flight. A requirement may be dynamic (e.g. the wind may change). That leads to definitions of the optimum flight according to the prevailing wind condition of the day. For the optimum flight definition there is the following granularity to adapt to the predominant situation: 1) It is a flight on the shortest path assuming no wind influence. 2) It is a flight on the shortest flight path influenced by the wind. 3) It is a flight which must not follow the shortest path if according to the wind another trajectory is more favourable. The analysing part may choose which granularity fits best for the according investigation and consider sub-optimising parameters if beneficial to provide a reliable and comparable indicator, but the OF set of requirements will remain as optimised and static as possible to serve as the ultimate trajectory in terms of CO2 emissions.

The flights ALBATROSS will demonstrate are called the Green Flights (GF) (Figure 1). For those flights as much constraints as possible are taken away from flight executions. So, the Green Flights will not achieve a fuel consumption as low as OFs do, but the project teams' ultimate goal is to demonstrate Green Flights as close as possible to the theoretically optimal OF. In fact, a GF without any constraint would be equivalent to the Optimum Flight, but this rarely happens in real life, as operating procedures require a set of limitations to maintain a certain level of safety.

Figure 1: Air France Takeoff [1]

The differences between the Greener Flights and the Baseline Flights will provide an indication of the gain in performances (fuel and CO2 savings), thanks to the set of solutions implemented in each of the demonstration trials. The differences between GF and OF flights will give concrete indications of the streams for improvements (but maybe not viable today) that would allow to save more fuel and CO2.

2. Concept of operations

The investigation of BF, OF and GF implies the different scientific methods and the comparability of the flights always have to be a major focus of the work to create consistent results. With regard to that a concept of operations is worked out to identify constrains counteracting the optimum trajectory and thereby finding possible areas of improvements.

As a first step the OF has to be defined. Figure 2 illustrates the simplified idea of an OF.

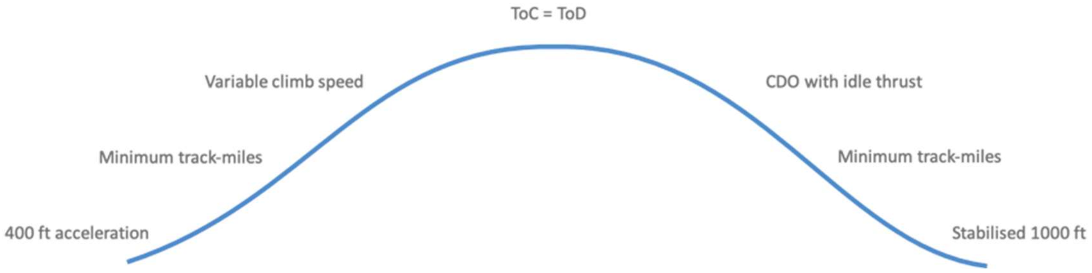

Figure 2- Step 1 – defining OF (example) [2]

The optimum flight is a theoretical construct with as less constraints as possible. The only prevailing constraints are aircraft type, take-off weight, and airports. If no wind is considered the optimum flight is performed directly on the great circle from airport to airport. If there is wind the flight track is optimised accordingly. It may happen, that small deviations in horizontal and lateral path lead to larger distances flown but less fuel consumed over the whole flight. This is the theoretical optimum. The runway chosen for start and landing has always to be the one with the most favourable headwind component. The optimum in terms of turns (without special wind situations) is to have just two turns. The first turn is performed after take-off to set course to the destination airport and a second turn as late as possible before landing (e.g. before passing the stabilization altitude). Due to the changing weather situations the optimum flight between two city pairs can be different each day. So, the definition of the optimum flight is, that there is one distinct optimum flight for predominant weather conditions of the day, but a large set of optimum flights for a city pair within a longer time frame.

The in ALBATROSS applied calculation of the optimum flight is restricted to the great circle flight path with the shortest distance including the two turns. No deviations due to wind influence in the lateral path, but adaptions of the horizontal path in 500ft increments according to the wind are considered. This is done due to simplicity reasons in the computation.

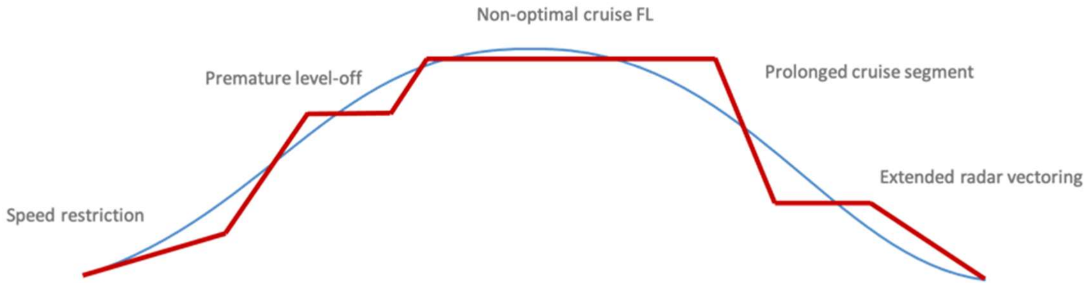

Figure 3 - Step 2 – finding constrains and highlight some discrepancies (example) [2]

Knowing the optimal trajectory and the wished sequence of procedures to be applied in a second step the constraints are also considered to identify the sources of suboptimal fuel consumptions. Figure 3 exemplarily shows some of those constraints. Figure 3 highlights some discrepancies solely regarding the vertical profile of an example flight in comparison to the Optimum Flight. Including horizontal deviations and a further dimension for the timing of sequences of actions the identified discrepancies might be more numerous.

