ALGORITHMS AND SYSTEM FOR CURVED AND CONTINUOUS DESCENT TRAJECTORIES IMPROVING FUEL EFFICIENCY IN TMA

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Abstract

One of the most important challenges in Air Traffic Management (ATM) is to increase the efficiency of flights arriving at busy airports. The effects of aircraft noise, fuel consumption and related pollutant atmospheric emissions can impact the quality of life in populated areas near to airports and represent environmental issues resulting in restrictions for air traffic procedures, aircraft manufacturing and airport facilities design. ICAO and EUROCONTROL provide guidance and recommendations on environmental measurements in order to overcome these difficulties, contributing to a sustainable balancing between the positive growing demand in the Aviation sector and the negative consequences of human activities.

This paper is focused on the development of arrival trajectories automatic generation algorithms. The implementation of these algorithms is aimed to generate curved and continuous descent approach trajectories, by remodeling or adjusting the arrival procedures, for the future efficient flight operations in Terminal Maneuvering Area (TMA), so increasing environmental efficiency and capacity in proximity of airports. Furthermore, the paper reports and discusses the main concepts and mathematical models needed to implement an overall system, including the algorithms cited above, able to generate descent profiles suitably optimized in terms of fuel consumption with respect to conventional step-down arrival paths.

1 Introduction)

The hasty increase of Aviation demand is generating many positive aspects such as jobs, understanding between cultures and access to products from different parts of world. Furthermore, the human activities derived from these benefit contribute to the introduction of innovative technologies in the ATM systems to support a higher traffic density with different typology of airspace users and aircraft operations. However, these benefits lead to some negative consequences mainly due to the pollution, noise and climate change. The task of Aviation is to find a sustainable balance between competing economic, social and environmental demand. In recent years, these considerations have been taken in the development of new operational concepts, such as those developed in NEXGEN and in Europe's SESAR Programme, that aim at strategically remodeling and adjusting the arrival procedures in a more efficient way increasing capacity, productivity and safety and reducing the environmental impact in proximity of airport. One of the innovative concepts introduced in the last years in order to reduce noise and pollutant emissions is a direct descent at idle or near-idle thrust, beginning at entry to the terminal control area from cruise until touchdown. This technique is generally referred to the Continuous Descent Operation (CDO).

This paper provides a methodology for generating vertical profiles for a generic aircraft and validate a system enabling to compute curved and continuous trajectories along more optimized approach and landing profiles in terms of aircraft fuel consumption, in TMA environment typically rich of obstacles. Specifically, such techniques are implemented to compere the continuous vertical profiles with the conventional techniques of descent. Furthermore, the proposed algorithms are designed to generate curved and continuous

trajectories. These functions take into account the dynamic restrictions of the considered aircraft and external space constraints in TMA, in order to avoid automatically any obstacles along the final phases of aircraft route, and to select the optimal trajectory in terms of reduction of fuel consumption.
The following section presents an overview of the CDO operational methods including the Continuous Descent Approach CDA concept. After that, the section "Methodology" describes the proposed curved and continuous trajectories generation system and the setup for fast-time simulations. In addition, this section reviews the mathematical model to compute these trajectories and the fuel consumption. The assumptions, the implemented scenario, the metrics for validation and the results of the simulations are presented, finally, in the section "Experiments and results" including the conclusions.

1.1 Overview of Continuous Descent Approach (CDA) concept and operation

ICAO defines CDO "an aircraft operating technique aided by appropriate airspace and procedure design and appropriate ATC clearances enabling the execution of a flight profile optimized to the operating capability of the aircraft, with low engine thrust settings and, where possible, a low drag configuration, thereby reducing fuel burn and emissions during descent. The optimum vertical profile takes the form of a continuously descending path, with a minimum of level flight segments only as needed to decelerate and configure the aircraft or to establish on a landing guidance system (e.g. ILS)."[1]. Generally, the continuous descent is a technique that simplifies the non-precision final approach with precision curved approach and vertical guidance procedures, resulting in a continuous vertical path calculated by on-board equipment or manually based on a required rate of descent without level flight segments. Fig. 1 shows the typical profile of an aircraft from the end of the cruise phase to landing in comparison with the conventional trajectory.

