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Energy and emission assessments of continuous descent approach

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Abstract

Purpose – Continuous descent approach (CDA) is a method, which allows the aircraft flying its individual optimal vertical profile down to runway threshold with engines operating at low-thrust power. The main objective of this paper is to provide less-fuel consumption, less noise and less emission with using CDA procedures instead of conventional procedures.

Design/methodology/approach – Conventional and CDA procedures were modelled in the Istanbul terminal area (TMA), which has five entry points. The real speed and the real altitude limitations were maintained on these entry points. System for Assessing Aviation's Global Emissions research results were also used to determine the emission savings.

Findings – With CDA procedures, more than 40 kg fuel and 2 min time savings per flight are obtained; furthermore, regarding CO_2 and H_2O, significant emission savings are also noted.

Originality/value – Some of the benefits of CDA procedures are reported for Istanbul TMA by using true flight data.

Keywords Aircraft, Emission, Energy consumption, Flight operations

Paper type Research paper

I. Introduction

An efficient energy management has been focused as the main objective for numerous researches dealt with systems in which fuels are proceeded to various kind of products. Usually, the idea is having more products for the same amount of fuels without considering the other matters. Beside, the scope of this study also covers mostly the aforementioned objective there are some other factors that should be taken into account, which are inherent to the aviation industry itself. Among them, emission and noise are the two of the most important ones, which have effects on environment at different forms. We, in this study, excluding the noise issue performed an analysis about continuous descent approach (CDA) in the perspectives of energy and emission.

CDA first emerged to abate the noise problem in the vicinity of the airports, while then the fuel consumption benefits has led to be focused more. One of the good definitions of CDA can be given as:

> CDA involves the management of the aircraft configuration (flaps, speed brakes, landing gear and throttles) by the pilot or autopilot to use the minimum required thrust on a continuous glide angle into an airport (The Sacramento County Airport System, 2006).

As seen from the definition, the main goal is conducting the descent phase with as possible as minimum thrust. Hence, let the airliner takes the descent distance helping partly with its available potential energy would also lead to increased service life of turbine and engine material due to the reduced thermal and kinetic loads.

Mainly participation of Boeing and limited Eurocontrol involvement some studies related to the advanced approaches including fuel efficient, less noise and conflict free procedures were implemented. Wubben and Busink (2000) investigated the environmental benefits of CDAs at Schiphol Airport compared with conventional approach procedures. Effects of the CDA procedures that are used for only one-runway and night hours were observed for B747 and B737 equipped with flight management systems (FMS). The results showed that the fuel consumption is approximately 25-40 percent lower during the last 45 km of the flight for each aircraft, which correspond to fuel savings of 400 and 55 kg, respectively. However, the savings obtained in that study seem to be overestimated compared with the literature. The noise footprints were also reported to reduce with using CDA procedures.

Tong *et al.* (2003) studied on noise reduction via introducing the CDA procedures from 6,000 ft or higher instead of level flight between 2,000 and 4,000 ft. They performed simulation sessions and compare the results with the actual flight data obtained from several B767 s. Although the 3° flight path angle (FPA) is found to be the most suitable approach procedure in term of noise reduction, in order to secure the sufficient deceleration that they had to agree on 2° FPA.

Clarke *et al.* (2004) stated that it could be possible to gain significant reduction of noise as 3.9 and 6.5 dBA that is

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resulted by simulation and demonstrated flights of B757 and B767. They also reported that 180-225 kg of fuel savings could be obtained by switching from the conventional approach procedures to CDA.

Wilson and Hafner (2005) conducted three scenario simulations for the landings based at the airport of Atlanta and measured the impacts of these scenarios on time, fuel consumption and distance. The best saving conclusions they found are 45 h, \$80,000 and ~9,000 nm/day. It is also stated that these findings correspond to reduction of flight time and distance as 1 min and 3 nm/aircraft, respectively, and saving of fuel as \$29 million annual.

