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A New Method to Validate the Route Extension Metric against Fuel Efficiency

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Abstract— **The Flight Efficiency indicator is used to measure how closely the actual (and eventually the planned) trajectory flown by an aircraft approaches the optimum (or more efficient) trajectory between the departure and arrival airports. While this is a clear definition from a purely conceptual point of view, is not trivial to determine that so-called optimum trajectory, and thereby its practical calculation.**

Considering this perspective, the most common implementation of the Flight Efficiency indicator (for instance, in the SES Performance Scheme) limits the calculation to the horizontal component of the flight and considers the optimum or reference trajectory as the Great Circle one, introducing the concept of "achieved distance", what is in fact an apportion of the first. This direct, geodesic route, (only taking into account the horizontal component) is considered in this algorithm as the cheapest and thereby most efficient option (with the additional benefit of being a constant benchmark, independent of individual strategies). In reality, some objections can be put to this methodology, as aircrafts often do not follow this direct route since airlines have to make tradeoffs between several factors, such as meteorological conditions, which may lead to definitions of optimum which differ from Great Circle distance. In particular, many of the considerations on the limits of the Horizontal Flight Efficiency indicator lead to the inclusion of the vertical component in the Flight Efficiency computation, what is in fact is a major improvement in the ATM Performance Monitoring field that hasn't been deployed yet, and that may lead to confirm if these Great Circle trajectories are really efficient in terms of fuel consumption.

This paper explores this innovative direction in a practical way by using real operation data to validate, addressing first the study of the correlation between the Horizontal Efficiency metric proposed by Eurocontrol and used in the SES Performance Scheme and the estimated real fuel efficiency, and secondly it proposes a new methodology that constructs an Enhanced Flight Efficiency indicator that captures better this fuel efficiency by considering also the vertical component of flight. In addition, there is a preliminary study on the relationship of this new metric with the cost efficiency, taking as a reference the published initial flight plan from the airline.

Keywords-performance, flight efficiency, trajectory, fuel efficiency, route extension, KPI, KPA

I. INTRODUCTION

A. *ATM Performance Monitoring background*

"What can't be measured, cannot be managed" is a common truism, often reformulated in modern times to management mantras such as "If you can't measure, you can't improve it" [1, 2]. Even though these aphorisms simplify quite a bit a more complex idea behind them, they clearly point the direction where many areas, ATM (Air Traffic Management) amongst them, are increasingly heading to: quantitative measuring of the systems performance is essential for understanding (and further effective improvement) them.

In the ATM field, description of the system in terms of measurable, quantifiable Key Performance Indicators (KPIs) properly representing the Key Performance Areas (KPAs) is already a fact [3, 4]. The development and applications of these measuring and monitoring are continuously growing and speeding up, already bringing a better knowledge and awareness of the overall air transport system, paving the way for a better management that will bring benefit to every actor, with the necessary trade-offs (that can be also quantified, additionally).

Moreover, this is a global movement, both in the US and Europe [5-7], as well as in other countries such as Australia [8]. In the first case, Federal Aviation Administration (FAA) formally reports Operational Performance under several frameworks, which cover management processes that incentivize pay-for-performance, some indicators that support tactical management of the system, metrics reported to external stakeholders as well as indicators directly required by U.S. Congress. The European case is different as involves 37 different Air Navigation Service Providers (ANSPs) in a coordinated way, organized around the Single European Sky (SES) Performance Scheme (one of the pillars of the SES), organized around fixed Reference Periods (RPs) for which legally binding performance targets are set both at EU-wide level and National/Functional Airspace Block (FAB) level [9-13].

Priorities on performance monitoring and reporting can be different, as a consequence of the particularities of each system: for example, official targets for FAA are focused on

Capacity and Capacity Efficiency; while in Europe horizontal Flight Efficiency and ATFM delay are considered for this goal [12]. However, no matter which the particular focuses of the different Performance monitoring implementations are; there are common features amongst them.

Additionally, both FAA and Eurocontrol (on behalf of the European Union), regularly publish joint reports comparing their ATM-related performance [6, 14-16], what clearly reinforce the principles stated for this Performance Monitoring activities (in particular, the declared interest of these reports is to understand differences between the two systems and identify best practices for optimizing ATM performance and the overall air transport system) of measuring to manage and improve.

B. *Flight Efficiency Computation*

In this Performance Monitoring scenario, one of the most relevant areas under study is Flight Efficiency, due to the direct economic and environmental impacts it has according to well-known studies [17-20].

Flight Efficiency is a generic term that can refer to different concepts and definitions, and has been widely analyzed in a set of researches [21-23]. From a general perspective, it can be very simply defined as the comparison between a specific trajectory and the ideal or benchmark related one between its endpoints. Of course, this ideal trajectory will depend on the viewpoint, as every actor in the system will possibly have a different perspective of efficiency: for an airline it would be their preferred trajectory, having both horizontal and vertical components, and mostly related to cost index (ratio between time cost and fuel cost). Thus, the indicators measuring Flight Efficiency may vary according to the situation under analysis. Flight Efficiency is often used as a conceptual synonym of Route Extension, as all the extended flight distance respect to the optimum reference trajectory is in fact the inefficiency incurred by that particular flight.

There is a specific need for this indicator which stems from the requirements of SES Performance Scheme Reference Period 2 (RP2) to measure local performance (FAB level) while at the same time keeping the network perspective. The introduction of local efficiency measurements requires the ability to decompose the Flight Efficiency observed for the entire flight into a portion of the flight, such as, for example, the part of a flight within a given airspace (FAB, ACC, etc.).

The European en route Flight Efficiency KPI is itself a special case of local measurement in which the 40 NM circles around the departure and arrival airports of the flight (Arrival Sequencing and Metering Area circles, or ASMA [31]) are excluded (in the case of FAA, as well as in the common US-Europe Performance Reports, for the arrival airport a 100 NM is excluded [6]).