In current TMAs the routing towards the planned cruising altitude as early as possible is not always achievable due to the TMAs' design and noise abatement procedures. For the climb it would be beneficial to climb with a variable CAS to always hit the optimum operating point of the aircraft and the engines, but this causes implications on pilots and ATC. In the cruise flight there is an optimum speed and altitude to maximize the specific range, that depends on aircraft weight. Ideally the pilot would constantly adapt the cruise altitude accordingly. Unfortunately, ATC requires speed control and there might be restrictions for level capping due to route availability (Route Availability Document – RAD). Direct routing to fly to the destination in the shortest distance possible is normally hindered due to restrictions according to the route network. Military areas and activities require a certain segregation of the airspace that creates deviations. Network restrictions – commonly known as Route Availability Document (RAD) measures - enable Air Navigation Service Providers (ANSPs) to manage major traffic flows through the airspace in their area of responsibility, helping to maintain safety and enlarge capacity. The general idea is to use these restrictions in a more dynamic way, introducing a daily management process in order to ensure their utilisation only when necessary. The effectiveness of improvements is determined by the factual involvement of the different stakeholders, both in the preparation and executions.

Another factor that sometimes prevents the most fuel-efficient flight is the route charging or the fuel pricing at different airports. For airlines it may be beneficial to avoid routes with high route charges even if the overall fuel consumption is higher. At the same time, it may be beneficial to carry more fuel than necessary to avoid higher fuel prices. The airplanes are heavier than necessary for the actual mission and therefore consume more fuel. Estimations of Eurocontrol show, that the additional fuel consumption in the European Civil Aviation Conference (ECAC) area is roughly 286,000 tons kerosene [3].

Coming to the approach phase continuous descent approaches are seldom possible. The airspace in the TMA or ASMA (Arrival Sequencing and Metering Area) is strictly regulated. Often environmentally friendly operations can't be applied because of capacity or safety issues. The airplanes are organized via vectoring, longitudinal holding ("tromboning") or holding patterns. The resting track miles until touchdown are not known by the crew and in that way the following flight is not sufficiently predictable to perform an energy efficient approach.

The application of all employable solutions to reduce fuel consumption leads to the green flight solution as shown in Figure 4.

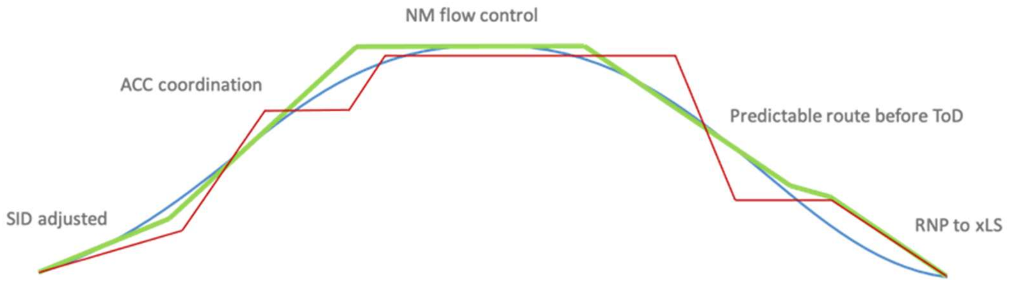

Figure 4 - Step 3 – the application of all employable solutions to reduce fuel consumption leads to the green flight solution (example) [2]

3. Exercises and Clusters

In ALBATROSS one of the major challenges is to coordinate the variety of trials performed to reduce fuel consumption. The several individual activities driven by project partners are united and coordinated. Each separate activity can be counted as stand-alone solution to save fuel concerning one specific aspect of flight, which might either be a procedure, a new system application or a changed planning (ATC).

The ultimate goal would be to display all solutions to save fuel in one single demonstration. Since the capabilities of all partners are restricted to enable all solutions in their area of responsibility (airport ground services, ANSP, airline fleet, etc.) several aspects must be demonstrated individually, but the conclusion on the potential to save fuel will include results of all of them.

ALBATROSS is structured in exercises. Such an exercise might either be arranged around one single solution or it combines multiple solutions. The local arrangement of multiple solutions is called cluster. Such a clustering of solutions is favourable when multiple solutions might be easily combined. Mostly this is due to geographic proximity of the acting parties and linked to the interest of the collaborating partners to demonstrate all solutions to save fuel they can integrate in their operations.

The actions can be structured according to the place where they are applied. This is the airport field itself, the TMA and the en-route part of the flight.

3.1 Gate-To-Gate Exercises

For the en-route part especially network managers (NMs') and air navigation and service providers (ANSPs') as Eurocontrol, Austro Control, DSNA and LFV are working together in Europe wide activities. The most extensive exercise is about the organization of Gate to Gate flights between fixed city pairs. Three city pairs are selected to collect reference data for actual non-optimized flights.