Hoffman *et al.* (2007) performed a study about CDA and demonstrated the effectiveness of the procedure in terms of human factors considering the airliner pilots. They used a full simulator of A330 and all the participants were agreed on the feasibility of CDA at airborne spacing from top of descent (TOD) until 2,000 ft altitude.

Another paper published by Tong *et al.* (2007) reported the descent profile options for CDA for the aircraft of B737 and B777. Taking into consideration of 35,000 ft altitude and 290 kts CAS for the TOD, the end point of the first segment of continuous descent at constant FPA was defined as 11,000 ft altitude and 240 kts CAS at no wind condition. The study stressed that B737 could pass more time at high altitude than B777 as starting to descent ~20 nm later than B777 to intercept at 11,000 ft with that aircraft. Regarding to the fuel and time parameters, it was indicated that 2.2° and 2° FPAs are the most suitable options for the aircraft types of B737 and B777, respectively.

Ledesma *et al.* (2007) evaluated the idle descent for the CDA modes of reduced noise, reduced time, reduced fuels and constant aerodynamic FPA. The simulation program they run consists obtaining of total flight time of each modes at no wind condition and then comparing the results with an assumption of 15 kts constant wind. They also run a sensitivity analysis for the uncertainty of the wind element and found the effects of wind to the total flight time.

According to the demonstration flights conducted by Sprong *et al.* (2008) significant reductions were found in terms of fuel consumption, time flown and time in level flight for the traffic based at airports of Atlanta and Miami.

Penhallegon and Bone (2008) investigated an aircraft-oriented concept named as Flight Deck Merging and Spacing. The main objective of this concept is stated as to provide consistent and low-variance spacing between aircraft pairs, while to reduce noise, fuel consumption and controller workload. With the simulation sessions the concept found acceptable by airliner pilots who work with the simulation program.

The studies given above focused mainly on the airports in the USA by experimentally or by using simulation equipments. However, despite important findings on noise, the effects of CDA on emissions were not mentioned sufficiently and also it is difficult to obtain a realistic fuel gradient of CDA according to the conventional approach procedures at these studies. Therefore, in this study we focused on the potential abatement of energy consumption and emission while implementing the CDA procedures.

II. Superiorities and weakness of CDA

CDA is intended to be used mainly for noise and fuel reduction. Although the noise abatement studies are more essential for the takeoff phase, which could also evoke much more fuel consumption since it is not allowed to takeoff with takeoff power, low-level flights in descent phase lead community discomfort at the vicinity of the airport. Comparing with the low-level flight in conventional approaches, continuous descent leads to less noise problem.

Discussed at following paragraphs, due to the level flights at higher altitudes, less fuel consumption could be achieved. This can be provided from the opportunity of flying faster true air speed in particular under the restriction of the certain indicated air speed in terminal area (TMAs) and the lower drag force for the same distance. Flying faster also reduce the time required to descent.

However, the air traffic volume does not allow CDA implementation easily because of increasing the conflict potential which is already an important trouble for the heavy loaded airport. Therefore, the main obstacle of traffic makes the integration of CDA with current air traffic procedures necessary. Furthermore, the vertical profile must be carefully arranged for not arriving to the way points too early.

The CDA procedures are used during night time in some airports such as London and Amsterdam (Oseguera-Lohr *et al.*, 2007). Nevertheless, in order to be able to use widespread, CDA should be also integrated with the FMS of airliner (The Sacramento County Airport System, 2006).

III. Methodology

This study was implemented for different approach routes to the Istanbul TMA. Locating at 40°58′56.46″N and 28°48′26.55″E, International Istanbul Ataturk Airport has been ranked as 16th according to the 2006 total departure among the largest 25 European airports (Eurocontrol Trends in Air Traffic, 2007). It is equipped with three configuration of runways, so-called as 06/24, 18L/36R, and 18R/36L. Most used configuration of runway is a06/d36, which the statistics in 2000 states that this runway (arrivals on RWY 06 and departures on RWY 36) was used 60 percent of time, while the remaining 40 percent being on configuration a24/d18 (Eurocontrol Assistance to Turkish State Airports Authority, 2002). For this reason, the runway 06 was chosen for arrival airliners. Furthermore, it has five entry points through the TMA. Entry point names and their locations are given at Table I. The speed maxima for entry points and for the final approach point (FAP) are 250 and 210 kts, respectively. The required altitude at the FAP points ended for the paths of all the entry points are 2,600 ft and the FPA is assumed as 3° throughout the study since it is an optimum descent angle.