The most extended methodology for Flight Efficiency computation used both by FAA and Eurocontrol Performance Review Unit [24, 25] is the Achieve Distance Methodology. It is based on computing the length of the additional distance flown in a reference airspace with respect to the *achieved distance*. The achieved distance is basically an apportion of the Great Circle Distance (the shortest distance between the two endpoint airports), flown in that reference airspace. Achieved distances provide an indication on how much closer to destination and how much further away from origin a flight gets within a given airspace (H1, H2, H3 in Figure 1) and captures "network/interface" component in a consistent way,

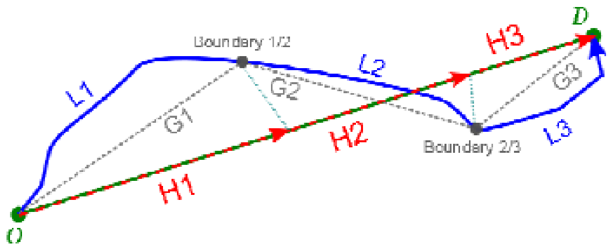

Figure1. The sum of achieved distances is equal to the Great Circle from Origin to Destination

Figure 2 illustrates the difference between the Achieved Distance and the Great Circle Distance from the entry and exit point in the reference area. This figure shows how the Achieved Distance is more restrictive, as it considers the inefficiency due to the fact that the entry and exit point in the respective ASMA circles around the departure and arrival airports are not aligned with the Great Circle from the Origin to the Destination.

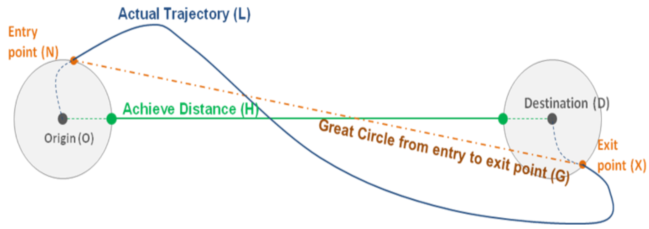

Figure 2. En route flight efficiency for domestic flights (Achieved Distance vs. local Great Circle)

Since this methodology focuses on the horizontal component of the flight, it is usually referred as Horizontal Flight Efficiency (HFE). However, it is usually acknowledged that this distance based approach for flight efficiency estimation does not necessarily capture the "optimum" trajectory according to airspace user's preferences, or when considering weather factors. Any deviation of this optimum trajectory will mean additional fuel burn and emissions (apart from flight time), with a subsequent impact on airlines' cost and environment. The usual reason for not considering in the optimal trajectories in the Flight Efficiency computation is the unavailability of gathering airlines preferred trajectory factors, such us weights, cost index, or relevant performance data. In this situation, the HFE methodology is an approximation that allows obtaining valuable results for flight efficiency [26].

Researching in this direction, this paper aims to bridge the gap towards this ideal Flight Efficiency computation based on a reference preferred optimal trajectory and the HFE. For this, we propose to use real traffic data and fuel consumption models generate new metrics and to validate their values against the results obtained by using the currently usual HFE methodology. These new metrics are correlated to the current

HFE for a particular research scenario presented herein. Thus, this paper addresses (i) the methodology used to calculate the reference trajectories that will be considered in the proposed new flight efficiency metric based in fuel efficiency, (ii) the enhanced flight efficiency indicators proposed and their correlation to the Horizontal Efficiency indicator, and (iii) the relationship between the new flight efficiency indicator and the theoretical optimum one based on the flight plan information.

In the first part of the paper it will be assumed that the Flight Efficiency policy is to minimize fuel consumption, i.e., cost index zero. This implies that fuel efficiency will be considered as the representation of Flight Efficiency and its correlation with the HFE indicator is analyzed from a validation perspective. In the second part of the research, a preliminary analysis of Flight Efficiency taking as the reference "business trajectory" those trajectories generated using the initial flight plan issued by the airline is performed. Since weights, cruise speeds and/or cost index are not available for these flight plans, focus is put on the combination of the elapsed time at the entrance of the destination ASMA circle and the fuel consumption for different weights and speeds. These combined intervals should capture the business strategy chosen by the airline during the planning phase, enabling this proposed new methodology to work without knowing the specific user preferred trajectory.

II. METHODOLOGY

A. *Scenario definition*

The study case presented in this paper consists in a set of 45 flights for which the complete radar tracks and initial flight plans filed by the airlines were collected by the local Spanish ANSP (ENAIRE). All 45 flights date from 2013 and involve 6 different routes within Spain connecting the airports of Madrid (LEMD), Asturias (LEAS), Bilbao (LEBB), Barcelona (LEBL), Malaga (LEMG), Ibiza (LEIB) and Valencia (LEVC). Figure 3 shows the set of trajectories used in the study case.

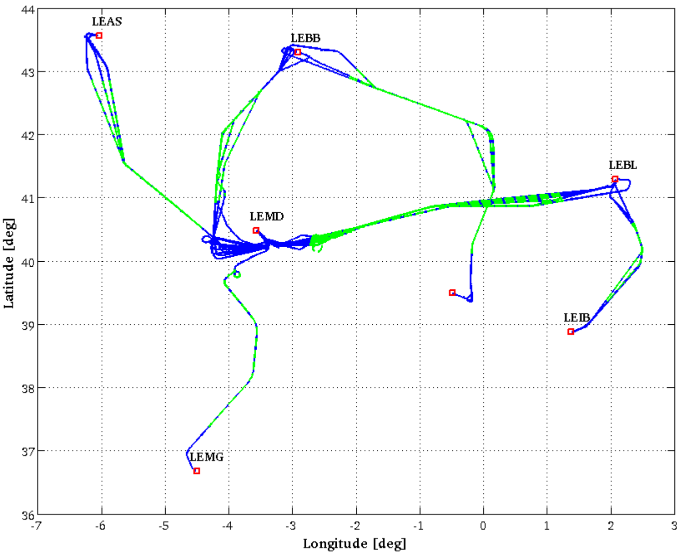

Figure 3. Horizontal view of the radar tracks used to reconstruct the real trajectories. In blue, the portion of the trajectory within the ASMA circle

The fleet composition of the data set involves a mix of small/medium sized aircraft consisting in A32x, B738 and CRJx aircraft types, as shown in the pie chart displayed in Figure 3.