The potential to improve the Gate to Gate operations from ATM's perspective is to treat constraints of RAD, ASM and ATFM. ATM improvements that are investigated in ALBATROSS are: the dynamic adoption of RAD's, Green Flight priority for ATFM measures, FRA (free route airspace) to improve the usage of unconstrained DCT's (direct routing chart), usage of an opportunity tool, dynamic profile tuning restrictions (PTR) and slot swapping. Complex TMA procedures or not yet full FRA are reorganized and non-optimal route catalogues are under investigation as well. Currently Airline Operators often do not fully consider the opportunities offered by dynamic ATM. Also, the Flight Planning Process (FPL) is not dynamic enough to capture all dynamic opportunities. RAD's are preventing the optimal trajectory and military activities can be better coordinated. Route charges that prevent the selection of the most fuel optimum route have to be mitigated.

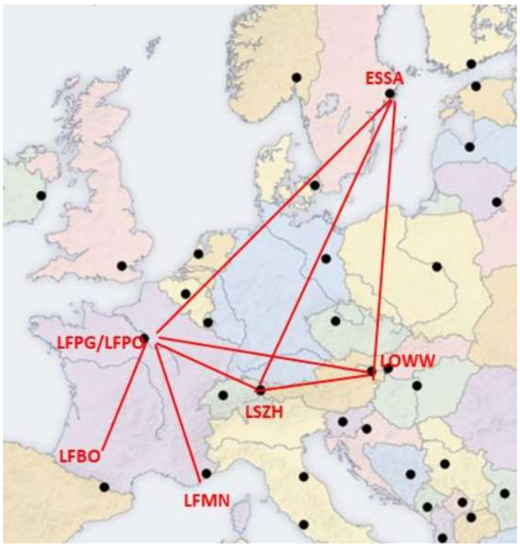

Figure 5: City Pairs under investigation in ALBATROSS

Figure 5 shows the City Pairs investigated in ALBATROSS for the Gate to Gate demonstrations. The decision in ALBATROSS was to concentrate on three of them for the investigations and live trials. Paris Charles de Gaule (LFPG) to Stockholm (ESSA), Paris Charles de Gaule (LFPG) to Vienna (LOWW) and Paris Charles de Gaule (LFPG) to Zürich (LSZH).

3.2 Local Exercises

In Sweden a dedicated cluster is established. Trajectory-based operations (TBO) on extended projected profile (EPP) at will be performed at the airport Arlanda/Stockholm (ARN). Furthermore, unconventional Performance based Navigation at Air Traffic Services Route Network and “Greener” Airspace procedures at Arlanda Airport. Novair uses internal Green Operation Procedures such as Single Engine Taxi -In and enhanced flight planning like no destination alternate. As part of the Swedish cluster LFV supports the gate to gate trials from an ATM perspective.

For Frankfurt airport Lufthansa is performing a data analytics study to organize traffic in the TMA and the ASMA. This exercise is relying on historical data. The data is analysed with methods using artificial intelligence to identify possible ways to save time and fuel in the extend approach to the airport. The main task at this stage is to identify similar aircraft trajectories, e.g. lateral tracks that are close to each other. Definitions for proximity could be derived by calculating the discrete Hausdorff or Fréchet distance. Therefore, each trajectory must be discretized in the same way (e.g., by using similar time steps or similar number of grid points). Because TMA operations are complex due to special rules to ensure safety during approach and departure procedures, a trajectory may have more requirements than time, position, altitude, and speed, e.g., origin/destination airport, aircraft type, landing time. In particular, each trajectory must also be reconciled with features addressing the current environmental and operational conditions (e.g., airspace and runway utilization, weather constraints).

Focused on the TMA and especially the approach an activity is performed by a collaboration of DLR and Swiss at Zürich airport. It is investigated how to minimize the TMA region emissions using the LNAS (Low Noise Augmentation System) [4]. LNAS is enhanced to work on the A320neo. Swiss equipped their A320neo with the LNAS software on the Pilots EFBs' (Electronic Flight Bags). At Zürich approaches will be performed with LNAS online. The system calculates the top of descent for a Continuous Descent Approach (CDA) or Low Drag Low Power Approach (LDLP). ATC Speed restrictions or vertical speed commands are considered. LNAS constantly adopts the optimum approach solution to the current situation and thus reacts on unforeseen changes like wind etc. [5],[6]. Figure 6 shows some results for approaches on Frankfurt airport. The red lines symbolize approached performed without LNAS support and the blue lines with LNAS online. The use of speed brakes was minimized and the approach profile was structured more efficiently.

