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MULTI-OBJECTIVE TRAJECTORY OPTIMIZATION TO REDUCE AIRCRAFT EMISSIONS IN CASE OF UNFORESEEN WEATHER EVENTS

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Abstract

During the flight, aircraft produces several pollutant emissions and the amount is deeply related to the atmospheric conditions (especially pressure, humidity, temperature, air density and wind), the aircraft performance and the phase of flight. In this paper an approach, based on Dijkstra algorithm, to calculate optimized trajectory in terms of several emission reduction (multi-objective trajectory optimization) is illustrated and some results, in case of a real flight and real weather conditions, are reported. The emissions to be simultaneously reduced are CO2 (proportional to fuel consumption [1], NOx and noise and the aircraft considered is an A320, DAL1451, in USA, in climb phase. The simultaneous reduction of all these three pollutants is nontrivial as reducing one pollutant can lead to an increase in the others [2]. The optimization of more than one objective sets a problem on how to combine the single objectives in order to find a satisfactory solution. The chosen approach is to combine the different pollutant using a linear combination. The weight to be assigned to each pollutant could vary and lead to different results. In this paper it is proposed the use of the Pareto optimal solution method to determine a set of optimal weights for multi-criteria optimization of pollutant emissions.

1 General Introduction

During the different phase of flights the aircraft engines emit a lot of chemical pollution and Noise.

The most important chemical emissions emitted, and connected with greenhouse effect, are carbon dioxide (CO2), water (H2O), nitrogen oxides (NOx), and sulfur oxides (SOx) [3, 20].

In accordance to ACARE target [4] and Clean Sky [22] program (that has founded the research reported in the paper), to reduce some of these emissions, NOx, CO2 and Noise are considered.

Inter-dependencies between noise, NOX and CO2 emissions are complex and require careful evaluation prior to regulatory, operational or design decisions [2].

In this paper such emissions are calculated in accordance to the meteorological conditions in climb phase the 18th June 2012 and it is proposed a method for multi-object trajectory optimization to reduce all the considered emissions.

In the following paragraph, an overview of models and data used to calculate aircraft emissions is provided.

1.1 Aircraft Performances: Model used and Emission Calculation

To calculate aircraft emissions (CO2 and NOx, Noise), EUROCONTROL aircraft BADA model [5], ICAO [6] data and NASA Method2Boeing [7,21], Doc29 [8] are used. The considered aircraft model is based on BADA (Base of Aircraft Data) developed by Eurocontrol [5]. BADA is a collection of ASCII files that specifies operation performance parameters, airline procedure parameters and performance summary tables for a huge number of aircraft types.

The most important equations used by the BADA operations performance model is the Total-Energy Model that allows one to compute thrust using the aircraft velocity vector as a function of true airspeed and rate of climb or descent, in addition to other parameters [5].

From thrust computation, BADA model is used to evaluate the fuel flow of the aircraft. For the jet and turboprop engines, the fuel flow is a function of true airspeed and thrust, in addition to other parameters (pressure, humidity, temperature, air denstity, etc.).

1.1.1 Emissions model

Emissions from aircraft originate from fuel burned in aircraft engines CO2 and NOx are most important, for the greenhouse effect, but also methane, nitrous oxide and other by-product gases are emitted. The emissions depend on the fuel type, aircraft type, engine type, engine load and flying altitude.

It is common usage to specify the amount of produced emissions of aircraft engines in the form of so-called emission indices (EI). The EI is the mass of a substance in grams per kilogram of fuel burned [9].

The emission model considered is the Boeing method 2 algorithms [7] for the correction of the ICAO [6] engine emission indices in order to take into account weather parameters, such as temperature, pressure and relative humidity at various altitudes.

The Boeing method 2 (BM2) algorithms are used in AEM3[7] for the adjustment of the ICAO NOx, CO and HC engine emission indices to allow for changes in temperature, pressure and relative humidity at altitude.