Radar tracks consist in position records for the 45 flights containing latitude, longitude, barometric altitude, and other reference information. Flight plans contained information on lateral route, flight level, waypoint flyover times and other reference information. This data was complemented for the purpose of trajectory computation with weather information from the National Oceanic and Atmospheric Administration (NOAA). In particular, NOAA's Global Forecast System (GFS [27]) models were employed.

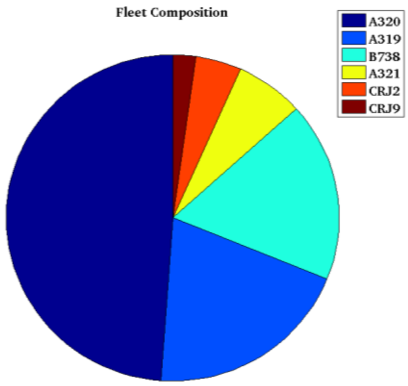

Figure 4. Fleet Composition

For the definition of the new performance indicator proposed, explained in Section II.D and the study of the correlation among the different KPIs (see Section III), three different sets of trajectories were generated:

Actual Trajectories (ATs): From the radar track and weather data information, the whole trajectory for the 45 flights was reconstructed assuming three different possible take-off weights: low, medium and high (based on [36]). 145 trajectories (3 per flight), covering three different loading alternatives for each flight were reconstructed in this set. These reconstructed set contains all the aircraft state variables needed, in particular fuel consumption.

Great Circle Trajectories (GCTs): Taking as an input the reconstructed real trajectories (i.e., the ATs) for the three different possible take off weights and the exit and entry points to the ASMA circle around origin and destination airports respectively, a new alternative "minimum flown distance" trajectory was proposed for three different Cost Indexes. 405 trajectories (nine per flight) were generated in this set. The initial conditions at each of the exit points were taken from the reconstructed trajectories.

Flight Plan Trajectories (FPTs): For the generation of this set, the initial flight plan issued by the airline was taken. The Cost Index used in each flight was identical to the Great Circle trajectory set. To make this set comparable with the other sets, it was assumed that the mass and time at the exit point was the same as the reconstructed and great circle trajectory sets.

The following two sections describe in more detail the processes to reconstruct the real trajectories from radar data and weather, and the generation of the Great Circle and Flight Plan Trajectory sets.

B. Building Scenario: Trajectory Reconstruction

The input to this process is a set of flights with associated surveillance tracks and aircraft type information, for example, from flight plans. The objective of the process is to reconstruct, for each of the flights, the evolution of the aircraft state (chiefly speed and mass) from the surveillance data, in order to estimate the fuel consumed during the flight. To that aim, we first build an instance of aircraft intent that fits the flight track and then feed the resulting aircraft intent expressed in Aircraft Intent Description Language (AIDL, see [28, 29]) to a trajectory computation software that integrates the full trajectory. This trajectory contains a sequence of aircraft states, including position, altitude, airspeed and instantaneous aircraft mass, from take-off to landing. The process is briefly described below:

- For each flight, build an instance of aircraft intent expressed in AIDL that fits the surveillance tracks of that flight. This AIDL instance includes a lateral thread, which consists of a sequence of geometric constructs (segments of geodesics and circular arcs) that match the horizontal projection of the surveillance reports (LAT/LON coordinates), and two vertical threads, which consist of sequences of kinematic instructions (altitude and speed) that match the sequence of the aircraft's altitudes and speeds.

- Aircraft mass may be estimated based on the AIDL instance obtained in step 1 and by setting the total aircraft weight at some point of the flight to a given value. If no actual weight information is available, total aircraft weight may be assumed for some point of the flight, typically at take-off or landing (e.g. landing weight equal to 120% of the Operating Empty Weight (OEW) of the aircraft type in question).

- The resulting AIDL instance is fed to the Trajectory Computation Infrastructure together with the initial conditions (time, mass, position, altitude and speed). To integrate the aircraft's trajectory, the Trajectory Computation Infrastructure uses BADA 3.10 [30] as aircraft performance model and the GFS forecasts as the model of the meteorological conditions encountered by the aircraft as it flies.

- The estimate of the fuel burn during the segment of trajectory considered is calculated from the trajectory output by the Trajectory Computation Infrastructure as the difference between the initial mass and the landing mass.

Depending on the quality of the data source, the surveillance tracks used as input for this process may require some post-processing to perform validation, track indexing, outlier removal, smoothing, flight plan matching, etc.

C. Building Scenario: Trajectory Generation

The trajectory generation from a flight plan and a given set of initial conditions (aircraft state variables, such as position, time or speed) requires the knowledge of airspace information (e.g., waypoints, routes), weather information (e.g., wind, pressure, temperature), user preferences (e.g., cost index, cruise altitude and speed) and performance data (e.g., thrust and drag, rate of climb). Trajectory Predictors make use of these sets of data to build firstly an instance of future behavior that the aircraft will elicit to comply with the flight plan, user preferences and airspace restrictions (aircraft intent) and later the trajectory from the integration of a set of equations of motions using the specific performance characteristics and weather information affecting the flight.

BR&T-Europe AIDL-based trajectory predictor [36] was used to build the GCT and FPT sets. The common elements used in both calculations where: cost index, airspace data, weather forecast and aircraft performance data (BADA 3.10) and initial weights (low medium and high) at the beginning of the computation (exit point form the origin ASMA circle). The elements that changed between GCTs and FPTs calculations were:

- Lateral path: GCTs lateral path was the geodesic line joining the real trajectory exit and entry points to the ASMA circle. FPTs follow the route published by the airline 24 hours in advance

- Cruise altitude: GCTs follow the cruise altitude detected in the ATs. FPTs follow the cruise altitude included in the flight plan

- Initial position (latitude, longitude and altitude): GCTs start in the intersection between the real (reconstructed) trajectory and the 40NM circles. FPTs start at the intersection between the initial flight plan and the ASMA circles. Reader should notice that these points will be different in general since the real trajectories flown different paths than those indicated in their initial flight plans.

