Preliminary Investigation of Metrics Governing Continuous Descent Approach

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Abstract: Continuous Descent Approach (CDA) is a flight procedure for aircraft landing. CDA posses both environmental sustainability and operational benefits as it reduces carbon footprints, and noise levels around airports as well as fuel consumption. This paper presents a preliminary investigation of the feasibility, appropriateness, and adaptability of CDA as it relates to airports' particulars.

Keywords: Continuous Descent Approach, Airports, Sustainability

Introduction

As a global industry, air transportation represents a critical element of countries' economic sector and people's lives. The demand for air transportation is projected to grow in the upcoming years affecting an already-at-capacity operating national airspace system (NAS). Airports is expected to experience unprecedented levels of congestion, longer and more frequent delays, and eventually increasing negative impacts on environment in terms of greenhouse emissions and noise levels around airports. Thus, the Federal Aviation Administration (FAA) developed and initiated a NAS-wide transformation program called the Next Generation Air Transportation System (NextGen). With NextGen, FAA aims at modernizing NAS in terms of air traffic management (ATM) technologies and procedures, airport infrastructure, and operations to enhance safety, security, and environmental sustainability aspects. Among these modernization terms are; Trajectory-based Operations (TBO) and Continuous Descent Approach (CDA), also referred to as Optimized Profile Descent (OPD). In fact, the Joint Planning and Development Office (JPDO); the government office oversees NextGen implementation and progress, had developed the Environmental Management Framework (EMF), which is fully integrated into all NextGen operations, specifically to address negative impact of aviation operation on environmental resources (Joint Planning and Devlopment Office 2011).

This preliminary work is a treatise to investigate the effect of the various aspects and particulars as well as their interaction that determine the adoptability of CDA in an airport. Initially, this paper focuses on modeling the traffic volume and how it affects the adoption of CDA.

This paper is organized as follows. After this introduction, we present a brief review of the pertinent literature. This is followed by describing CDA procedures as the aircraft approaches the landing facility. This is succeeded by analytical models that estimate the governing parameters of CDA. Finally, we present concluding remarks of this early work.

Literature Review

Since it is being considered by the FAA in the NextGen, countless research efforts dedicated to study and quantify the operational, economic, and environmental benefits of CDA and its potential contribution to environmental sustainability. In their field test of CDA procedures at Louisville International Airport, (Clarke 2004) concluded that CDA provides consistent noise reduction of up to 3 A-weighted Decibels (dBA). In a simulation study conducted on Atlanta's Hartsfield-Jackson International Airport (ATL), (Wilson and Hafner 2005) outlined in that the emissions footprints and noise levels were considerably reduced at ATL when CDA procedures were applied. A work by (Clarke 2013) designed and implemented OPD arrival procedures at Los Angeles International Airport and concluded that, among other benefits, OPD provides environmental benefits by reducing engine emissions and community noise exposure. Hence, CDA has been recognized as an operational procedure for sustainability in terms of environmental performance through the reduction of noise at airports and its surrounding populated areas (Janić 2007).

Continuous Descent Approach Service Facility (CDA-SF)

As the aircraft at the final en route phase, pilot may prepare to conduct CDA procedure. The pilot may then initiate CDA procedure from cruise altitude. Since the location of the Top of

Descent (TOD) is uncertain (Johnson 2011) and is subject to real-time computations at the cockpit, the CDA service facility boundary is shifted a little upstream the flight path. Once the aircraft crosses the CDA Service Facility boundary, it may start CDA at any point on the flight path. Once the aircraft starts the CDA procedure, the service time starts. By CDA definition, the aircraft will descent continuously, without intervention from air traffic controllers (ATC), with idle-engine settings, until it reaches the final approach fix (FAF). The altitude of the FAF varies from airport to another. However, when the aircraft reaches the FAF, it will intercept the instrument landing system (ILS) beacon, from which the aircraft will continue the final approach segment to landing. After landing, the aircraft would occupy the runway until it reaches an exit to clear the runway for another aircraft wants to use the runway. So, the service time is giving by:

$$\text{Service Time} = \text{CDA time} + \text{ROT} \qquad (1)$$

Considering this process, CDA can be considered as a service within a service facility. Figure 1 illustrates the vertical profile of CDA and defines the Continuous Descent Approach Service Facility (CDA-SF).