1.1.1.1 The Boeing 2 Method

The Advanced Emission Model 3 (AEM3) uses a modified version of the Boeing Method 2 (BM2) to estimate emission calculations (NOx, CO and HC).

The International Civil Aviation Organization (ICAO) has established standards and recommended practices (Annex 16 to the ICAO Conference, "Environmental Protection") for the testing of aircraft emissions on turbojet and turbofan engines. The world's jet engine manufacturers have been required to report to ICAO the results of required testing procedures, which pertain to aircraft emissions. ICAO regulations require reporting of emissions testing data on the following gaseous emissions: NOx, HC, CO and smoke. In addition to this, ICAO requires that information be reported on the rate of fuel flow at various phases of flight. Hence, ICAO maintains a database of this where information is available to find out this information for each of the phases of flight as ICAO defines them such Operating Mode Throttle Setting (percent of maximum rated output)

- Take off 100%
- Climb out 85%
- Approach 30%
- Taxi/ground idle 7%

The Boeing Aircraft Company conducted an extensive study for NASA on emission inventories for scheduled civil aircraft worldwide. The Boeing 2 Method is an empirical procedure developed for this study which computes in-flight aircraft emissions using, as a base, the measured fuel flow and the engine ICAO data sheets. Whereas the first Boeing method took into account ambient pressure, temperature and humidity, the second method was more complicated (and accurate). This new method allowed for ambient pressure, temperature and humidity as well as Mach number.

The used methodology to calculate the emissions is reported in [7].

1.1.1.2 Noise Model

There are various decibel scales used to define and measure sound in terms that can be related to human perception. An important property of sound is its frequency spectrum - the way that its acoustic energy is distributed across the audible frequency range (from 20 Hz to 20 kHz approximately). Two particular scales are important for aircraft noise - A-weighted sound level and Tone-corrected Perceived Noise Level [8].

The A-weighting is a simple filter applied to sound measurements which applies more or less emphasis to different frequencies to mirror the frequency sensitivity of the human ear at moderate sound energy levels [10]. A-weighted sound level is an almost universally used scale of environmental noise level: it is used for most aircraft noise monitoring applications as well *as* for the description of road, rail and industrial noise. A-weighted levels are usually denoted as LA. The noise impact assessments that generate the need for noise exposure contours generally rely on A-weighted metrics and these are therefore of primary interest in this guidance; although there are exceptions, Perceived Noise Level applications are confined mostly to aircraft design and certification.

Noise metrics may be thought of as measures of noise 'dose'. There are two main types, describing (1) single noise events (Single Event Noise Metrics) and (2) total noise experienced over longer time periods (Cumulative Noise Metrics).

Noise levels are usually defined at fixed observer locations or mapped as contours (i.e. iso-lines) depicting the area where the specified levels are exceeded. They are used - especially cumulative metrics - in all domains of transportation noise, in our case air-traffic.

These are used to describe the acoustic event caused by a single aircraft movement. Two types are in common usage, both can be determined by measurements as well as by calculations using suitable models (that are the principle subject of this guidance). They are (1) Lmax, based on (1) the maximum sound intensity during the event and (2) LE, based on the total sound energy in the event. The total sound energy can be expressed as the product of the maximum sound intensity and an 'effective duration' of the event.

An aircraft noise event can be described by its observed level-time-history L(t).

These are the maximum (frequency-weighted) sound level Lmax and a duration t. Common definitions of the duration are the effective duration, te, i.e. the duration of a noise event with the constant level Lmax that contains the same sound energy as the noise event described by the level-time-history L(t).

Three corresponding single event metrics of particular importance in aircraft noise [11, 12, 13] are (1) Maximum A-weighted Sound level (abbreviation LAmax), (2) Sound Exposure Level (acronym SEL, abbreviation LAE) and (3) Effective Perceived Noise Level (acronym EPNL, abbreviation LEPN).

LAmax is still the favored metric for day to day noise monitoring at airports.