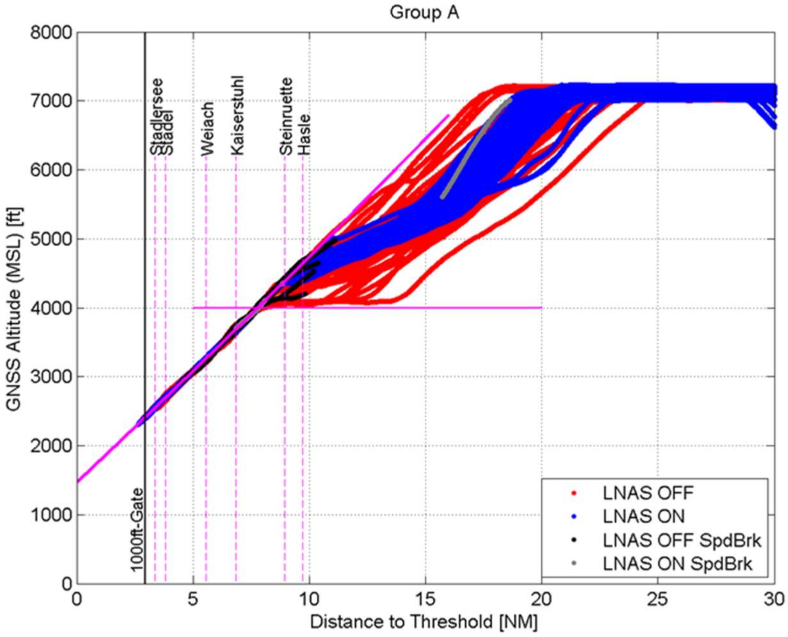

Figure 6: LNAS approach [5]

In Vienna PBN to ILS Approaches will be performed. Austro Control as local Air Navigation and Service Provider (ANSP) coordinates this exercise. Furthermore, Vienna is part of the Gate to Gate trials. As a second trial Wizzair uses a tool that adapts to the individual airplane characteristics for climb and descent operations flight optimization developed by NAVBLUE.

In Paris CDG PBN-to-ILS approaches will also be demonstrated by Air France. Continuous descent operations are facilitated by inter-center cooperation. Data analytics tools from Air France for trajectory optimization are applied.

3.3 Ground based exercises

In Paris CDG one engine off taxiing will be demonstrated by Air France. Especially the taxi out procedure with one engine off is extended. DSNA is contributing on another field with SEPHER. This is an approach to provide renewable energy as secondary energy source to isolated sites of air navigation infrastructure.

At Schiphol airport an exercise is showcasing the use of two taxibots (see Figure 7). Those vehicles demonstrate sustainable taxiing solutions in real traffic situations [7]. In a series of live trials, it is demonstrated, that aircraft engines will not be used to taxi from gate to runway and from runway to gate. The current challenge is to organize a mixed traffic of taxibots and conventional taxiing procedures.

Figure 7: Taxibot in Schiphol [8]

Use of sustainable taxi assistance with semi-robotic hybrid towing vehicle designed for taxiing airplanes from the boarding gate to the take-off runway and vice versa without the use of jet engine power. The use of these vehicles will have a significantly positive impact on the environment and airline expenditure, leading to up to 85% reduction of fuel consumption, CO2 and other noxious emission during taxi.

One exercise has a different character than all the other exercises. The physical impact on sustainable fuel use and CO2 reduction is not measurable directly on the plane. The link is created via the fuel marked. This exercise targets to make use of some sustainable aviation fuel (SAF) [9] on ALBATROSS flights, by addressing some of the current obstacles to the deployment of SAFs. It explores the potential chain of custody for SAF integration, via dematerialization ("Book-and-claim"); 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.