In conventional approaches the profile between these entry points and the FAP depends on the pilots as long as the altitude and the speed restrictions do not be exceeded. For the numerous approach cases, after the entry points the pilots descend until the minimum altitude limits and proceed low-level flights until the FAP. However, this approach leads more fuel consumption and takes more time according to the CDA. Furthermore, some entry points would let this kind of approach with two steps as descent to 3,000 ft and level flight at 3,000 ft, while for the others four steps stair approach is required as two descents and two low-level flights.

Table I Istanbul TMA entry points

	Biga	Tekirdag	Unsav	Beykoz	Yalova
ID	BIG	EKI	UNSAV	BKZ	YAA
Location	40°17′03″N 027°21′55″E	40°57′03″N 027°25′34″E	41°28′42″N 028°47′23″E	41°07′37″N 029°08′34″E	40°28′30″ 029°12′27″E
Distance to airport (nm)	85	68	72	75	67
Altitude restriction (ft)	9,000	8,000	8,000	12,000	11,000

According to the Table I, level flights altitudes between 8,000 and 12,000 ft instead of 3,000 ft (as being in the conventional procedures) are proposed. The FPA from the entry points are all-same for either approach procedures for an individual flight profile except the two of them which have stepped descent profile. Moreover, the level flight distances are also same for either approach procedures. The single distinction is the altitude of the level flight took place.

This study is modelled for one single flight per entry point. For this context, B757 was selected in order to demonstrate the results of CDA procedures in terms of fuel consumption, time and emission. It has two PW2037 medium by-pass turbofan engines, which has 166.4 kN thrust each. Taking into consideration that airliners can use various type of engines, some flight data attributed for the case flights of the airliner are listed at Table II.

Table II involves four phases of flight as the names of takeoff, climb out, cruise and descent. The main reason of the weight reduction is the fuel consumption which equals 9.9 t and this does not include the APU fuel which could be additional several hundred kilograms (*ICAO Airport Air Quality Guidance Manual*, 2007). The fuel allocation share is calculated as 4, 21.2, 70.7 and 4 percent as the aforementioned order of the phases of flight. The inequality of the sum of the percentages as 0.1 percent is due to the round-off error. Since it is a required consumption, excepting the takeoff phase, both of climb out and cruise phases are optimized for the minimum fuel consumption as considering the optimum altitude. However, despite relatively low share among the entire fuel consumption, the descent phase has significant fuel saving potential in terms of operation and traffic procedure.

The fuel flow records represent ranges instead of absolute values. The reasons could be listed as the changes in altitude according to climb or descent and weight reduction result from the fuel consumption on board, particularly in cruise. These parametric changes have impacts over the fuel consumption since the thrust demand should also be changed to offset the required lift continuously and safely. In climb out phases, increasing the altitude has positive effect over the engine performance, which leads lower fuel consumption for the same amount of thrust or the rate of climb. Moreover, almost 7,000 kg fuel usage reduces the required lift of the airliner and the fuel consumption.

Regarding to the engine pressure ratio (EPR) indicator, which is used for the determining the thrust, the maximum value occurred in the end of the climb out phase. Since the EPR measures the ratio of the compressor inlet pressure and the turbine outlet pressure, the ambient pressure is revealed as an important factor. Therefore, high EPR at the end of the climb out phase could be explained by having relatively high-engine power and low-ambient pressure. Further focused on EPR, provides an objective of the descent as minimum EPR as sufficient to maintain the speed and glide path as possible as. This minimum EPR leads also minimum fuel consumption. As seen at Table II, lowering the altitudes increase the EPR, since 0.741 and 0.917 denote the altitudes of 37,000 and 3,000 ft, respectively. This objective is also one of the supports to the general rule of "level flight at lower altitudes leads more fuel and time consumption" (Tong *et al.*, 2007).