EPNL is the metric for aircraft noise certification limits laid down by ICAO Annex 16 [13], which all new civil aircraft have to meet. Certification gives noise levels at specific points rather than information on the total noise in the general vicinity of the flight path. An indication of the latter is provided by contours of constant single event noise level - so-called "noise footprints". Noise footprints are useful performance indicators for noise abatement flight procedures since they reflect the impact of noise on the ground of the whole flight path (flight altitude, engine power setting and aircraft speed at all points) rather than only from a part of it.

As the decibel scale is logarithmic, long term aircraft noise exposure indices can be logically and conveniently expressed in the form L+ K lg N, where L is the average event level (in decibels of some kind), N is the number of events during the time period of interest, and K is a constant which quantifies the relative importance of noise level and number.

1.1.1.3 Weather data

As mentioned before, in order to compute aircraft emissions, it is required the atmospheric distribution, in altitude, of the following meteorological data: density of air, pressure, temperature, relative humidity, wind intensity, speed and direction, and clouds reflectivity. These data, except density of the air, are available through numerical weather models that several weather organizations in the world develop for analysis of current situations and forecasts.

For the tests were used data from USA, available in internet, in particular the Rapid Refresh (RAP) model from NOAA/NCEP operational weather prediction system, running every hour.

The RAP is an atmospheric prediction system that consists primarily of a numerical forecast model and an analysis system to initialize the model. Models run hourly, with analysis and hourly forecasts out to 18 hours. RAP files are stored in the GRIB2 file format. GRIB (GRIdded Binary) is a mathematically concise data format commonly used in meteorology to store historical and forecast weather data. The minimum grid spatial resolution is 13 km. In particular, for the tests were used GRIB2 file that uses 37 vertical levels (isobaric levels) with a grid having a horizontal spatial resolution of 20 km with a dimension of 225x301 grid cells. From these files were used geo-referred information about pressure, temperature, relative humidity, wind speed and direction, and clouds reflectivity (from on-ground the weather radar data), the other variable needed were taken from ISA standard model.

1.2 Problem Approach

To calculate the emissions associated to the selected trajectory, identify better trajectories in terms of emission reduction and the weights to perform multi-object trajectory optimization, a graph approach, with algorithms coming from the operational research, field are used (i.e. Djikstra, genetic algorithm and Pareto front).

1.2.1 Graph construction (base of data of feasible trajectories)

Using the previous models and equations, a graph of all feasible trajectories, for the selected aircraft, in a certain volume of space, in which are available the previous listed atmospheric information, is constructed. Such a graph is used to calculated the emissions associated to all the trajectories and to select the better one in terms of emission and noise reduction.

Using aircraft and atmospheric parameters, it is possible to decide whether there is an arc in the graph G. The arch exists if the following four quantities lie within suitable bounds: the distance between 2 adjacent nodes, the bank angle between the 2 adjacent nodes, the speed and the altitude variation. The bounds are determined considering the limitations imposed by the pilot manual [14,15] of the considered aircraft with the selected engines, so the corresponding maneuvers are safe as they are inside the flight envelope of the selected aircraft for the current metereological conditions.

The Graph is constructed by means of recursive algorithms: starting from a node, all the nodes that are close to it in the components latitude, longitude and altitude, are checked to see if they can be reached and thus the corresponding arc in the Graph exists [19]. The reachable states are recursively checked against their neighbors, until all the possible arcs of the Graph are created, obtaining a Graph representative, with its arcs, of a set of feasible trajectories under aircraft constraints.

Hence, the proposed model can consider the avoidance of the No-Flight zones, i.e., regions where flights are not permitted due to bad weather conditions, NOTAM or other conflicts. In order to define No-flight zones, other meteorological data from airborne, ground weather radars, and available forecasts can be used. An arc is removed from the graph if it intersects the forbidden region on the basis of the corresponding spatial coordinates.

