DEVELOPMENT OF AN ADVANCED CONTINUOUS DESCENT CONCEPT BASED ON A 737 SIMULATOR

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Summary

It is well known that noise restrictions impact airport approach and departure procedures at many airports worldwide. The research described here presents an Advanced Continuous Descent Approach (CDA) concept using current and future capabilities of Flight Management Systems (FMS) to allow Idle thrust (low noise) descent from about 8000 ft to 2000 ft yielding significant reductions in aircraft noise on the local airport community. The advances in Flight Management technology described here would allow tailoring of the final descent path to include aircraft type, predicted winds, initial altitude, vehicle weight, time of arrival, and initial/final descent speeds.

This research is based on a high fidelity simulation of a 737-700 aircraft. Conclusions and techniques based on this aircraft would have to be adjusted or re-tuned before they are applied to other aircraft types to correctly match thrust/drag characteristics.

Also, this advanced Continuous Descent Approach procedure may not be available in daily flight for many years, depending on advancements in displays and FMS capabilities. At present and in the near future there are Interim-Concept CDA procedures [1,2,3] such as those being flown at Schiphol and Heathrow in Europe which require only standard autopilot/autothrottle flight equipment.

Coordination and intermixing of CDA descents with conventional descent procedures and different aircraft types is a subject currently under consideration. Indeed, the planning and execution of the CDA descent requires not only the flight crew and aircraft FMS, but also communication and coordination with ATC controllers. Agreement must be reached on CDA characteristics before the CDA is initiated. As will be shown, advanced planning capability may include the effects of many descent parameters, including changing winds.

New displays may be needed to allow the pilot to safely monitor the mix of speed / altitude / energy variables that must stay within operational guidelines if the CDA aircraft is to arrive at the required endpoint at the right time with the right speed and altitude.

Introduction

Considerable research and development of low noise approaches has established the potential value of CDA procedures. Earlier simulation studies, such as [1], have shown that the potential noise reduction for a heavy turbojet following a continuous Idle descent from 7000 ft altitude to about 2000 ft is on the order of 6 DBA average noise reduction. This is in comparison to a conventional approach with 2000 ft intermediate altitude prior to glideslope capture and final descent. CDA procedures are now flown regularly at Heathrow [2] using conventional altitude and speed clearances and manual autopilot parameter selections. These manual procedures are workload-intensive and occasionally result in undesirable vertical profiles, e.g. a level off at intermediate altitude may be required to intercept the glideslope. In order to reduce pilot and controller workload, FMS-based CDA procedures have been established at Schiphol [3] and elsewhere to reduce noise during nighttime operations.

The current FMS procedures require substantially greater separations than for peak operations, however, due to uncertainty in the velocity profile and time of arrival at an appropriate Final Approach Fix (FAF). The FAF in our research studies is the glideslope intercept point, nominally 2000 ft altitude and 6.8 NM from the runway threshold. In addition to improvements in time of arrival at the FAF, the proposed advanced CDA procedure should offer the benefits:

- accurate computation of top-of-CDA-descent location
- correction for predicted winds
- reaction to unpredicted wind changes during descent
- reduced cockpit workload with FMS-guidance
- simple estimation of FAF time of arrival

Standard Approach Vs CDA Approach

The goal of CDA approach is to reduce community noise levels below aircraft approach paths significantly (approximate 6 DBA decrease) compared to conventional approach procedures. These noise reductions will occur in the region of 25 to 5 NM from the runway, and are due to two factors: The conventional aircraft will descend more rapidly to FAF altitude (typically 2000-3000 ft) at 15-20 miles from the runway, and increase engine thrust to maintain target speed.

In contrast, the CDA profile descends slowly at Idle throttle, yielding the advantage of higher approach altitudes and Idle thrust levels. Traditional approach / land procedures allow the aircraft to either descend or decelerate, but usually not both at the same time. The CDA approach specifically descends and decelerates simultaneously over an approach segment to gain the advantages of higher altitudes and lower thrust levels – yielding lower noise on the ground. Both the standard approach and the CDA approach should arrive at the FAF at the same altitude (2000-3000 ft) and the same speed (140 – 170 kts).

A typical conventional descent path is shown in Figure 1. The top plot shows calibrated airspeed or CAS as a function of distance in nautical miles, NM, with positive distance in the direction of motion. Flap engage points and landing gear deployment are indicated in the figure. The upper and lower dotted lines show flap placard speed [4] and flap maneuver speed [5], respectively. These profiles provide maximum and minimum speed limits for a given flap setting. The second plot of Figure 1 shows altitude as a function of threshold distance. These altitude plateaus at 8000 and 3000 feet are sample values representative of standard operational practice. Actual plateau levels could be higher or lower. The third plot in Figure 1 shows thrust level as a function of threshold distance.