The general altitude limits for splitting the phases referred at Table II can be given as:

- *takeoff* – up to 3,000 ft;
- *climb out* – between the 3,000 ft and the cruise altitude; and
- *descent* – below the 3,000 ft.

In order to distinguish the gains between conventional and CDA procedures, one needs to obtain the airliner performance for level flight at different altitudes, in particularly lower than FL120, since the descent flight path to 3,000 ft from the entry points altitudes are same. Hence, Base of Aircraft Data (BADA) performance table of B757 is used for the level flight performance data (Eurocontrol, 2004). Moreover, since these performance parameters (i.e. both the real flight data logs and the BADA) are recorded for calm wind conditions, the wind impacts are not taken into consideration throughout the study.

Up to now, we discussed the traffic and the operation perspectives of the methodology. After providing the area, entry points, airliner, and the other flight data, it is required to determine the emission values produced from both

Table II Flight data records of B757

	Takeoff	Climb out	Cruise	Descent
Weight (tonnes)	100	99.6	97.5	90.5
Fuel flow (kg/h)	9,683-9,388	9,388-4,448	3,217-3,007	741-812
EPR[a]	1.255	1.261-1.503	1.243-1.197	0.741-0.917
Ground speed (kts)	254	261-447	447	447-259
Altitude (ft)	0-3,000	3,000-37,000	37,000	37,000-3,000

Note: [a]Engine Pressure Ratio (EPR) conventional and CDA procedures. However, there is no any absolute model about determining the actual amount of emission that completely agreed since the fuel consumption depends upon numerous uncertain parameters including weight, weather, operation, traffic, etc. besides the other certain parameters such as cruise altitude and range. Therefore, for this study the model is selected in such a way that could be able to cover wide range of engine and airliner types.

In this context, with a project implemented by FAA and the other partners, System for Assessing Aviation's Global Emissions (SAGE), wide range data dealt with emission impacts of aviation were gathered together for the years from 2000 to 2004. These data are also classified due to the airliner, engine, country, region and, etc. within that project. Besides, the SAGE, one of the other emission databases, ICAO engine database was also used where SAGE values needed to be checked at some part of the study.

IV. Results and discussion

The flight profiles begin from the five different entry points of which their distance to FAP and altitude restrictions are given at Table I. Also the 3D grids of the TMA and the locations of these points are shown in Figure 1. The entry points particularly established where the hills cause obstacles to the safe flight inside the TMA and approach patterns.

The effects can be grouped in two main titles since the main estimated benefits are fuel and emission. There is also another benefit in which revealed as time, which was attributed into the energy part.

A. Energy management aspect

Before the study, the expected results were significant fuel and duration savings, which lead to lower emissions, since the objective was flying as higher as possible. Regarding to the results, it is seen that the expectations were considerably reached.

In Figure 2, the total fuel savings for the various level flights are presented. Considering the five entry points, 7-9 percent of fuel savings are obtained. The largest saving is observed at the entry point of BIG as 44 kg, since this entry point has the longest level flight distance as 55 nm. However, the lowest fuel saving is obtained at YAA as 27 kg for a level flight distance of 30.4 nm. From the figure, despite the fact that the level flight distance is directly proportional with the fuel burned, the other important factor is the percentage of how many miles are flown at relatively higher altitudes. For this reason, considering the EKI (35 nm) and YAA (30.4 nm), one can see that despite difference of almost 5 nm and also the level flights at the same altitudes (6,000 and 3,000 ft), the fuel savings (or fuel burned) are quite close to each other. The reason could be explained in such a way that in EKI the level flight distance at 6,000 ft is 10 nm, while in YAA it is only 5.4 nm. Therefore, in EKI, since the distance difference of 4.6 nm (35-30.4) is flown at high altitudes, the fuel burned is maintained at modest level according to the YAA.