1.2.2 Generation of Non dominated solutions: Pareto

The optimization of fuel consumption (proportional to CO_2 emission), NO_x and Noise in many cases and phase of flight are concurrent [2,16], so it is not so easy to find a way to optimize together all the 3 emissions.

In general for a nontrivial multi-objective optimization problem, there does not exist a single solution that simultaneously optimizes each objective. In that case, the objective functions are said to be conflicting, and there exists a (possibly infinite number of) Pareto optimal solutions. A solution is called non-dominated, Pareto optimal, Pareto efficient or non-inferior, if none of the objective functions can be improved in value without impairment in some of the other objective values. Without additional preference information, all Pareto optimal solutions can be considered mathematically equally good (as vectors cannot be ordered completely). The set of Pareto optimal solutions is often called the Pareto front. The methodology proposed in this paper aims at combining the set of emissions computed during a flight phase (the results in climb phase are reported below), considering the aircraft moving from an initial waypoint toward a final waypoint.

The emissions, that typically have different units of measurement and different ranges, have been normalized considering the typical range of emissions in that flight phase as described in the ICAO databank for CO2 [6,17], the Boeing model for NOX [7] and the DOC29 [8] for Noise. The aircraft model used in the simulation is derived by BADA database [5] for A320. The optimized trajectory is then used to compute the emissions in climb phase given that set of weights. Changing the set of weights at the input and computing the corresponding optimized trajectories and related emissions, it is possible to determined what set of weights produces non-dominated Pareto solution. Repeating this computation on different flights and different weather condition, it is possible to study what is the best set of weights for that type of aircraft. The main contribution of this paper is to investigate the optimal values for the emissions weights in a specific climb phase. In general more than one solution was obtained and the decision maker, typically the flight company, can choose which pollutant is more important to be reduced in that flight area and determine the cost index.

The Pareto optimal solution method is tested on the climb phase of the trajectory of an A320, DAL1451 (from Flightaware), in USA and using the real atmospheric condition contained in a GRIB file downloaded from NOAA database to calculate the emissions. The multi-objective function was computed using a linear combination of the three pollutants: CO2, NOx and Noise. The weights for each pollutant in the optimization algorithm are chosen between 0.1 and 0.8 and the sum of the three weights is one.

2 Results: an A320, DAL1451 emissions in climb phase in real atmospheric condition

The considered trajectory is originated from Minneapolis/St Paul International Airport (KMSP) (44.88°, -93.22°) on June 18th 2012 at about 03 a.m. (UTC): DAL1451. It is considered the climb phase, until cruise flight level is reached. The aircraft is A320 and it is supposed that its mass is 64000 kg.

2.1 Meteorological data

Meteorological data are RAP data of June 18th 2012 at 03.00 am (UTC) (available here: http://motherlode.ucar.edu:8080/thredds/catalog/fmrc/NCEP/RAP/CONUS_20km/files/catalog.html). Wind speed and direction at altitude equal to about 3000 m and 8000 m are depicted in the following figures.

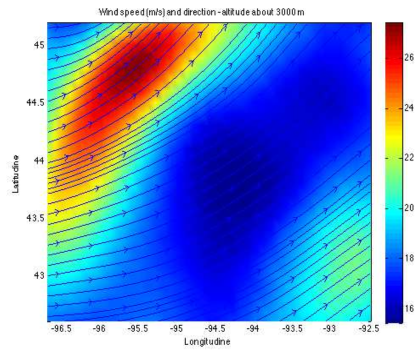

Fig. 1. The Wind speed, direction and intensity (different colors) at 3000 m.

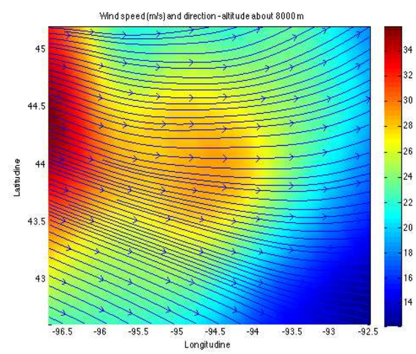

Fig. 2. The Wind speed, direction and intensity (different colors) at 8000 m.