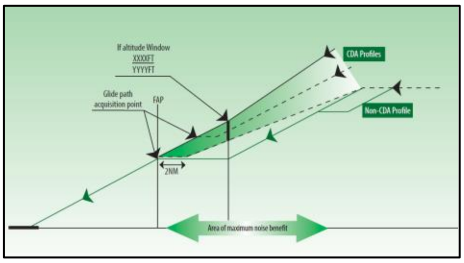

Fig. 1. CDO Concept [1]

As defined by EUROCONTROL [2], Continuous Descent Approach (CDA) procedure is achieved through collaboration between operational stakeholders, in order to satisfy functional and non-functional requirements. Particularly, the Air Traffic Controls (ATCs) could have some difficulty predicting an aircraft descent trajectory at idle trust as the CDAs could differ with respect to wind, temperature, and aircraft characteristics (i.e. adopted flight management system FMS, airframe, weight, engines and speed). Furthermore, the radar vectoring and vertical profile management can influence the arrival phase increasing the ATCs workload. Hence, the implementation of a curved and continuous vertical profile is expected to eliminate the level flight segments as far as possible. This is achievable through applying the Rules of the Air [3], and considering the air traffic control procedures based on the advanced flight transitions over curved trajectories directly connected to satellite systems for the precision final approach such as the Performance-Based Navigation PBN [4].

Since there are no specific guidelines for designing CDAs, the CDA implementations differ with respect to the start altitude and speed as stated from many different researches. Furthermore, to evaluate and demonstrate the benefits of CDA procedure, several flight trials have been conducted at several airports in the US and the EU. For example, in U.S., a program known as Partnership for AIR Transportation Noise and Emission Reduction (PARTNER), also designed detailed CDA models, and conducted field tests at Louisville International Airport (KY, U.S.) and at Los Angeles International Airport [5,6]. For the flight trials at Louisville International airport5, CDAs started at 11000 ft. The trial was conducted during late night landing operations by UPS aircraft at

Louisville International Airport (KSDF) in 2004. This flight trial, leveraging the capability of the FMS, proved the stated benefits of a CDA procedure [5]. European Commission initiated a program, known as Optimized Procedures and Techniques for Improvement of Approach and Landing (OPTIMAL) in 2004, in which CDA profiles and associated descent procedures are established [7]. Two major CDA trials were conducted at the Schiphol Airport, Amsterdam, Netherland, in 2006, and at the Heathrow Airport in 20077. The aim was to define and validate innovative procedures for the approach and landing phases of aircraft and rotorcraft. The objective was to increase airport capacity and to reduce environmental impacts (noise and carbon footprints) while maintaining or even improving operational safety. In the EU co-funded Project within the Sixth Framework Programme (FP6), the Project namely Environmentally Responsible Air Transport (ERAT) [8], was defined to select the terminal airspaces above the airports Stockholm Arlanda and London Heathrow as reference site to focus the development of concepts aimed at improving environmental performance in terms of noise, fuel burn and emissions. The objective was to develop and validate the CONOPSs for the extended terminal airspace (eTMA) of a medium and a high density traffic airport, in such way that the environmental impact of air traffic in 2015 is significantly reduced while maintaining safety levels and airport and airspace capacity. Other researches continued to propose alternatives to reduce noise levels around airports based on previous experiences. For instance, the Project named Study of Optimisation procedURes for Decreasing the Impact of NoisE around airports (SOURDINE) aimed at defining new procedures for selected airports (Schiphol, Madrid and Napoli) in order to evaluate more predictable continuous descent operations [9,10].

Even if this technique is preferred to the conventional descent, as it requires less engine thrust and consequently less emissions and acoustic impacts, the CDA procedure is influenced by the capacity of air traffic controllers and air traffic control systems, common speed constraints, altitude and separation, especially for high traffic areas. Many research project investigated on implementing of an appropriate arrival flow management in order to support the implementation of CDAs simplifying controller tasks, reducing communications and workload, and providing a better trajectory prediction, allowing for improved flight efficiency. The EUROCONTROL Experimental Centre (EEC) developed the Point Merge (PM) as an innovative technique designed to improve and harmonise arrival operations in terminal airspace with a pan-European perspective [11]. PM is designed to work without radar vectoring, and to enable, even under high traffic load, extensive use of lateral guidance by the FMS and CDA. EEC presented the main findings regarding more complex environments and advanced continuous descent [12].