4. The setup of gate to gate scenarios

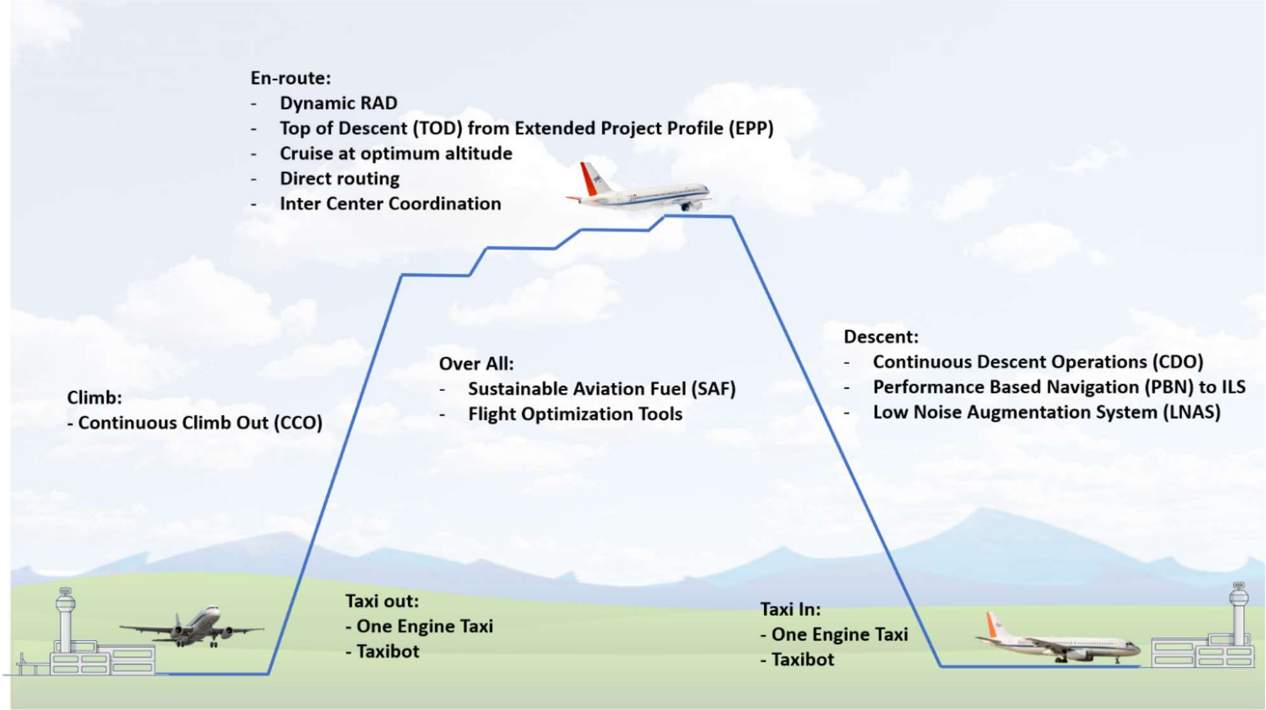

Figure 8: Gate to Gate Scenario Scheme

Figure 8 displays the project idea of gate to gate scenarios. The ideal green flight would be using all solutions investigated in ALBATROSS. A taxi-out phase using a taxibot or applying the single engine taxiing technique followed by a continuous climb out (CCO) with optimum power setting for minimum fuel consumption. The cruise flight is supposed to be as close as possible to a direct flight along the great circle distance. To optimize the en-route segment a special focus is on ATM/ATC. 4D-trajectory-based operations are applied and advantages for an optimized trajectory are generated by the application of dynamic RAD. The flight is conducted at the optimal altitude level. To calculate such altitudes and power settings multiple performance tools and big data analysis are used. Such tools will also be compared within the project within the performance analysis part. The descent segment is operated by Performance Based Navigation to ILS (PBN-to-ILS). Furthermore, tools for the optimum calculation for top of descent (TOD) and minimum emissions in the TMA (LNAS) are demonstrated. At the arrival airport the taxi procedure will again be adopted to single engine taxi or taxibot usage.

We are conscious that the goal to combine all possible solutions will not be applicable for the ALBATROSS Gate to Gate trials. Nevertheless, the applying as many solutions as possible will be great advantage for investigating fuel savings. The analysis of the demonstration flights will be done in a way that the impact of each measure shall be isolated. The combination of several solutions might turn out not to be less favorable than applying just an isolated solution. Isolated wins like e.g. less emissions in the TMA might be compensated by unfavorable conditions for the choice of TOD.

To investigate the overall and isolated impacts of the solutions ALBATROSS has a dedicated work package for the performance assessment.

5. Performance Assessment

Next to the Concept of Operations, that deals with the conceptual and organizational work in the earliest stage of the project the according detailed analyses for the evaluation of success criteria are worked out in parallel. The performance assessments are prepared by the definition of key performance indicators (KPI) that are applied on the flight demonstration data. Since ALBATROSS includes multiple solutions to reduce fuel burn the granularity of the KPIs is chosen quite fine to trace impacts of single solutions too. The KPI’s include fuel burn separately for all phases of flight, taxi time, fuel consumption on ground, vertical and horizontal deviation of the flight path and the according lack of efficiency and some more.

5.1 Key Performance Indicators

The ALBATROSS exercises are quite heterogenous. For that reason, the key performance indicators have to be valid for a wide range of different experiments but also adopted to display the outcomes of each exercise fine enough to identify possible benefits or losses. Even small fuel savings demonstrated in some exercise have to be transformed to the application in European and global aviation’s daily operations. In this big scale small savings suddenly may become a relevant number of saved fuel or prevented CO2 emission.

The number of KPI’s has to reflect the level of granularity to be investigated and displayed.

Table 1: Key performance indicators [10]

Subject	Key Performance Indicator
On ground	• Total On Stand Fuel Burn Off, • Taxi Out Fuel Burn Off, • Taxi Out Time, • Taxi Out Average Fuel Flow, • Taxi In Fuel Burn Off, • Taxi In Time, • Taxi In Average Fuel Flow
Climb	• Climb Fuel Burn Off, • Climb Out Fuel Burn Off, • Vertical Flight Efficiency
En-Route	• Direct Horizontal Route Efficiency • En-route Horizontal Deviation Fuel Burn Off, • En-route Vertical Deviation Fuel Burn Off
Approach	• Approach Fuel Burn Off, • TMA Departure Fuel Burn Off, • Additional ASMA Time, • Vertical Flight Efficiency
Over all	• GF vs BF excess fuel burn using Enhanced Traffic Flow Management System (ETFMS) data as baseline, • GF vs BF excess fuel burn using Flight Management System (FMS) data as baseline,
Emissions	• CO2 emissions, • Other Fuel Dependent Emissions, • CO2 emissions efficiency, • Geographic distribution of pollutants, • Noise area, • Number of people inside Noise contours, • Average total climate impact, • Average Ratio NonCO2/CO2

The KPI’s can be calculated for the Baseline Flights and the Green Flights using Data either from Quick Access Recorder (QAR), Digital Access Recorder (DAR) or Flight Data Recorder (FDR). The important information on fuel on board (FOB) can be extracted from Touchdown (ON) and Gate-in (IN) messages.

For the Optimum Flights the calculations of some of the KPI’s have to rely on accurate calculations of trusted and proved computerized flight planning systems (CFP). In ALBATROSS several CFP are used. The systems tested for this purpose are in use at AIRBUS, THALES and EUROCONTROL.