2.2 Route and aircraft emissions

In the following table are reported the starting and ending points of the climb phase of the three considered trajectories.

Start Lat (°)	Start Lon (°)	Start Alt (m)	End Lat (°)	End Lon (°)	End Alt (m)
44.82	-93.23	914	43.33	-95.91	10363

Table. 1. Initial and final position of DAL1451 trajectory considered.

In order to compute noise emissions three observation points are set: Minneapolis (44.993N, -93.265E), St. Paul (44.9536N, -93.092E) and Rochester (44.031N, -92.467E).

The real trajectories are taken from "FlightAware" website (http://flightaware.com).

In the following figure (Fig.3) the "normal" trajectory (in this case the trajectory of June 17th 2012 at about 03 a.m.) (blue) and the trajectory of June 18th 2012 (black) are depicted, related to real cloud reflectivity the June 18th 2012 at 03 a.m.

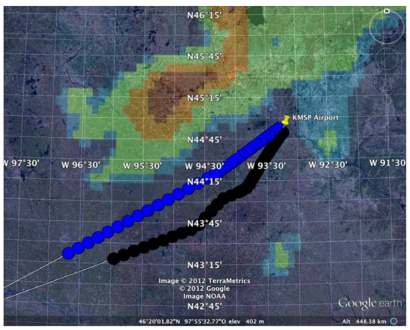

Fig. 3. Two trajectories performed by DAL1451 in different days and atmospheric conditions are reported.

In the following tables, emissions of the aircraft are reported. In table 2 the estimated emissions of the trajectory in different atmospheric conditions are reported. In particular are calculated the emissions associated to the same trajectory with the real meteorological conditions and the ones forecasted one, three and six hours before, in order to assess the impact of meteorological conditions on the emissions.

DAL1451	Real meteo	1 h forecast	3 h forecast	6 h forecast
CO2 (kg)	5366	5315	5323	5307
NOx (kg)	62.99	59.76	59.98	59.63
Noise (dB)	53.33	53.18	53.03	52.93

Table. 2. estimated emissions of DAL1451 in different atmospheric conditions.

The differences in the calculated emissions depend mainly on wind and cloud reflectivity values that are not so reliable for what concern the prediction [18]. On the other side, pressure, temperature and humidity prediction are more reliable [7].

Then, using the weighted Graph of the feasible trajectories, are calculated the emissions associated to different trajectories. In table 3 are reported the emissions associated to the real flight (column 2 in table 3) and the ones associated to optimized trajectories, applying Dijkstra mono or multi-object and a genetic algorithm to select an optimized trajectory in accordance to different criteria (table 3, in column 3 Dijkstra Mono-objective CO2, 4 Dijkstra Mono-objective NOx, 5 Dijkstra Mono-objective Noise, 6 Dijkstra Multi-objective,7 Genetic Multi-objective)

	FA emit	Dijkstra's algorithm				Genetic Algo
		CO2	NOx	Noise	MO2	MO2
CO2 (kg)	5366	5204	6370	6897	5255	5266
NOx (kg)	62.99	88.28	52.24	112.08	53.81	61.05
Noise (dB)	53.33	61.60	49.45	45.58	51.38	49.02

Table. 3. DAL1451 emissions and emission associated to optimized trajectories.

2.3 Comparing multi-objective trajectories using Pareto front

The optimization of more than one objective sets a problem on how to combine the single objectives in order to find a satisfactory solution. In the reported tests the three pollutants (CO2, NOx and Noise) were combined using a linear combination. Varying and combining the different weights it was possible to find a set of solutions "ordered" using the definition of Pareto optimal solutions often called Pareto Front.