2 Methodology

2.1 Project Efficient Air Transport System (EATS)

This study was developed within the framework of the Efficient Air Transport System (EATS) Project [13], carried out by the Italian Aerospace Research Center (CIRA). The EATS model aims to generate different Curved Continuous Descent Approach (CCDA) trajectories to provide the optimal continuous descent in terms of fuel efficiency and develop Airborne Sequencing and Merging algorithms for such some efficient operations in TMA. In the Project, many scenarios were defined to cover a wide spectrum of possible arrival procedures in TMA. Different BADA performance aircraft models [15] were adopted to investigate on the feasibility of the methodology. The proposed high-level system is shown in the Fig. 2.

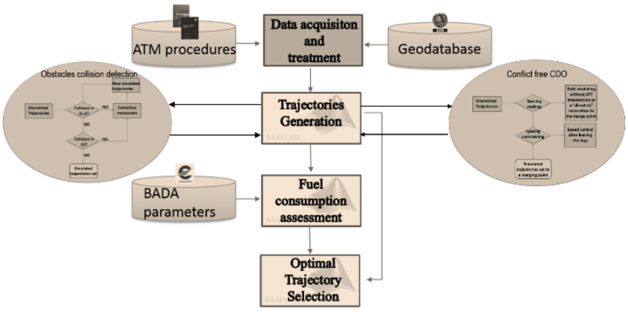

Fig. 2. High-level Process Sequence

The core of the proposed method is a dedicated system for generating the trajectories that has been developed in Matlab®. As shown in Fig. 2, the system first receives and elaborates the external data. In particular, the inputs necessary to generate the trajectories are constituted by ATM operations including restrictions like speed and minimum distance from obstacles, standard arrival procedures (STARs) and P-RNAV navigation published on Aeronautical Information Circular (AIC) and designed according to GNSS and DME/DME criteria. In particular, the adopted ATM parameters set includes standard arrival procedures (STARs), ICAO minimum wake turbulence separation standards, and restrictions like speed and minimum distance from obstacles. In addition, the obstacles mapping for airport and external environmental constraints are built by using aeronautical charts georeferencing processes and suitable Digital Surface Models (DSMs) and Digital Terrain Models (DTMs).
The system is constituted by different concatenated tools, which have been developed starting from one or more assumptions depending on the choose of the calculated top of descent point (TOD). The main steps are listed below:

- Computation of TOD according to predefined angle or along a path at a fixed altitude up to intercept the glide path for the descent at constant or variable path angle.
- Automatically generation of different curved continuous descent approach trajectories (CDAs at different path angle, Optimized Profile Descent, Increased Glide Slope, CDA supported by PM structure). The lateral profile is generated as a path on a certain flight level turning at constant bank angle and using pre-defined waypoints, such as aRea NAVigation (RNAV) and Performance-Based Navigation (PBN). Cubic interpolation technics are here adopted for aircraft trajectory generation, in order to insure a continuous trajectory curvature. The vertical profile is generated as a precision vertical guidance on direct descent path, discretized through a set of infinitesimal straight-line segments. The system is able to re-calculate each trajectory in order to avoid a potential collision with the obstacles and to take into account restrictions related to the constraints of air navigation19. Aircraft descent paths are simulated from the top of descent (TOD) to runway. A merging point is fixed between Initial Approach Fix (IAF) and Final Approach Fix (FAF) in order to specify the flight trajectory designed by the air traffic controller, so facilitating the conflict-free continuous descent operation and allowing aircraft to maintain an appropriate interval with a preceding aircraft by airborne separation.
- Comparison of CDAs profiles to the conventional routes in terms of fuel efficiency. The fuel consumption is calculated for each generated trajectory by elaborating the applicable aircraft performance parameters obtained from Base of Aircraft and Data (BADA). The mathematical model used to compute the fuel consumption of the single specific vehicle under consideration has been elaborated in terms of equations derived by using flight dynamics concepts and Base of Aircraft and Data (BADA) Total Energy Model (TEM) [15].
- Finally, the trajectory characterized by the maximum fuel consumption reduction with respect to the standard arrival route is selected as the optimal descent profile. This selection is automatically performed by comparing the percentage of fuel saving associated to each designed trajectory, so individuating the one that leads to the

minimum fuel consumption, resulting in turn in the lower environmental impact [16].