Nine different trajectories were generated per flight covering different situations of payload (light, medium and heavy) and Cost Index (low, medium-low, medium-high).

Figure 5 illustrates the 45 different flights for a specific Cost Index and payload. Purple trajectories correspond to GCPTs whereas in orange are the FPTs

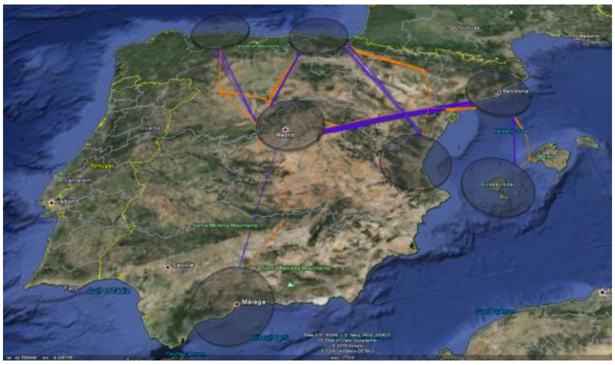

Figure 5. Great Circle and initial flight plan trajectories

D. Proposed Enhanced Flight Efficiency Metrics

As mentioned, this study considers Fuel efficiency as the representation of Flight Efficiency and its correlation with the Horizontal Flight Efficiency indicator is analyzed.

As stated in section I, a key feature of the Achieved Distance is that it considers the inefficiency due to the fact that the entry and exit points in the 40 NM circles around the departure and arrival airports are not aligned with the Great Circle trajectory from the origin to the destination.

Thus, for the calculation of the fuel consumption of the Great Circle generated trajectories the exit to entry points in the 40 NM circles around the departure and arrival airports have been considered, thereby excluding the inefficiency due to those points are not aligned with the Great Circle trajectory. So, it will be taken as reference Horizontal Flight Efficiency two indicators, the Additional distance of the Actual Trajectory with respect to the Achieved Distance and the Additional Distance of the Actual Trajectory with respect the Great Circle between the entry and exit point into the 40NM area around the origin and destination airport, (to be comparable with the new fuel efficiency based indicator):

$$A.D_{Great\_Circle} = \left(\frac{D_{Actual}}{D_{Geodes}} - 1 \right)\% \qquad (1)$$

$$A.D_{Achieved} = \left(\frac{D_{Actual}}{D_{Achieved}} - 1 \right)\% \qquad (2)$$

The enhanced Flight Efficiency indicator proposed in this paper is the Additional fuel consumption of the Actual Trajectory with respect to the consumption flying the Great Circle between the entry and exit points into the 40NM area around the origin and destination airport (as in the reference Horizontal Flight Efficiency methodology, these circles may vary on radius depending on particular implementations).

$$A.F_{Geodes} = \left(\frac{F_{Actual}}{F_{Geodes}} - 1 \right)\% \qquad (3)$$

The comparison of metrics (1) and (2) with (3) is presented in section III.A, complementing a study of the aircraft mass values influence and considerations on the vertical component of the flight in this enhanced Flight Efficiency indicator.

It will also be analyzed the fuel efficiency with the Initial Flight Plan issued by the company as the reference trajectory. For this matter, the fuel efficiency alternative indicator will be the Additional fuel consumption of the Actual Trajectory with respect to the reconstructed Flight Plan trajectory fuel consumption (that can be considered the airspace user flight intention), both between the entry and exit points into the 40NM area around the arrival and departure airports:

$$A.F_{FP} = \left(\frac{F_{Actual}}{F_{\mathrm{Re}const\_FP}} - 1 \right)\% \qquad (4)$$

The comparison of (3) and (4) is included in section III.B, together with an analysis of the differences between the reconstructed Flight Plan trajectory (*Reconst FP*) and the Initial Flight Plan (*Real FP*) declared by the airline, comparing their elapsed times.

Finally, an analysis on the adherence of the elapsed time of the Actual Trajectory and the Great Circle Trajectory with respect the real time established by the company in the Initial Flight Plan is performed, for which the following metrics are considered:

$$A.t_{Act} = \left(\frac{t_{Actual}}{t_{FP}} - 1 \right)\% \qquad (5)$$

$$A.t_{Geodes} = \left(\frac{t_{Geodes}}{t_{FP}} - 1 \right)\% \qquad (6)$$

These two metrics are used to complete the results showed by the $A.F_{FP}$ metric capturing the time deviation with respect to the initial flight plan, hence deviation from the original cost assumed by the airline in the flight plan. The computation of metrics (5) and (6) is presented in the section III.C.

III. RESULTS

A. Analysis of the Enhanced Flight Efficiency Indicator proposed

This analysis aims to establish the goodness of the Great Circle trajectory from exit to entry points in the 40 NM circles around the departure and arrival airports as the optimal trajectory, not only based on saving miles flown (as established in Eurocontrol metric definition [25]), but on fuel savings. This required the variation of the estimated takeoff weight used for the trajectory reconstruction and the Cost Index used in the trajectory generation.

The value of the fuel consumption of the Actual Trajectory and the Great Circle trajectory for each flight from exit to entry points to the origin and destination ASMA circles was calculated as the average of the fuel consumption for three different takeoff weights (and Cost Indexes in the GCTs case). This allows calculating the Additional Fuel Consumption of the Actual Trajectory respect to the Great Circle Trajectory, being this one the definition for the Enhanced Flight Efficiency Indicator that this paper addresses.