This method was tested on the climb phase of the trajectory DAL1451. The multi-objective function was computed using a linear combination of the three pollutants: CO2, NOx and Noise. The weights for each pollutant in the objective function used by Dijkstra's algorithm are between 0.1 and 0.8 and the sum of the three weights must be one. The objective function used by Genetic algorithm takes into account the linear combination of the three pollutants (as explained for Dijkstra's algorithm) and also the number of consecutive turns.

In the following table the 36 solutions found using Dijkstra algorithm are reported. The first three columns report the weights used in the multi-objective function, the successive three columns report the value of the three pollutants computed. In bold are reported the solutions belonging to the Pareto front.

Dijkstra Pareto Front					
CO2 weight	NOx weight	Noise weight	CO2 emission	NOx emission	Noise Emission
0.1	0.1	0.8	5812.52	54.87	48.80
0.1	0.2	0.7	5866.44	53.92	48.81
0.1	0.3	0.6	5866.44	53.92	48.81
0.1	0.4	0.5	5978.30	53.33	48.81
0.1	0.5	0.4	6061.76	52.97	48.82
0.1	0.6	0.3	6241.41	52.38	48.77
0.1	0.7	0.2	6241.41	52.38	48.77
0.1	0.8	0.1	6241.41	52.38	48.77
0.2	0.1	0.7	5506.27	62.52	51.29
0.2	0.2	0.6	5812.52	54.87	48.80
0.2	0.3	0.5	5866.44	53.92	48.81
0.2	0.4	0.4	5866.44	53.92	48.81
0.2	0.5	0.3	5866.44	53.92	48.81
0.2	0.6	0.2	5866.44	53.92	48.81
0.2	0.7	0.1	5866.44	53.92	48.81
0.3	0.1	0.6	5437.68	64.85	54.63
0.3	0.2	0.5	5557.44	60.71	51.29
0.3	0.3	0.4	5697.09	56.96	51.30
0.3	0.4	0.3	5866.44	53.92	48.81
0.3	0.5	0.2	5866.44	53.92	48.81
0.3	0.6	0.1	5866.44	53.92	48.81
0.4	0.1	0.5	5372.47	68.96	54.68
0.4	0.2	0.4	5472.44	63.30	54.63
0.4	0.3	0.3	5697.09	56.96	51.30
0.4	0.4	0.2	5697.09	56.96	51.30
0.4	0.5	0.1	5866.44	53.92	48.81
0.5	0.1	0.4	5296.21	75.87	54.70
0.5	0.2	0.3	5437.68	64.85	54.63
0.5	0.3	0.2	5557.44	60.71	51.29
0.5	0.4	0.1	5697.09	56.96	51.30
0.6	0.1	0.3	5244.65	80.49	57.77
0.6	0.2	0.2	5437.68	64.85	54.63
0.6	0.3	0.1	5472.44	63.30	54.63
0.7	0.1	0.2	5244.65	80.49	57.77
0.7	0.2	0.1	5397.78	67.14	54.65
0.8	0.1	0.1	5244.65	80.49	57.77

Table. 4. Emissions associated to multi-object optimized trajectories (underlined in green the minimum CO2 emission, in pink min NOx, in cyan min Noise; in dark green min CO2 for min NOX and Noise).

In the following table the 36 solutions found using Genetic algorithm are reported. The first three columns report the weights used in the multi-objective function, the successive three columns report the value of the three pollutants computed. In bold are reported the solutions belonging to the Pareto front.