2.2 Mathematical model

The following sub-sections describe the mathematical analysis of the four main models: trajectories generation, fuel computation, conflict free continuous descent operation, and obstacle detection model.

2.2.1 Trajectories generation model

The trajectories generation model is based on three kinds of mathematical approaches depending on the sort of trajectory to be generated. We have differed the step-down trajectories generation, the CDA trajectories generation and finally the PM-based CDA trajectories generation modules. The conventional step-down paths are automatically built through the linear interpolation of the given waypoints in suitable metric coordinates. The CDA trajectories generation sub-model receives the known conventional waypoint in input and provides a set of new correspondent waypoints at higher altitude. The CDA paths are generate by using the cubic interpolation techniques in order to insure a continuous trajectory curvature. Many consolidated study and research activities investigated on interpolated methods and related issues [17]. From a mathematical point of view, cubic interpolation technics are usually adopted for aircraft trajectory generation in TMA in order to insure a continuous trajectory curvature [18]. A generic polynomial p_n of order n can be written in the following canonic form:

$$p_n = f(x) = \sum_{i=0}^{n} a_i x^i \qquad (1)$$

with coefficients a_i.
The conditions for a polynomial interpolation expressed in the canonical form are:

$$\sum_{i=0}^{n} a_i {x_j}^i = y_{i,} \qquad {}_{j=0,\dots,n} \qquad (2)$$

The PM-based CDA trajectories generation sub-model takes into account the CDAs until the designed entry points. Then, it receives in input the coordinates of the entry points and the sequencing legs at prefixed different altitudes on which the pair of aircraft are assigned for arrival descent until to merging point. This module applies the same interpolation algorithms used for CDAs in order to ensure the continuously and curvature descent, resulting in higher altitudes with respect to the set of CDA-alone trajectories due to the flight level constraints for sequencing leg in PM system.

2.2.2 Fuel efficiency assessment model

The developed model for fuel consumption evaluation is based on equations derived by using flight dynamics concepts and BADA Total Energy Model (TEM) [15].
The Total-Energy Model equates the rate of work done by forces acting on the aircraft to the rate of increase in potential and kinetic energy, that is:

$$(T - D)V_{TAS} = mg\frac{dh}{dt} + mV_{TAS}\frac{dV_{TAS}}{dt} \qquad (3)$$

where:
D = Aerodynamic drag [N]
T = Thrust acting parallel to the aircraft velocity vector [N]
V_{TAS}= true airspeed [m/s]
m = aircraft mass [kg]
g = gravitational acceleration [9.81 m/s^2]
d/dt = time derivative [s^{-1}]
h = altitude [m]

The fuel flow rate is derived by considering above terms. The fuel consumption, then, is evaluated as the integral of the fuel rate with respect to time:

$$fr = \left(\frac{C_{f1}}{C_{f2}}\frac{C_{D0}\rho S}{2}\right)v^3 + \left(\frac{C_{f1}C_{D0}\rho S}{2} + \frac{C_{f1}}{C_{f2}}m\frac{dv}{ds}\right)v^2 + \left(C_{f1}m\frac{dv}{ds} + \frac{C_{f1}}{C_{f2}}mg\sin\gamma\right)v + C_{f1}mg\sin\gamma + \left(\frac{C_{f1}}{C_{f2}}\frac{2C_{D2}m^2g^2}{\rho S}\right)\frac{1}{v} + \left(C_{f1}\frac{2C_{D2}m^2g^2}{\rho S}\right)\frac{1}{v^2} \qquad (4)$$

$$FC = \int_0^{T_f}[fr]\,dt$$
(5)

where:

C_{f1} = first thrust specific fuel consumption coefficient kg/(min·kN) for jet, kg/(min·kN·knot) for turboprop, and kg/min for piston
C_{f2} = second thrust specific fuel consumption coefficient [knots]
C_{D0} = parasitic drag coefficient
C_{D2} = induced drag coefficient
ρ_0 = air density at sea level [kg/m^3]
ρ = air density [kg/m^3]
S = wing area [m^2]