In Figure 3, effects of CDA on the flight durations are shown. The savings are risen to the degree of minutes. The reductions of duration are the range of 17.8 and 19.3 percent by CDA, which correspond up to 2.8 min. Considering the investigated conditions (descent from the altitude of 37,000 requires 25.5 min for a distance of 125.8 nm), it is revealed that the amount of savings which could be around 10 percent of the total descent duration is significantly high.

Furthermore, as can be noticed, the fuel savings are not only acquired from the reduction of the descent time, but also from the elevating the level flight altitude, which addressed the low-power usage. This effect is shown at Figure 4.

B. Emission management aspect

The amount of emission is directly proportional with the fuel consumption, while the altitude that these emissions are produced has further impacts (i.e. greenhouse effects), which were kept out of the scope of this study. However, taking the fuel savings amount into account, these impacts due to the altitude could be negligible.

Emission data of some engines, which constructed from the SAGE databank are given at Table III. According to the SAGE, PW2037 type of engine has powered average of 352,875 flights annually made this engine second most used

Figure 1 The 3D illustration of the Istanbul TMA with the entry points added

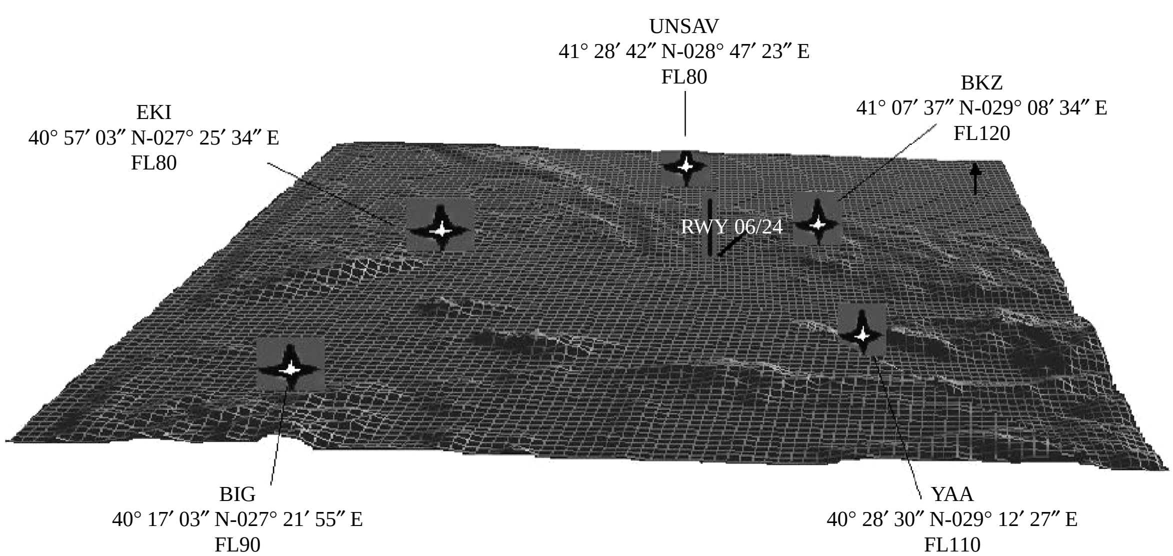


Figure 2 Difference of fuel burned between conventional procedures and CDA beginning from the entry points

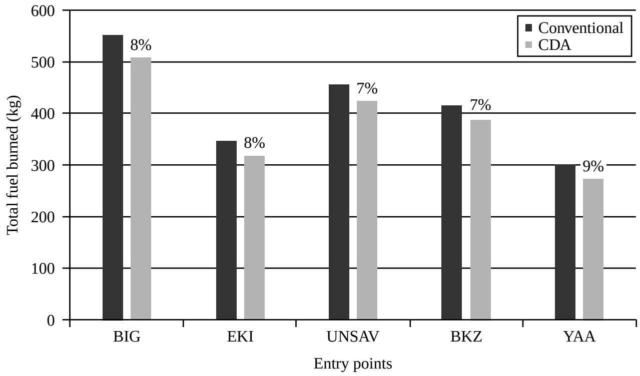


Figure 3 Difference of flight duration between conventional procedures and CDA beginning from the entry points