Genetic Pareto Front					
CO2 weight	NOx weight	Noise weight	CO2 emission	NOx emission	Noise Emission
0.1	0.1	0.8	5855.31	56.89	50.19
0.1	0.2	0.7	5866.44	53.92	48.81
0.1	0.3	0.6	5866.44	53.92	48.81
0.1	0.4	0.5	5978.30	53.33	48.81
0.1	0.5	0.4	6119.26	53.10	47.92
0.1	0.6	0.3	5999.97	55.36	50.21
0.1	0.7	0.2	6119.27	53.17	48.84
0.1	0.8	0.1	6172.95	53.26	47.95
0.2	0.1	0.7	5546.12	61.57	52.14
0.2	0.2	0.6	5669.47	58.79	52.13
0.2	0.3	0.5	5866.44	53.92	48.81
0.2	0.4	0.4	5866.44	53.92	48.81
0.2	0.5	0.3	5866.44	53.92	48.81
0.2	0.6	0.2	5866.44	53.92	48.81
0.2	0.7	0.1	5866.44	53.92	48.81
0.3	0.1	0.6	5900.51	62.25	48.80
0.3	0.2	0.5	5625.76	59.75	51.30
0.3	0.3	0.4	5785.34	56.68	52.11
0.3	0.4	0.3	5866.44	53.92	48.81
0.3	0.5	0.2	5866.44	53.92	48.81
0.3	0.6	0.1	5866.44	53.92	48.81
0.4	0.1	0.5	5384.73	71.16	54.67
0.4	0.2	0.4	5632.85	59.12	51.28
0.4	0.3	0.3	5476.67	64.35	54.66
0.4	0.4	0.2	5809.84	55.38	48.84
0.4	0.5	0.1	5866.44	53.92	48.81
0.5	0.1	0.4	5296.21	75.87	54.70

0.5	**0.2**	**0.3**	**5766.74**	**58.20**	**52.09**
0.5	**0.3**	**0.2**	**5632.85**	**59.12**	**51.28**
0.5	**0.4**	**0.1**	**5783.44**	**57.01**	**50.18**
0.6	**0.1**	**0.3**	**5244.65**	**80.49**	**57.77**
0.6	0.2	0.2	5560.73	64.46	54.66
0.6	**0.3**	**0.1**	**5444.42**	**66.76**	**52.18**
0.7	**0.1**	**0.2**	**5244.65**	**80.49**	**57.77**
0.7	**0.2**	**0.1**	**5204.02**	**88.28**	**61.61**
0.8	**0.1**	**0.1**	**5244.65**	**80.49**	**57.77**

Table. 5. Emissions associated to multi-object optimized trajectories (underlined in green the minimum CO2 emission, in pink min NOx, in cyan min Noise; in dark green min CO2 for min NOX and Noise).

It is possible to notice that in the selected case the Minimum Noise emission is connected to the minimum NOx emission (generally both are minimized in case of constant engine regime). On the contrary Fuel consumption (and CO2 that is proportional by a factor of 3.18) are minimized when NOx and Noise increase.

It is possible to identify some cases (underlined in dark green in table 4 and 5) in which there is a limited emission of CO2 (fuel consumption) in correspondence of low emission of NOx and Noise. Generally, the decision maker (i.e. the flight company) chooses the trajectory emission index and the weights and the criteria to be used to optimize the trajectory.

3 Conclusions

The tests carried out to define a set of weights for a climb phase of a trajectory have been executed considering the trajectory of DAL1451 in climb phase.

First the models used to calculate emissions (CO2, NOx, Noise) associated to the trajectories in different atmospheric conditions were described.

Then the procedure used to perform multi-object trajectory optimization and identify a set of weights, based on operational research concept and Pareto Front was reported.

Finally the test results for aircraft DAL1451 in climb phase the 18th June 2012 were provided.

In the chosen case it was possible to notice that NOx and Noise emission were lower with the same choice of emissions weights, and it was possible to identify some set of weights, and so some trajectories, for which CO2 emission was not so high while NOx and Noise emissions were low.

The choice of the weight of each pollutant remains a strategic decision in standard meteorological conditions; it has to be taken by the decision makers (regulatory agencies, aircraft company, etc.). The choice of the weights could be considered in no-standard meteorological conditions but it is not trivial to define what are no-standard conditions and to find in real cases.

Depending on atmospheric conditions and phase of flight, the emissions associated to the trajectories can be in accordance or concurrent [2], so would be interesting, for future works, to perform a statistic for different flights, in different weather conditions and different phase of flights.

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