Most of the KPI’s are designed to be expressed in distinct units as tons or kilograms. In ALBATROSS the referencing to another type of flight is of greatest interest. The comparison will be made between the three categories GF, BF or OF. One of them is taken as a reference. So, the KPI’s can also be expressed in relative numbers (%).

$$KPI_{eff} = \frac{KPI - KPI_{ref}}{KPI_{ref}} \cdot 100\ [\%] \tag{1}$$

KPI_{eff} is the KPI that references one sort of flight against the other and KPI_{ref} is the KPI from Table 1 in absolute numbers that is taken for reference. In most cases the baseline flights are the reference. Those flights have either been performed before ALBATROSS started and are extracted from historical databases or they are performed as reference flights.

5.2 Data Analyzing using the All Flight Path replay

This method is designed to isolate the effect of external impacts and constraints like ATC constraints from the BFs when comparing them with the executed GFs or the theoretical OFs. With the help of a flight planning system or a flight path analysis application the trajectories of the OF and the GF are reconstructed.

To obtain the so-called delta-fuel burn, which describes the difference of fuel burnt from a GF in comparison with a BF, different calculation and methods are applied. One is the replay method for the whole flight plan (Figure 9). Before starting such a calculation, the following constraints must be ensured:

- Same city pair,
- Same aircraft type,
- Same take-off weight and
- Same environmental conditions.

Since exactly the same conditions will never be applicable small deviations have to be accepted. Nevertheless, those shall be as small as possible in magnitude to reduce the potential to distort the results of the efficiency calculations.

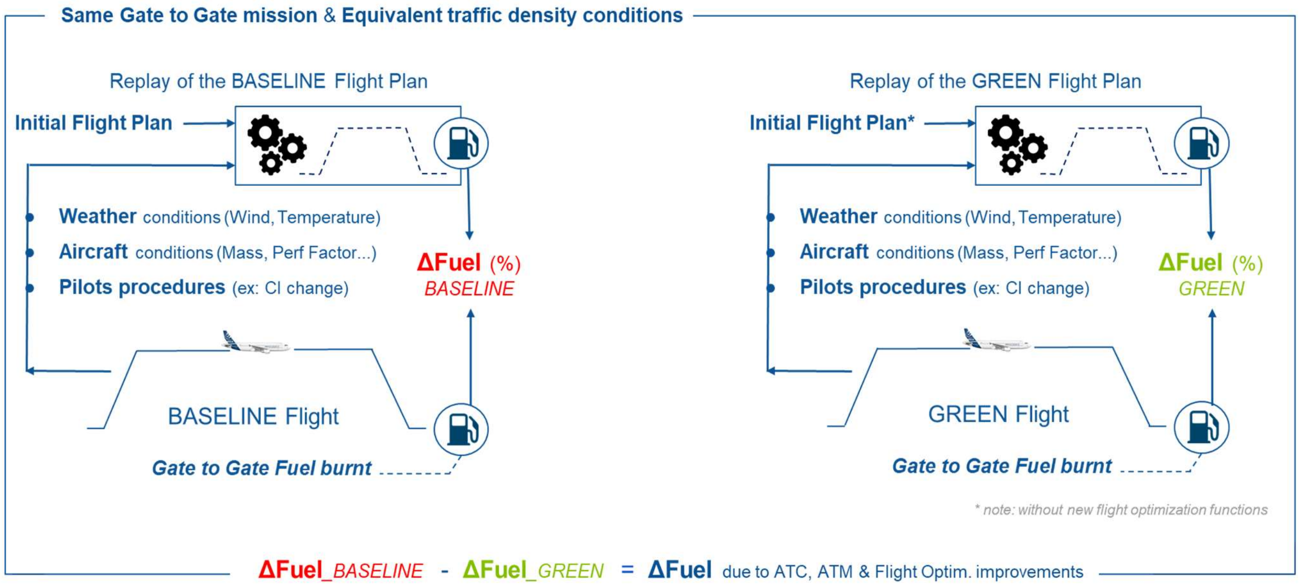

Figure 9 – All Flight Path Replay Method Scheme [10]

Figure 9 displays the procedure. A performed Green Flight is selected for comparison. An adequate comparable Baseline Flight is selected from historical data. According to the initial flight plan the Baseline Flight is re-simulated. This flight plan is based on the state-of-the-art procedures and constraints published in the AIP or the RAD. It can be seen from re-simulation which fuel burn was expectable for the Baseline Flight according to its initial flight plan. Tactical decisions that result from communication between pilot and ATC such as route offsets, shortcuts, deviations, sector speed/altitude changes or similar are not reflected in the initial flight plan. This is compared to the real recorded fuel burn for the gate to gate operation of the Baseline Flight. A delta fuel burn can be extracted.

The same will be done for the Green Flight. Based on the initial flight plan the expected fuel burn is calculated and then compared to the actual fuel burn recorded. It has to be noted, that the initial flight plan doesn't incorporate any of the solutions applied for ALBATROSS. The simulation of this flight and the comparison with the data from the real flight, that uses as much solutions as possible will also give a delta fuel.

The difference of those deltas is the fuel saved due to the improvements applied on the specific Green Flight. In that way single flights can be compared and specific impacts will be isolated. To get more generalized results on the overall effects of the ALBATROSS solutions on the chosen KPIs a high number of flights is investigated the same way. This reduces the effects of weather impact or other distorting events.