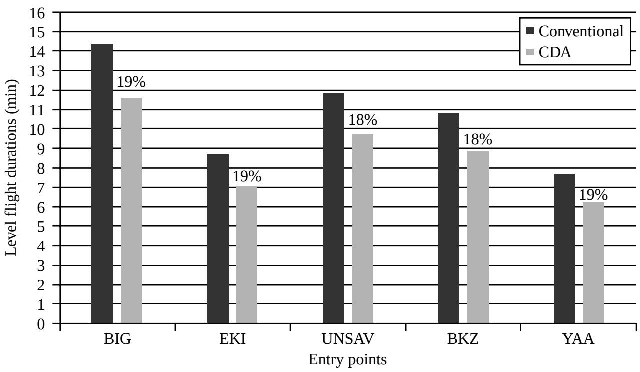
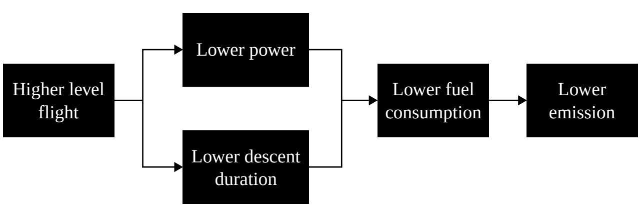


Figure 4 Effect of flying at higher altitudes at all normal conditions



engine at B757 type of airliner. In this regards, the widespread usage of this engine type would give sufficiently tangible and actual findings.

Considering the ICAO emission databank, it is seen that there are emission measurements for the four phases of flight called as takeoff, climb out, approach and idle. Meanwhile, the weak point of this databank is the lack of cruise emission measurements. On the other hand, in this study, one can be noticed that the cruise phase is out of the scope since the study dealt only with the part of the descent phase. However, despite focusing descent, we have some distance flown by level flight. For that reason, in comparing the impacts of CDA and conventional procedures, the cruise emission measurements are also required.

According to the Table III, the average emission indexes of NO_x, CO, and HC can be calculated as 15.9, 1.7 and 0.2 g/kg of fuel, respectively. The corresponded values can also be addressed from the AERO2K as 13.2 g/kg for NO_x, 3.25 g/kg for CO and 0.4 g/kg for HC, Considering the small values of NO_x, CO and HC, these species are kept out of the calculation since the advantage of the CDA procedure would be quite smaller compare to the other emissions. For the other emissions as CO_2 and H_2O, 3.155 kg/kg fuel and 1.237 kg/kg fuel constants are considered (SAGE, 2009; Hadaller and Momenthy, 1989). Comparing emission indexes obtained from the Table III with the ICAO emission databank for the same type of engine, it is seen that the values from the table correspond to the values between the climb out and approach as expected.

The effects of CDA on the emissions are shown in Figure 5. The highest reduction of CO_2 as 140 kg is obtained for the phases of flight beginning from the BIG. The minimum CO_2 abatement is found for the entry point of YAA as 86 kg. The values for the H_2O for the same entry points are 55 and 34 kg, respectively.

V. Conclusions

In this study, some of the benefits of CDA procedures are reported for Istanbul TMA by using true flight data belong to B757. The main objective is to maintain level flight of the airliner for the phase of approach as high as possible. This objective leads to positive direct impacts such as less fuel consumption, less duration and less emission beside the positive indirect impacts like operating the engine at higher power and exposuring the airliner to less drag force. At first glance, for only one flight the findings seemed not to be large enough. However, considering only 10 percent of the annual average flight number of the only one type of engine which corresponds to almost 35,000 flights, the fuel savings could be calculated as 1 M kg/year due to the minimum result of this study as 27.3 kg for the YAA case. Furthermore, they are not taken into consideration in this study, savings for the other emission species such as NO_x, CO and HC would have significant values as 24,500 kg for NO_x, 2,625 kg for CO and 280 kg for HC according to the example given above.