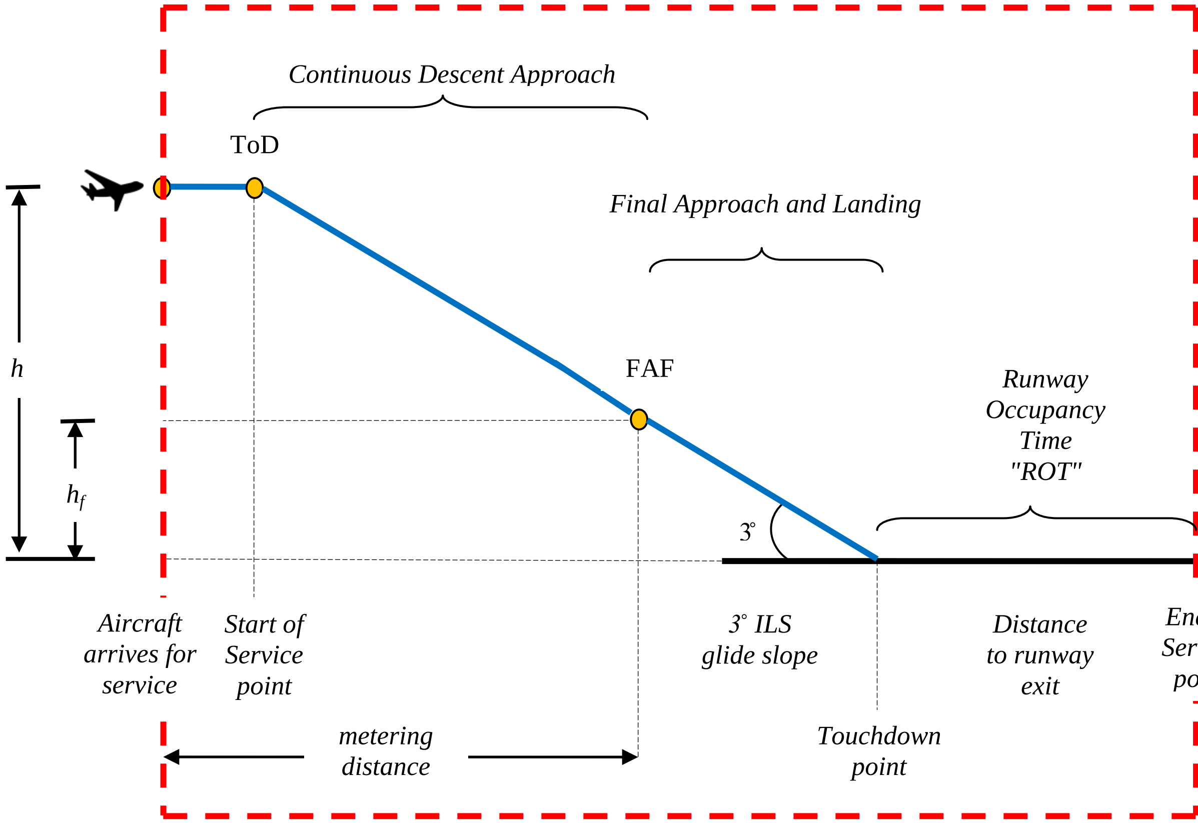

Figure 1 - Vertical profile of Continuous Descent Approach (CDA) and service facility system

Continuous Descent Approach Computational Model

As mentioned before, CDA, is a flight procedure in which the aircraft continuously descends with idle-thrust setting from the final cruise altitude to the final approach fix (FAF) altitude at which the instrument landing system (ILS) intercepts the 3-degrees fixed glide slope. In this section, a computational model for CDA procedure is presented. The computational model developed in this work is based on information and performance data of a fleet mix comprise of twenty (20) aircraft from various wake vortex class. These operational data has been obtained from the Operational Performance Files (OPF) of each aircraft considered in this study from the EURONCONTROL's Base of Aircraft Data (BADA), version 3.11(Nuic 2010).

The following are the major components of our model; Aircraft, Drag, Thrust, and Interval Computation Models.

Aircraft Model

For straight-and-level flight at cruise altitude, the aircraft speed is giving by:

$$V_{TAS} = a_o \cdot M_{cruise} \cdot \sqrt{\frac{T}{T_o}} \tag{2}$$

where V_{TAS} is aircraft true airspeed (TAS) in nautical miles per hour (knot), a_o is the speed of sound at sea level in knot, M_{cruise} is the Mach at cruise altitude, T and T_o are temperature at cruise altitude and at sea level, respectively.