Figure 6 illustrates the results of this process, showing the proposed Enhanced Flight Efficiency Indicator in comparison to the Horizontal Flight Efficiency indicator (according to each definition of the indicator, calculated as the Additional Distance of the Actual Trajectory with respect the Achieved distance and with respect the Great Circle distance from exit to entry points to the ASMA circles). Considering that they take into account different factors, if there is a correlation between them it is implied that the current indicator is a good estimation of Flight Efficiency and can be validated also as representing these vertical component factors that fuel efficiency includes.

	LEAS LEMD	LEBB LEMD	LEBB LEVC	LEBL LEIB	LEBL LEMD	LEMG LEMD
% Additional Distance (Actual Trajectory with respect to Achieved Distance)	10,4%	11,4%	24,1%	11,9%	3,1%	22,2%
% Additional Distance (Actual Trajectory with respect to Great Circle)	4,2%	2,9%	19,5%	8,5%	2,3%	22,5%
% Additional Fuel (Actual Trajectory with respect to Great Circle)	3,1%	1,0%	20,8%	15,4%	1,9%	20,9%

Table 1. Average of Additional Distance (respect to the Achieved Distance and the Great Circle Distance) and Additional Fuel per route

In the Figure 6, it can be noticed that for all flights the Actual Trajectory length is greater than the Achieved Distance and the Great Circle distance, but for 18% of the flights the Actual Trajectory consumes less fuel than the Great Circle trajectories. Furthermore, for the 80% of flights analyzed the percentage of extra fuel consumption is less than the Additional Distance calculated with respect the Achieved Distance, and for the 60% of flights the percentage of extra fuel is less than the Additional Distance calculated with respect the Great Circle. Thus, as a first key and global result of this analysis it is clear from this study they behave differently in a representative number of occasions and thereby cannot be directly linked in every case, allowing an enhancement in the indicator calculation. This margin is reduced but significant, marking the Horizontal Flight Efficiency as representative, but not fully accurate and thereby likely to be enhanced (as this paper proposes).

Also, as shown in Table 1, for most of the routes analyzed (but not for all) the percentage of extra fuel consumption is less than the Additional Distance.

In order to analyze the influence of the initial aircraft mass values in the results, Figure 7 shows the decomposition of the purple bars of the Figure 6 (percentage of Additional Fuel of the Actual trajectory with respect the Great Circle one), for three different initial payload values (light, medium and heavy) also representing the percentage of Additional distance (yellow line). It can be noted how for most of the flights the behavior of the Additional fuel with respect the Additional Distance is similar for the three values of the initial aircraft mass/payload.

It has been relevant to illustrate the variation range of Additional Fuel for the nine combinations of cost index and payload considered, as Figure 8 does. These values provide an idea of the impact of variations in the Additional Fuel values and, as can be observed, sensitivity may vary from less than 5% up to 20% of Additional Fuel depending on the route considered (even with similar route lengths) providing space for future study in this topic.

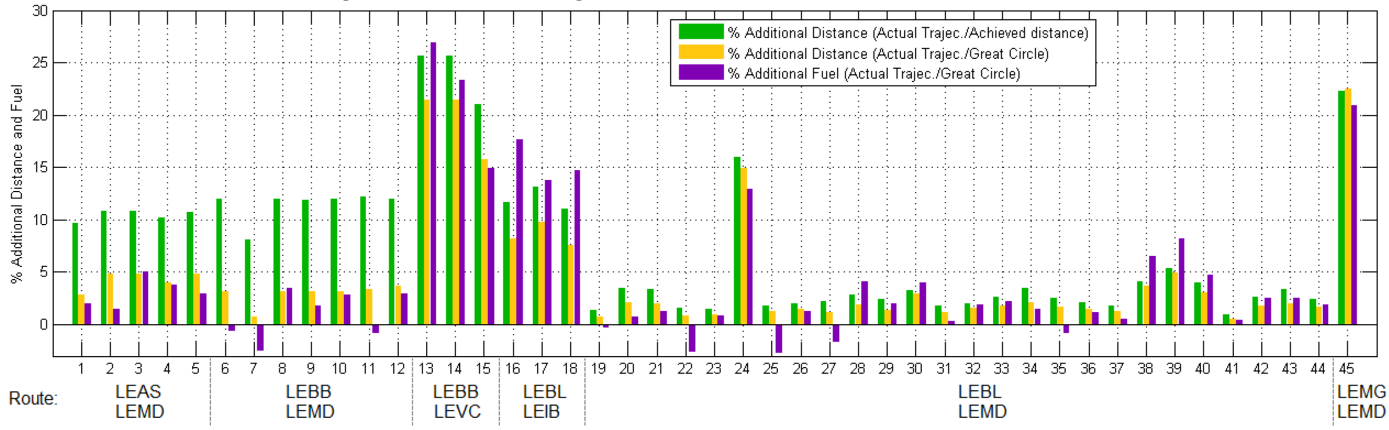

Figure 6. Additional Distance of the Actual Trajectory (with respect the Achieved Distance and the Great Circle Distance) vs. Additional Fuel of the Actual Trajectory with respect the Great Circle.