Table III Average values per flight for five years belonging to various types of engines, which are used at B757

Engine type	Distance (nm)	Fuel burned (kg)	NO_x (kg)	CO (kg)	HC (kg)	CO_2 (kg)	H_2O (kg)	SO_x (kg)	Averaged flight counts (annual)
RB211-535E4	919	7,757	81	21.06	0.29	24,421	9,585	6.20	361,118
PW2037	951	8,098	129	14.07	1.43	25,563	10,022	6.48	352,875
PW2040	1,142	9,556	141	19.50	1.74	30,142	11,825	7.64	178,331
RB211-535E4-B	1,319	11,091	117	30.26	0.61	35,020	13,752	8.90	163,378
RB211-535C	657	5,697	68	8.87	2.89	17,980	7,048	4.56	37,785

Source: Constructed from SAGE (2009) database

Aircraft Engineering and Aerospace Technology: An International Journal
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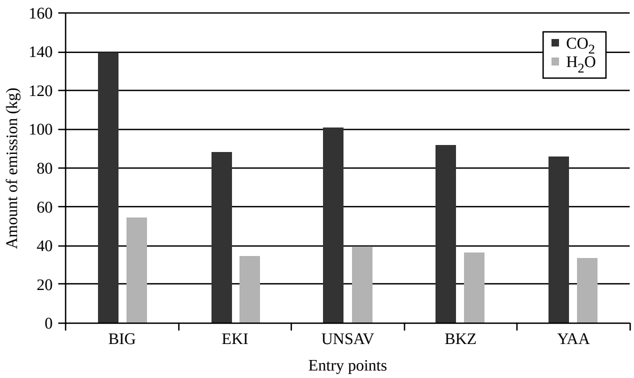
Figure 5 The emission savings of CDA



The fuel savings for a single airliner is obtained as up to 44.3 kg for switching from the conventional to CDA procedures. This saving is occurred mainly by flying higher altitude, which leads flying against to less drag force. Time savings is also seen with a maximum value of 2.8 min since the airliner would fly faster at higher altitudes. The real data for this study were taken from the real flight data record of a B757 airliner and some parameters dealt with the level flight like true air speed and fuel flow in kg min^{-1} at various level flight altitudes were also provided from the BADA tables. Moreover, SAGE and ICAO databases were used for the value of emission indices.

In comparing the other studies, the results of fuel savings found seem relatively low. For instance, 400 and 55 kg of fuel savings have found for a 45 km (24 nm) level flight distance for the airliners of B747 and B737, respectively, (Wubben and Busink, 2000). According to this study, one would expect higher result than 55 kg of fuel savings due to longer level flight distance and having larger engines. Moreover, in the same study, 25-40 percent savings have reported for the same level flight distance, while in the present study this saving corresponds only 7-9 percent for the level flight distance. It is possible to compare the results with another study such as Clarke *et al.* (2004), which points out as 180-225 kg savings for the airliners of B757 and B767, respectively. In conclusion, stated before, fuel consumption is a very complex function of many factors impacted at the same time. Therefore, comparison of results tested at different conditions could not provide consistent results between each other. However, to reach consistency around numerous conditions, the results are classified in such a way that these factors are as possible as similar.

Nevertheless, the traffic density is the main limitation to obtain these savings. Although, there are some ongoing researches to use CDA procedures at heavy traffic airports without any negative impact over both the controller and the pilots currently they do not seem technically viable. The main goal of these studies is to solve the problem with integrating highly computerized FMS and to use exclusive software to which intends only optimizing the traffic problems. In this context, a good CDA procedure must satisfy three groups, which are controllers, pilots and the airline itself. Therefore, the future researches should involve multidisciplinary studies to extract these considerable savings from the approach procedures.

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