The lift coefficient, C_L, can be calculated from the classical lift force formula as the product of the dynamic pressure, as follows:

$$L = C_L \frac{1}{2} \rho V^2 S \tag{3}$$

where ρ is the density of air in kilograms per meter cubic , V is the aircraft speed in meter per second, and S is the aircraft's wing area in meter square.

In cruise flight, the lift force in Newton, L, may assumed to be equal to the aircraft weight in kilograms, m , then:

$$C_L = \frac{2mg}{\rho V^2 S} \tag{4}$$

where g is the acceleration due to Earth gravity in meter per second square. Assuming no-wind scenario, and the flight path angle in degrees is γ, then the relationship between ground speed and true airspeed is giving by:

$$V_{\text{ground}} = V_{\text{TAS}} \cdot \cos\gamma \tag{5}$$

Drag Model

Drag is the aerodynamic force acting on aircraft body in terms of air resistance to aircraft motion through air. Similarly to the lift force, the aerodynamic drag is the product of the dynamic pressure and drag coefficient, as follows:

$$D = C_D \frac{1}{2} \rho V^2 S \tag{6}$$

The drag coefficient is giving by the sum of zero-lift, C_{Do}, and induced drag, C_{Di}, coefficients, where the later is a quadratic function of lift coefficient, as follows:

$$C_D = C_{Do} + C_{Di} C_L^2 \tag{7}$$

Typically, C_{Do} and C_{Di} are functions of aerodynamic configuration of aircraft flight phase. Generally, drag coefficients are functions of Mach number and Reynolds number ($Re = \rho VL/\mu$ where μ is the absolute viscosity coefficient of air). For each aerodynamic configuration, BADA models these coefficients as constants to provide computations for altitude and speed profile thresholds at pre-determined flight phases (i. e., takeoff, initial climb, clean, approach and landing).

Thrust Model

BADA uses a general formula to calculate the maximum climb and take-off thrust at standard atmosphere for three different types of engines; namely, jet, turboprop, and piston engines. For jet engines, the general equation is given as:

$$Thr_{\text{max,climb}} = C_{Tc,1} \times \left(1 - \frac{H_p}{C_{Tc,2}} + C_{Tc,3} \times H_p^2 \right) \tag{8}$$

The descent thrust is then calculated from the maximum climb thrust using adjustment coefficients for cruise, approach and landing configurations (Nuic 2010), respectively, as follows:

$$Thr_{\mathrm{des,low}} = C_{Tdes,\mathrm{low}} \times Thr_{\mathrm{max,climb}} \tag{9}$$

$$Thr_{\mathrm{des,app}} = C_{Tdes,\mathrm{app}} \times Thr_{\mathrm{max,climb}} \tag{10}$$

$$Thr_{\mathrm{des,ld}} = C_{Tdes,\mathrm{ld}} \times Thr_{\mathrm{max,climb}} \tag{11}$$

where $C_{Tc,1}$, $C_{Tc,2}$, $C_{Tc,3}$, $C_{des,low}$, $C_{des,app}$, and $C_{des,ld}$ are aircraft-specific coefficients.

The rate, in feet per minute, at which an aircraft's altitude changes with respect to time when descending and approaching the runway for landing is the Rate of Descent (ROD). ROD is giving by:

$$ROD = \frac{dh}{dt} = \frac{(Thr_{des} - D)V_{TAS}}{mg} - \frac{V}{g}\frac{dV}{dt} \tag{12}$$

Finally, the equations of the CDA computational model have been coded in MATLAB® programming environment.

Interval Time Computation

In this preliminary model, a single runway, with arrivals operations only, and Instrument Flight Rules (IFR) is considered. The runway capacity model (Kolos-Lakatos 2013) is used to compute the average separation time, in seconds, between successive aircraft pair.

The aircraft fleet mix considered in this study is illustrated in Table 1. It shows the percentage of each aircraft weight class in the fleet mix, the corresponding approach speed assumed in the study, and the average Runway Occupancy Time (ROT) that a single aircraft from the corresponding weight class might take until it clear the runway.