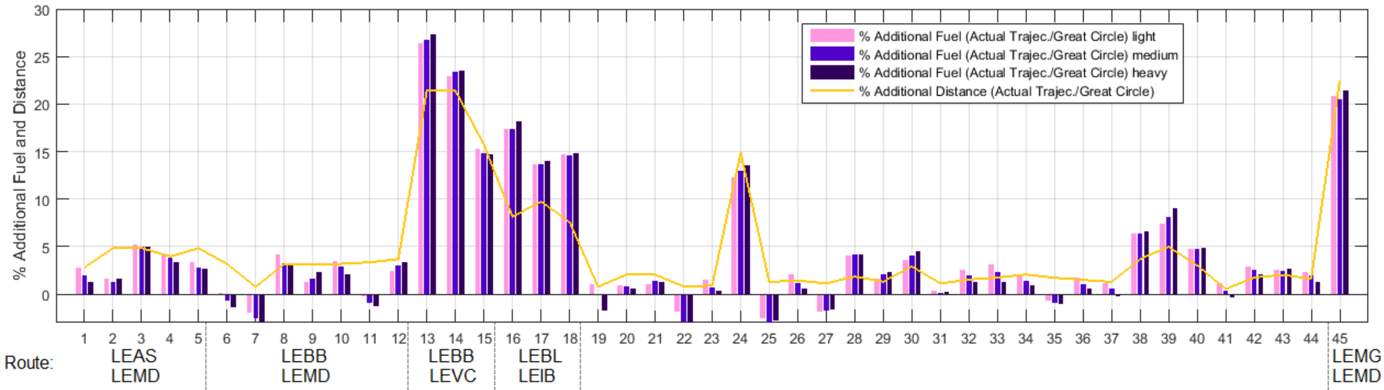

Figure 7. Additional Fuel of the Actual Trajectory with respect the Great Circle per mass/payload cathegory vs. Additional Distance of the Actual Trajectory (with respect the Great Circle Distance).

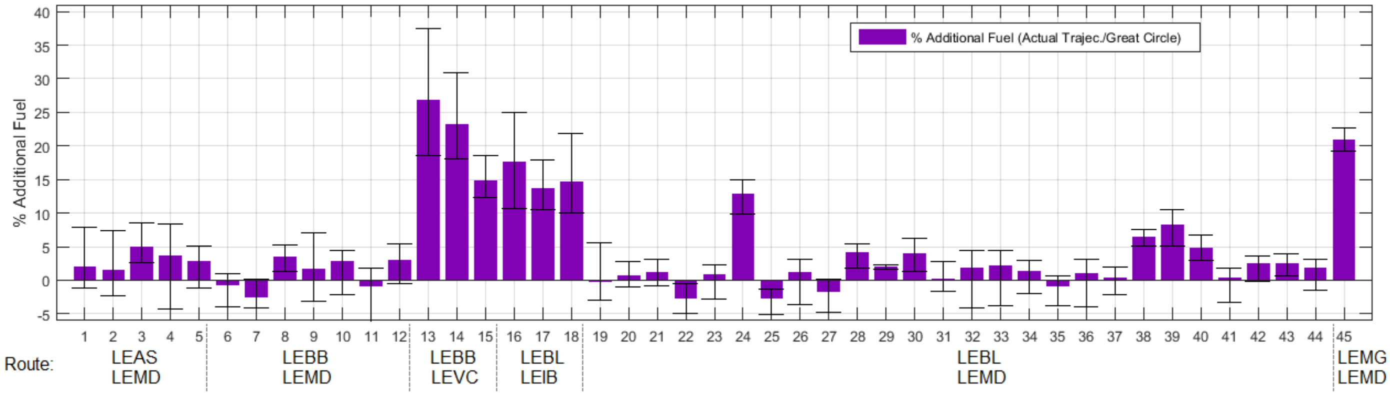

Figure 8. Variation range of the Additional Fuel of the Actual Trajectory with respect the Great Circle.

B. Relationship between the Enhanced Flight Efficiency indicator and the theoretical optimum one based on the flight plan information.

The aim of this analysis is to calculate Flight Efficiency taking as the reference "business trajectory" the one generated by using the Initial Flight Plan issued by the airline. To address this, Figure 9 illustrates a comparison of the Enhanced Flight Efficiency indicator new also proposed Flight Fuel Efficiency metric (as described in Section II.D).

As the blue bars on Figure 9 show (Additional Fuel of the Actual Trajectory with respect the reconstructed Flight Plan trajectory), for 78% of flights, the Actual Trajectory burn less fuel than the trajectory indicated in the Initial Flight Plan. This means that in terms of fuel savings the flight is also more efficient than the planned trajectory, and also that this Initial Flight Plan is not the optimum (or more efficient) trajectory, in terms of fuel efficiency at least.

Comparing both metrics, Additional fuel of the Actual Trajectory respect to the Great Circle Trajectory and the Flight Plan trajectory, Figure 9 shows that the Actual Trajectory usually burn more fuel than the Great Circle Trajectory (except in the 16% of flights, as previously mentioned, that remains as the non-correlated percentage, or percentage where the Horizontal Flight Efficiency and the proposed one based on fuel efficiency move in different directions) but this first one burns less than the Trajectory reconstructed thought the initial Flight Plan.

Table 2 contains the Additional Fuel of the Actual Trajectory respect to the Trajectory reconstructed thought the initial Flight Plan per route and for different Cost Indexes of the reconstructed Initial Flight Plan trajectory. For all of them, it can be observed that the Actual Trajectory burn less fuel than the trajectory reconstructed according to the Initial Flight Plan information.

	LEAS LEMD	LEBB LEMD	LEBB LEVC	LEBL LEIB	LEBL LEMD	LEMG LEMD
% Additional Fuel (Actual Trajectory with respect to Reconst FP Trajec)	-23,3%	-16,2%	-8,4%	-26,6%	-5,0%	-34,1%
% Additional Fuel Actual Trajectory with respect to Reconst FP Trajec (*Low Cost Index*)	-21,7%	-14,7%	-4,7%	-26,1%	-5,3%	-33,2%
% Additional Fuel Actual Trajectory with respect to Reconst FP Trajec (Low-Med Cost Index)	-23,3%	-16,7%	-10,1%	-26,6%	-4,5%	-34,6%
% Additional Fuel Actual Trajectory with respect to Reconst FP Trajec (Med-High Cost Index)	-24,8%	-17,3%	-17,2%	-24,5%	-5,5%	-34,3%

Table 2. Average of Additional Fuel by route

It is important to note that the speeds and flight levels that have been considered for the reconstruction of the Initial Flight Plans trajectories are not those proposed by the company (since there is not availability of this information at each waypoint of the Flight Plan). Therefore the speed and flight levels of the actual path have been considered, so those consumptions are not entirely representative of the actual initial intention of the airline, while no significant discrepancies are expected to appear (from a qualitative analysis).