5.3 Trajectories Normalization

The identification and analysis of punctual fuel overburn sources is done via a “paired trajectory” algorithm that computes fuel burn differences along two different trajectories, executed under different environmental and operational conditions. Furthermore, gross weight differences shall be corrected.

Every portion of the actual analyses' trajectory is compared with portions in a reference trajectory. The normalization is done considering the adjustment of the actual fuel burn at each portion of the actual trajectory considering the Equivalent Still Air Distance (ESAD) and Gross Weight ratios, computed from the actual trajectory related to the reference trajectory. The ESAD normalization considers the differences on environment conditions, altitude and true airspeed / Mach number differences in both trajectories. The gross weight normalization takes into consideration weight differences in both trajectories.

To be able to perform such an analysis the aircraft parameters True Air Speed (TAS), Indicated Air Speed (IAS), position, pressure altitude and weight have to be known. Also, environmental parameters as wind speed, wind direction and ISA deviation need to be available.

To compute the equivalent still air distance (ESAD) between the increments i and f of the trajectory, that are near the waypoints of the reference trajectory, the average headwind $V_{HW.avg(i,f)}$ and the average true airspeed of the airplane $TAS_{avg(i,f)}$ along the trajectory from i to f is needed. The corresponding fraction is multiplied by D_{actual}, the actual distance flown between the points i and f.

$$ESAD = \frac{TAS_{avg(i,f)}}{TAS_{avg(i,f)} + V_{HW.avg(i,f)}} \cdot D_{actual} \quad (2)$$

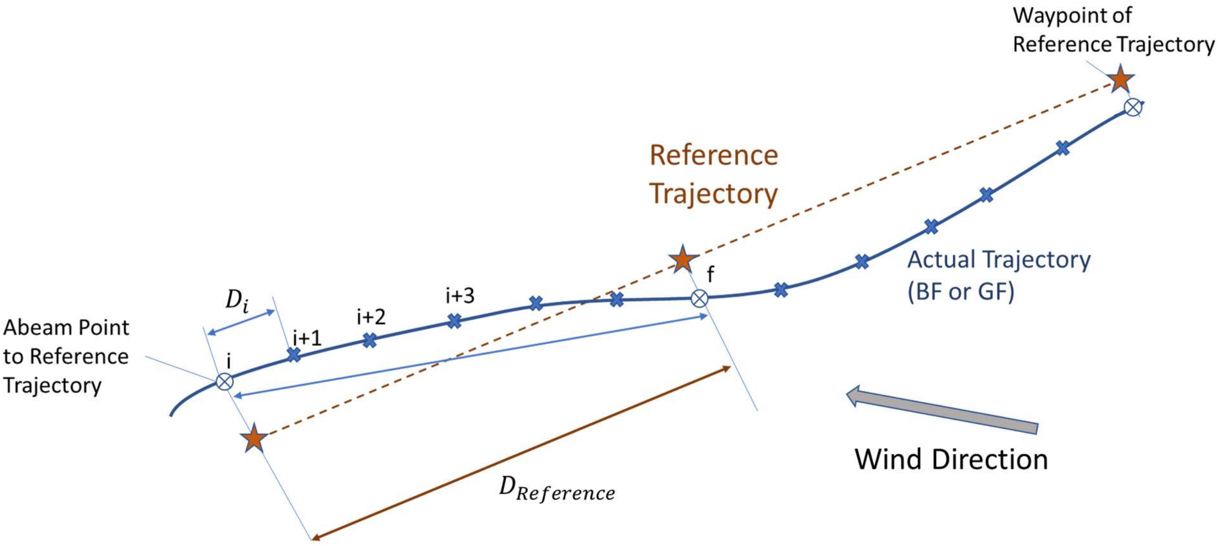

Figure 10 – Normalization via Reference Trajectories

This actual distance is the sum of the multiple segments from i to f. This sum approximates quite accurately the curved trajectory.

$$D_{actual} = \sum_{i=1}^{i=f-1} D_i \tag{3}$$

The ESAD for the reference is calculated in a similar way. Just the approximation of the smaller segments can be neglected since the trajectory between i and f is a straight line. $D_{Reference}$ is the distance between the waypoints of the reference trajectory. For the $ESAD_{ref}$ calculation the average head wind and the average true air speed has to be considered too.

$$ESAD_{ref} = \frac{TAS_{avg,ref(i,f)}}{TAS_{avg,ref(i,f)} + V_{HW.avg,ref(i,f)}} \cdot D_{Reference} \tag{4}$$

The equivalent still air distances are used for the normalization factor K_d.

$$K_d = ESAD/ESAD_{ref} \tag{5}$$

For the normalization the weight difference between the compared aircraft is also reflected via the factor K_W, which is the fraction of grossweight GW_i to reference grossweight $GW_{i,ref}$.

$$K_w = GW_i/GW_{i,ref} \tag{6}$$

The normalized delta weight ΔW_f can be calculated by multiplying the difference of the measured values of fuel weight at the point i ($W_{fuel,i}$) and f ($W_{fuel,f}$) by the factors K_d and K_w.

$$\Delta W_{fuel} = \left(W_{fuel,f} - W_{fuel,i}\right) \cdot K_d \cdot K_w \tag{7}$$

The reference delta weight $\Delta W_{fuel,ref}$ is calculated with the values measured or simulated from the reference trajectory.

$$\Delta W_{fuel,ref} = \left(W_{fuel,f,ref} - W_{fuel,i,ref}\right) \tag{8}$$

Finally, the delta fuel $\Delta Fuel_{(i,f)}$ can be calculated. It is the difference of the delta weights of the normalized flight and the weight difference directly experienced/simulated on the reference flight.

$$\Delta Fuel_{(i,f)} = \Delta W_{fuel} - \Delta W_{fuel,ref} \tag{9}$$

A positive value indicates a higher consumption of the actual flight in contrast to the reference flight. Since the increments can be chosen in desired granularity also very small segments of each flight can be investigated.