Table 1 - Aircraft fleet mix

Fleet Mix			
Weight Class	**Mix (%)**	**Approach Speed (Knots)**	**ROT (seconds)**
Heavy	45	140	60
Medium	50	128	55
Light	5	110	50

Time and Distance Estimation

In this section, we show two of the major building blocks of the CDA Computational Model that are essential to estimate the traffic capacity of an airport. They are the time and the distance of each type of aircraft to apply CDA procedure. Based on the previous models, Figure 1 illustrates the time each aircraft in the fleet mix takes to perform the CDA from a cruise altitude of 35,000 ft, plus an estimated average value of 60 seconds for the Runway Occupancy Time (ROT). The values of the service times in Figure 1 shows that a heavy aircraft, such as the Boeing 787-800, takes about 604 seconds (~10 minutes) to be serviced in the CDA-SF. Medium and Light aircraft, such as the Airbus A320 and the Cessna C525, takes about 719.5 seconds (~12 minutes) and 772.6 seconds (~12 minutes) to be serviced in the CDA-SF. From aerodynamics perspective, the service times values in Figure 1 seems valid, since heavy aircraft tends to be more efficient than light aircraft, in terms of aerodynamic performance efficiency (i. e., higher lift over drag ratio, or *(L/D)*).

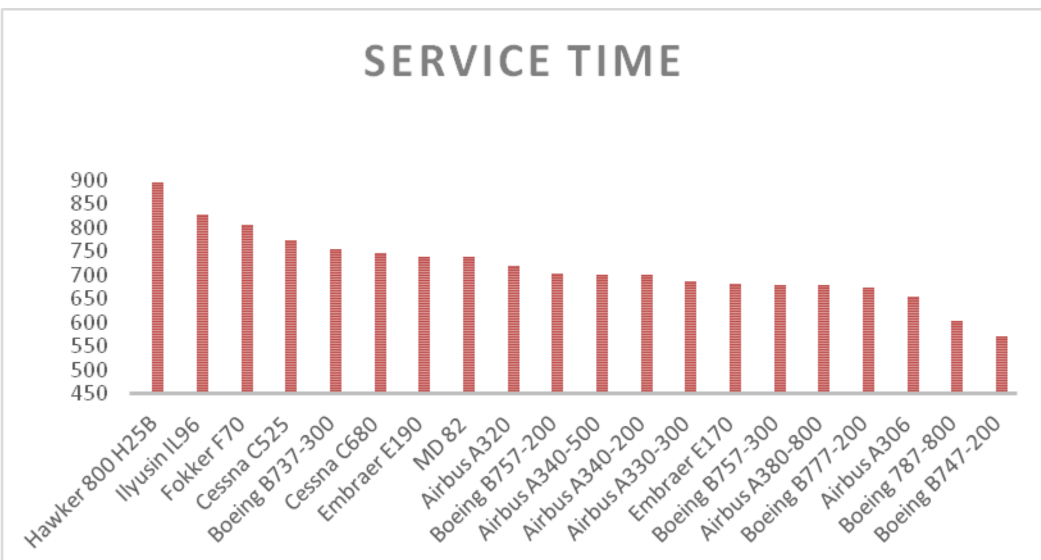

Figure 2 - Service time, in seconds, for the fleet mix of aircraft considered in the study

Figure 2 below illustrates the longitudinal distance, in nautical miles, travelled by each aircraft in the fleet mix performing CDA procedure in the CDA-SF. The results shows that for a heavy aircraft, such as the Airbus A380-800, performing CDA in the CDA-SF, it covers about 112 nautical miles. For a medium aircraft, however, such as the Boeing B737-300, it covers about 110 nautical miles. Lastly, a light aircraft, the Cessna C525, which is the only light aircraft in the fleet mix, the result shows that it covers about 104 nautical miles.

Figure 3 - Distance, in nautical miles, for each aircraft in the fleet mix considered in the study

Conclusion

In this paper, we presented preliminary work for the adoption of the concept of Continuous Descent Approach Service Facility (CDA-SF) in an airport to improve environmental sustainability. The initial findings show that heavier aircrafts require less time to perform CDA procedure, however, the distance required to embark on CDA seems to be less sensitive to the aircraft type. In the future, it is planned to obtain specific operational data for various airports vis-à-vis their location, proximity to other airports, traffic loads, and other related data, in order to develop a comprehensive model that encapsulates the governing parameters of CDA and their interaction as they relate to its adoptability based on individual airport specifics.

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