The fuel consumption is influenced by different factors. Many research projects investigated the impact of altitude, speed and path angle [19-22]. For some aircraft such as regional and business jets (not large jet), flying at a fixed flight path angle and constant Mach/calibrated-airspeed results in lower fuel consumption compared to standard descents at idle-thrust and constant Mach/calibrated airspeed [23]. Other researchers implemented CDA under traffic conditions based on air traffic simulation and BADA fuel model. They founded that the enabling large or heavy aircraft to engage in CDA achieved higher fuel benefits [24].

The integral in Eq. (5) can be considered as a discretized sum of fuel consumption on each interval segment of the trajectory along the whole distance from top of descent to touchdown13. Thus, the simulated trajectories have been previously discretized in three-dimension interval segment to calculate the fuel burn along each path segmentation interval, and along the whole generated trajectories from top of descent to touchdown.

2.2.3 Conflict free CDO model

Generally, separation requirements are based on the wake turbulence constraints, horizontal separation, and runway separation. A safely separation between the pair of aircraft is ensured by a suitable vertical design on entry points of sequencing legs and FAFs. In addition, according ICAO regulation [25], the minimum separation standards are given in Table 1.

Table 1. Separation Minima in MN. [25]

Category		Leading Aircraft		
		Heaving	Meduim	Light
Trailin	Heaving	4	3	3
	Meduim	5	3	3
	Light	6	5	3

A pre-defined merging procedure could manage the conflicts detection in CDO. The merge conflict detection problem is out of the scope of this paper.

2.2.4 Obstacle detection model

The potential collisions with obstacles are here investigated. This analysis is performed separately in the bi-dimension and in three-dimension space for each single identified obstacle.

From a 2D perspective, the condition to be satisfied is that the generated trajectory shall not intercept the set of the obstacles polygons plus the minimum lateral separation. Considered that both the reference and CCDA trajectories are discretized into sets of straight infinitesimal linear segments; considered that a closed oriented segmented line delimits the obstacle polygon, the problem is to identify the points of intersection between two straight lines R and S, that is, to solve a system of linear equations:

$$\begin{aligned} (R)\ y_r &= m_r x + q_r \\ (S)\ y_s &= m_s x + q_s \end{aligned} \qquad (6)$$

where q is the term known and m is the angular coefficient of the straight line.

From 3D viewpoint, the necessary condition is that the altitude of trajectory shall be major or equal to height of obstacles polygons plus the minimum vertical separation defined as the total obstacles buffer:

$$z_{i\_trajectory} \geq z_{altitude\_obstacle} + z_{minimum\_vertical\_separation} \qquad (7)$$

If the trajectory does not satisfy the above conditions, a corrective maneuver is necessary in order to avoid the potential conflict. The mathematical problem is firstly to identify the points surrounding the obstacles (that are the points of intersection between the inclined plane containing the trajectory and the total obstacles buffer) and then, to identify the points avoiding the obstacle and thus the potential applicable paths to which those points belong. The path generated, which minimizes the following distance, represents the corrective maneuver to be applied:

$$d = \sum_{i=1}^{n-1} \sqrt[2]{\sum_{k=1}^{3} ({p_k}^{i+1} - {p_k}^{i})^2} \quad (8)$$

where:

d is the total path of the generic corrective trajectory;

n is the total number of points in the trajectory;

k identifies the (x, y, z) components for each P point of the trajectory;

i identifies which P point belonging the trajectory is considered;

P_k^i determines the k-th coordinate of the i-th point belonging the trajectory.