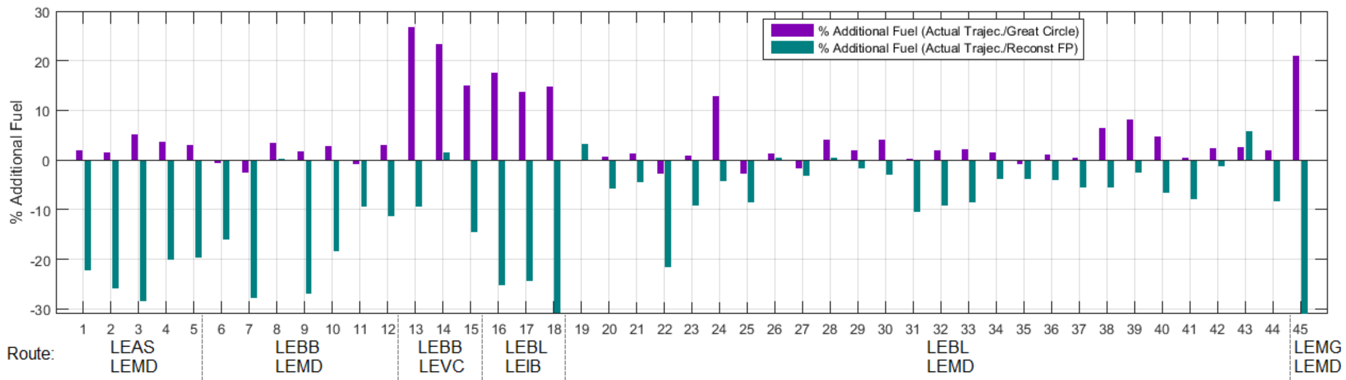

Figure 9. Additional Fuel of the Actual Trajectory with respect Great Circle vs. Initial Flight Plan trajectory

Additionally, to check the adherence of fuel consumption through the reconstructed flight plans trajectories, it has been calculated the additional flight time that those reconstructed trajectories generate vs. the total time proposed by the company in the Initial Flight Plan. These results are illustrated in Figure 10.

It is found that the reconstructed trajectories from the flight plan are not fully attached to the proposed Initial Flight Plan. So the cost index used is not exactly the proposed by the company. This implies that the trajectories reconstructed by using the Initial Flight Plan information cannot be taken as representative for the calculation of fuel consumption (or optimum/more fuel-efficient trajectories), since the airline calculated those ones with other parameters, variables and weather conditions that may result in other fuel consumption results (or different overall cost function where fuel is not the only cost, but taxes for instance).

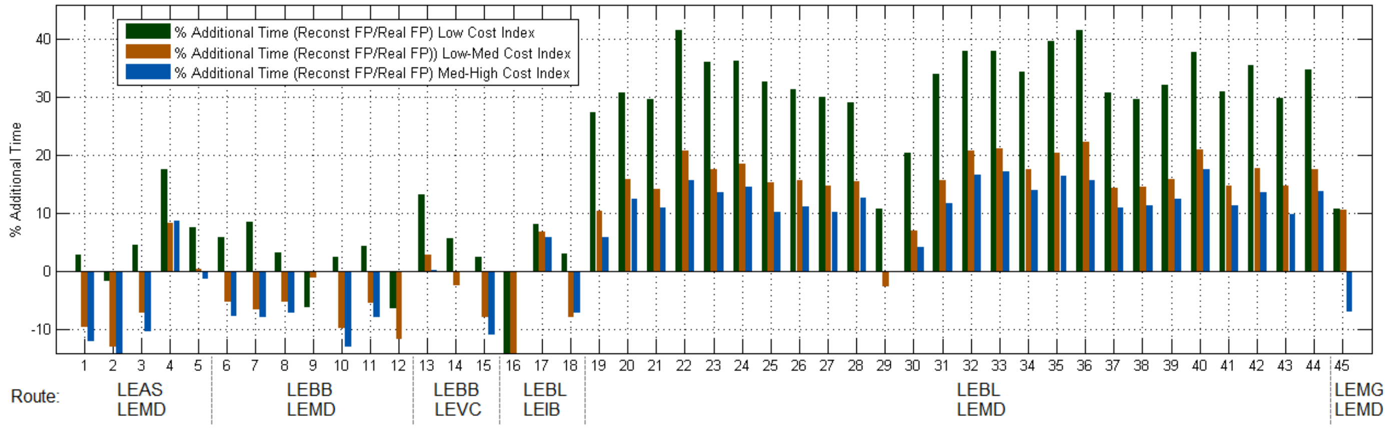

Figure 10. Additional Time of the Reconstructed FP trajectories respect to the Real Flight Plan information

C. *Adherence to the elapsed time established by the company in the original Flight Plan.*

There are many potential reasons for the aircraft operators to request different flight levels (headwinds/tailwinds, lighter payloads, etc), or different cruise speeds… and consequently deviate from the timing originally requested in the Initial Flight Plan, and consequently disruptions to a handling ACC or in the destination airport. To analyze this issue, Figures 11 and 12 illustrate the calculation of the additional time (of the elapsed flight time) for the Actual Trajectory and the Great Circle one (taken from the from exit to entry points in the 40 NM circles around the departure and arrival airports) respect to the time established by the company in the original Flight Plan.

Figure 11 clearly shows that for the analyzed sample of flights, in most of the considered routes the elapsed time of the Actual Trajectory is less than the one established in the Initial Flight Plan. In addition (as shown in Figure 12), if the Great Circle Trajectories used were generated with a Low Cost Index, a better time adherence to the Initial Flight Plan would be obtained. However, this is not a constant as in LEBL-LEMD route, these trajectories take more time than required in the Initial Flight Plan, while the Great Circle trajectories generated with a Medium-High Cost Index are those whose increase their adherence to the Initial Flight Plan time references.