In that way the comparison to an optimum reference trajectory can be performed for the baseline flight and the green flight as well. Since this is done portion by portion atmospheric disturbances can be excluded by normalisation. Finally, the normalised results for the GF are compared to the results for the BF.

6. Conclusion and Outlook

ALBATROSS follows a holistic approach by covering all flight phases, directly involving all relevant stakeholder groups (such as airlines, ANSPs, network managers, airports and industry) and addressing both operational and technological aspects of aviation and air traffic management (ATM). Many solutions will be put into practice during the flight demonstrations, from new precision approach procedures to continuous climb and descent, a more dynamic management of necessary airspace constraints, sustainable taxiing and sustainable aviation fuel (SAF) usage.

Demonstrating the benefits relies on comparable, reliable and easily interpretable results at the end of the day. To this end, the ALBATROSS partners aim to ensure that assessment methods and key performance indicators (KPIs) are defined and correctly applied in order to evaluate performance of the planned flight trials. The consortium is using recognised best practices to numerically evaluate the environmental efficiency and climate impact of the solutions that are being trialed. They consist essentially of three types of methodologies: “paired” gate-to-gate trajectories analysis (i.e. calculating deltas of the solution flight parametres matched over the trajectories related to reference flight parameters), statistical methods (when clustered results are compared with descriptive statistical tools) and AI methods (when machine learning algorithms are used to evaluate and predict of a certain operational solution is effective).

In order to compare the different exercises, we have come up with a list of more than 25 KPIs to evaluate each flight trajectory – for either solution or reference flights. These KPIs are expressed as industry standard metrics related to route performance, fuel efficiency (i.e. kilograms of fuel burn or CO2 produced in each different phase of flight) or environmental impact (i.e. approach noise contour area at selected airports). Each flight exercise has its own set of associated KPIs that can be compared to the baseline, i.e. operations where the SESAR Solutions have not been implemented, on single flight or on aggregated basis (statistical solutions) analysis.

The main objective of ALBATROSS is to evaluate the CO2 reduction related to the selected SESAR solutions, when compared with flights without these solutions. However, ad-hoc evaluations may be adopted related to airport noise and non-CO2 emissions reductions, in addition to airspace capacity improvements and pilot/ATC controller workload. Conclusions can then be extrapolated through similar scenarios at European level (i.e. European Civil Aviation Conference (ECAC)).

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References

[1] AIRBUS, 2021. Airbus and partners target more energy efficient flights. [Online]
Available at: https://www.airbus.com/en/newsroom/press-releases/2021-09-airbus-and-partners-target-more-energy-efficient-flights
[Accessed 18 May 2022].

[2] Linnér, A., 2021. SESAR 2020 ALBATROSS - D2.1 - CONOPS V1; Requirements, regulatory and evolutions for "Green Flights", Brussels: SESAR JU.

[3] EUROCONTROL Aviation Intelligence Unit, June 2019. Think Paper #1: Fuel Tankering: economic benefits and environmental impact, s.l.: EUROCONTROL

[4] Abdelmoula F, Scholz M, LNAS - A Pilot Assistance System for Low Noise Approaches with Minimal Fuel Consumption. 31st Congress of the International Council of the Aeronautical Sciences, Belo Horizonte, Brazil, September 09-14, 2018

[5] Gerber M, Schreiber Y, Abdelmoula F, Kühne C, Jäger D and Wunderli J M. Energy-optimized approaches: A challenge from the perspectives of pilots and air traffic controllers. German Aerospace Congress (DLRK) 2021, Bremen & online, 2nd September 2021.

[6] Roeser M S, Kühne C G, Abdelmoula F, Gerber M and Wunderli J M. Impact of ATC Speed Instructions on Fuel Consumption and Noise Exposure: An Assessment of Real Operations in Zurich. German Aerospace Congress (DLRK) 2021, Bremen & online, 2nd September 2021.

[7] Royal Schiphol Group, 2021. Schiphol Newsroom - Aviation sector presents sustainable taxiing roadmap. [Online]
Available at: https://news.schiphol.com/aviation-sector-presents-sustainable-taxiing-roadmap/
[Accessed 18 May 2022].

[8] Royal Schiphol Group, 2022. Schiphol Newsroom - Schiphol invests in vehicles to taxi aircraft sustainably. [Online]
Available at: https://news.schiphol.com/schiphol-invests-in-vehicles-to-taxi-aircraft-sustainably/
[Accessed 18 May 2022].

[9] AIRBUS, 2018. Focus on Fuel. FAST-Airbus technical magazine, Oct., pp. 4-9.

[10] Fregnani, J., 2021. SESAR 2020 ALBATROSS - D4.1 - Flight Analysis Methodology and KPIs Calculation, Brussels: SESAR JU.