3 Experiments and Results

3.1 Assumptions

Many assumptions have been made with the intent of showing the first stage of system development. In particular, even if EUROCONTROL BADA already provides a simplified model of fuel consumption, the step forward of the proposed polynomial approach (which is currently being developed by the authors) aims demonstrating how fuel consumption varies during approach and landing, not only along the entire trajectory, but also along defined infinitesimal segments of it. The fuel consumption formula in Eq. (5) is implemented considering the geopotential pressure altitude equal to geodetic altitude, and the true airspeed equal to ground speed (that is ISA and no wind condition) and constant. The evaluation of aircraft speed in terms of M/CAS will be in-depth analysed in the on-going work. Even if the mass variability affects the drags, the thrust and the fuel consumption, the mass of aircraft is assumed here as a constant. Its variability strongly related to descent path is considered in the future work. Under approach and landing configurations, the drag coefficient is specified as function of the lift coefficient and different drag coefficients based on different flap setting in each flight phase are considered. However, the capability of aircraft to perform CDAs is here out of the scope, i.e. it is assumed that the aircraft is technically equipped to perform the CDA. The vertical path is assumed as a perfect vertical profile not considering the variability of speed and aircraft mass. Another consideration is that descent profiles for the considered aircraft should evaluate the integration with the other traffic (departure and arrival) in conditions of low as well as of high density of air traffic. Therefore, for all these assumptions, the fuel consumption is overestimated.

3.2 Experiment

A small-scale experiment is done for the aircraft arriving at an Italian Airport (LIRN ICAO code identification) for which the P-RNAV instrument flight procedures are published. This zone is particularly affected by aircraft noise due to the proximity of the runway/airport to the highly populated city of Naples. Fig. 3 shows a zoom of the airport, in which it is possible to have an idea about the vicinity of the anthropic buildings.

Fig. 3 Zoomed framework of the study case.

The trajectories generation algorithm, implemented in Matlab® environment [26], elaborates predefined waypoints for both conventional stepdown arrival and CDAs. Fig. 4 shows the obtained different CCDA technics compared to conventional step-down descent.

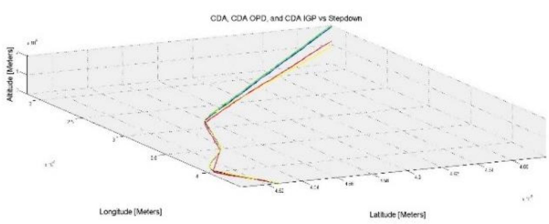

Fig. 4. Different CDAs technics (green, yellow and blue) compared to step-down trajectory (red).

In the Fig. 4, four generated trajectories are presented. The stepdown path (in red) flies over the predefined waypoints at altitudes fixed a priori. The tool achieves two CDAs with a constant path angle at 3.5 degrees (in green and in blue). The first path is generated without level flight segments; the second one is an optimized descent profile at different altitude and constant path angle. In this case, the trajectory follows a path at a fixed altitude up to intercept the glide path for the descent at constant path angle. In addition, the tool generates a CDA with an increased glide path up to 4 degrees (in yellow). For all CDAs, the TOD is calculated according to predefined angle. All CDAs report TODs higher than the conventional step-down descent. Furthermore, all CDAs are curved paths, resulting in a predictable and repeatable ground track during a turning. This implementation preserves the dispersion of tracks. Figure. 5 shows a zoomed particular of CDAs compared to conventional path, on order to emphasize the curvature property of CDAs.

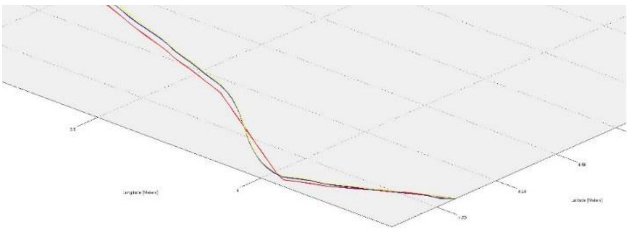

Fig. 5 Zoomed particular for the CDAs technics (green, yellow and blue) compared to conventional stepdown descent profile (red).

The trajectory is iteratively checked to identify other potential collisions. The algorithm provides a final trajectory avoiding all obstacles in the considered zone, optimizing the track distance within a tolerable range, as shown in the following figures.

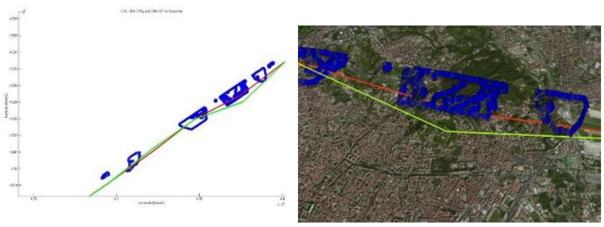

Fig. 6. Curved and continuous descent approach (green) compared to conventional stepdown descent approach (red) on the lateral profile from computational (left) and earth (right) perspectives.