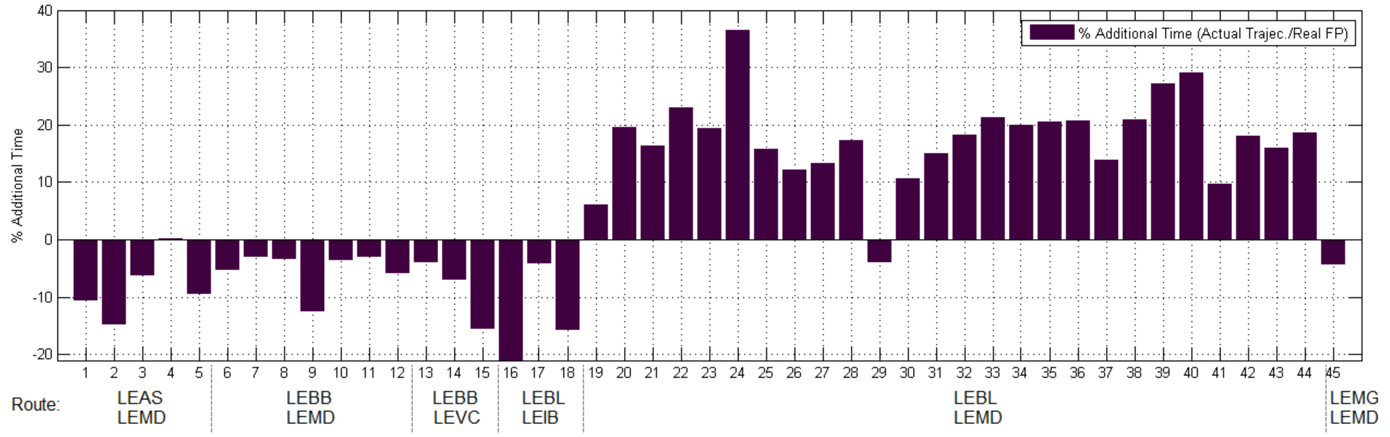

Figure 11. Additional Time of the Actual Trajectory respect to the Real Flight Plan information

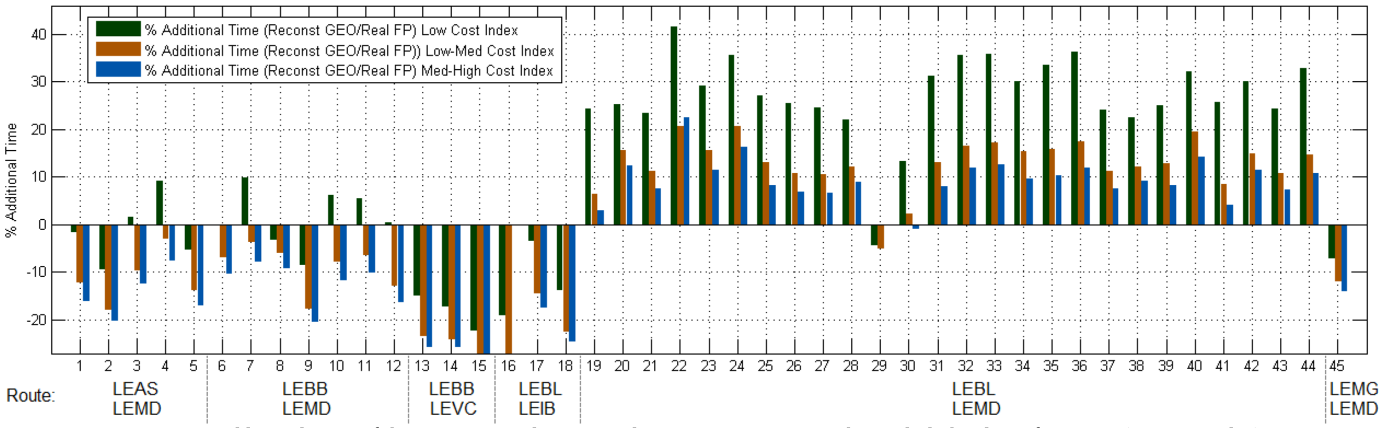

Figure 12. Additional Time of the Reconstructed Great Circle trajectories respect to the Real Flight Plan information (per Cost Index)

IV. CONCLUSSIONS

A new innovative methodology for Flight Efficiency calculation has been proposed, based on fuel efficiency and considering reference trajectories different to Great Circle trajectories. En-route environment has been considered in all this study.

This new, enhanced indicator covers the existing gap with the vertical component of Flight Efficiency, currently not taken into account due to unavailability of necessary information. This new method is able to deal with this lack of accurate information by covering different ranges of payload and cost index, providing a more complete and accurate Flight Efficiency indicator. For doing it, it uses features such as weather data, AIDL and BADA performance models as described.

It has been shown that the Horizontal Flight Efficiency methodology based on Achieved Distance does not fully capture the optimum trajectories or more efficient trajectories, that are essential in this indicator: in particular, results displayed in Section III state that in a considerable number of flights the values of Horizontal Flight Efficiency based on Great Circle trajectories act fully opposite to the values of Flight Efficiency when fuel efficient trajectories are used as a reference, thereby showing that there is no total correlation between them and that Horizontal Flight Efficiency indicator makes some error by considering Great Circle trajectories as the optimum ones.

Additionally, relationship between the Enhanced Flight Efficiency indicator proposed and the initial flight plan information (that can be considered as the optimum according to the airspace user, or the user preferred trajectory) is explored, demonstrating that the Initial Flight Plan trajectory is usually less efficient than the actual trajectory flown, thereby opening a new way for investigation on the optimum routes.

In conclusion, the results presented allow consideration of the Enhanced Flight Efficiency indicator as a more accurate and representative metric in Flight Efficiency computation. Its calculation just requires radar tracks and weather forecast; hence, no proprietary airline information is needed.

An initial assessment on time adherence to Initial Flight Plan reference values has been performed, as an approach to future work in this area, which is already ongoing and includes considering other factors for the generation of the optimum reference trajectory, leading to future improvements of the indicators.

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