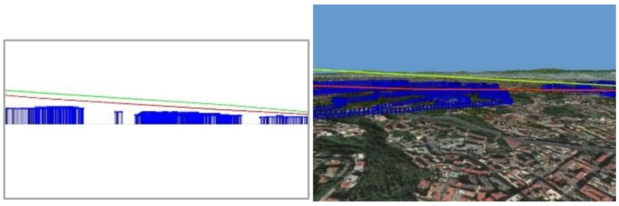

Fig. 7 Curved and continuous descent approach (green) compared to conventional stepdown descent approach (red) on the vertical profile from computational (left) and earth (right) perspectives.

3.3 Results and conclusions

All CDAs result more efficient with respect to conventional descent in terms of fuel consumption, leading up to 32-33% of fuel saving for the optimal CDA with constant angle fixed to 3.5 degrees.

Particularly, the analysis of the study case is done taking into account two main objectives: he fuel saving with respect to the reference trajectories, and how distance and altitude can affect the arrival flows structure.

The analysis on the study case is summarized in the following tables including the following data:

- the considered trajectory and glide path angle;
- the fuel saving with respect to the reference trajectory expressed in percentage [%].

Table 2.Fuel saving

Trajectory and glide path angle	**Fuel saving percentage [%]**
Stepdown, 3°.5	-
CDA, 3°.5	33.9
OPD, 3°.5	5.7
IGS, 3°.5 – 4°	32.5

Considering all cases as global simulations system, with respect to step-down approach, the theoretical CDAs with constant angle fixed to 3.5 degrees as for conventional trajectory, lead up to 33% of fuel saving. The optimized profile descent path provides a value similar to reference trajectory. The increased glide path provides values up to 32% of fuel saving. Even if this technique leads to very interesting results, in ATM practices, the implementation of CDA with great path angle (i.e. 4 degrees) are limited due to the parameters for intercepting the range and the angle of Glide Path of ILS systems (typically of 3.5 degrees). Furthermore, the table shows that the CDA procedure at fixed glide path angle (3.5 degrees) returns the best value of fuel saving. For this reason, this study is focused on the CDA at 3.5 degrees for the remaining analysis.

The simulated CDA trajectories result similar in average flight distance with respect to conventional descent. The following table shows the distance for respectively conventional step-down and CDA trajectories.

Table 3. Distance to runway for conventional step-down and CDA trajectories

Trajectory and glide path angle	**Distance to runway [NM]**
Stepdown, 3°.5	177.8
CDA, 3°.5	178.7

Furthermore, the CDA increases average altitude. A reference point (before FAF) was has been adopted to check the increased altitude in descent phase for continuous vertical profile relative to step-down approach. The CDA procedure at fixed glide path angle (3.5 degrees) returns the highest path. The table below shows the altitude in meters on to reference point for both cases.

Table 4. Altitude of the reference point for conventional and CDA trajectories

Trajectory and glide path angle	**Altitude at reference point before FAF [Meters]**
Stepdown, 3°.5	1020.61
CDA, 3°.5	1503.06

As assumed before, the true airspeed is equal to ground speed (that is ISA and no wind condition) and constant along equal flight distance interval in order to evaluate the fuel consumption. The evaluation of speed is out of scope for this paper. The speed profile generation will be examined in on-coming EATS research activity.

This paper has provided a methodology for generating different vertical profiles and evaluating the potential benefits for the curved and continuous descent approach. Particularly, considerations on the efficiency of a generic flight in TMA have been emphasized and studied in terms of fuel burn. The comparison of different flight profiles allowed identifying the optimal profile with respect to fuel consumption, indicating that the significant fuel savings can be achieved using CDA techniques with respect to conventional descent profile. Therefore, the results prove that the CDAs profiles are preferable to the step-down trajectories currently in use, because this innovative approach allows reducing the environmental impact in terms of fuel consumption. These trajectories with flight path angle at different altitude of TOD can provide support to the operational feasibility of CDA procedures for air traffic flow in TMA

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