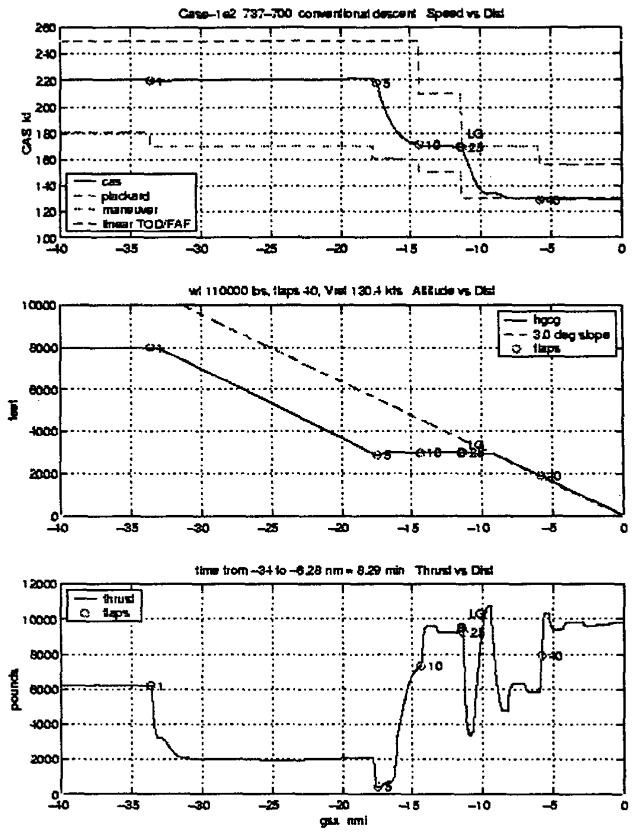

Figure 1. Typical Conventional Descent

Note that the speed/altitude clearance plateaus serve two purposes. First they allow for speed reduction. Also, by allowing some aircraft to reduce speed before others, the controller establishes adequate spacing between aircraft. Since the conventional descent and CDA will descend at different speeds, their nominal separation will change by approximately a nautical mile during descent. This change in spacing and FAF time of arrival will have to be included in ATC planning to insure that vehicle separation limits are maintained throughout airport approach and landing.

The CDA study presented here is based on the assumption of straight-in approach. Obviously most landing procedures require turns from downwind to crosswind to final approach. The top-of-descent (CDA) may occur 25-30 miles (approximately) from threshold and still be on the downwind leg. Once the CDA approach begins, it is important to avoid changes in the lateral path to achieve time and distance targets.

Since the CDA is designed to be an Idle thrust descent, the speed-altitude profile is determined by elevator (path-on-elevator) following a vertical guidance control law, flaps, wind (changes) and possibly speed brakes. If an under-speed condition is encountered during CDA descent, the autothrottle will increase thrust to maintain speed.

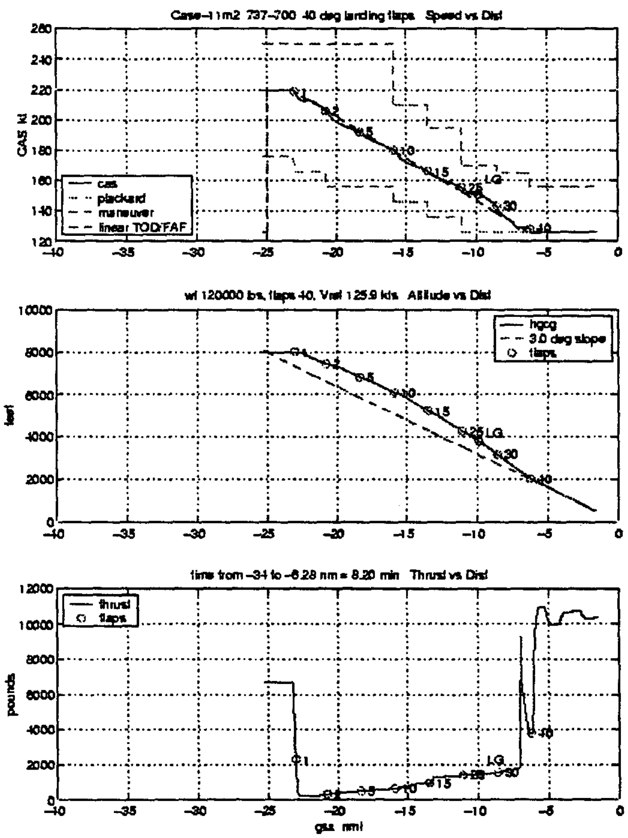

Figure 2. Typical CDA Approach

A typical CDA profile is shown in Figure 2. The full set of flap positions for the 737-700 is employed in the CDA case in order to achieve a uniform drag increase. The 2 degree landing flap setting [6] is included. The choice of CDA altitude and speed profile will be discussed later. The thrust level during descent corresponds to Idle throttle. In practice the use of Idle thrust may be affected by anti-ice or approach spool-up requirements.

Comparing the conventional and CDA descent profiles, the conventional has a thrust level around 10,000 lbs from between 10 and 15 nautical miles to the runway, whereas the CDA has a thrust level of 2000 lbs or less between 23 and 6 nautical miles. This is the operational advantage which is desired, i.e. to minimize noise.

Basic Descent Characteristics

As described above, the speed profile of the descending CDA aircraft is governed by drag, thrust (assumed Idle), approach flap, angle of descent, and in worst case, speed brakes. This is illustrated below in Figures 3, 4 and 5 which describe constant flight-path-angle descent at -2, -3 and -4 degree flight path angles. In all three cases the descent is from 8000 ft to 2000 ft, and the flight path angle changes to –3.0 degrees (glideslope angle) at the FAF. All the flap settings are used in the course of descent, and flap deployments are equally spaced in order to illustrate their effects on speed reduction. The altitude plot in each figure includes a -3.0 degree flight path for reference.

As shown in Figure 3, the -2.0 degree flight path angle is too shallow to maintain speed in the absence of thrust. The speed drops from 220 kt to 130 kt as the altitude drops from 8000 ft to 5800 ft, and the autothrottle engages to maintain 128 kt landing speed. The thrust increases from 1000 lb to 6000 lb, with a significant increase in noise levels. Flight from 24 nautical miles to the threshold at 128 knots would significantly increase flight time. Also, the aircraft speed decays to below the maneuver limit in this rapid deceleration, so flaps would have to be deployed earlier, increasing thrust requirements and thus noise. The rate of loss of speed at the shallow -2.0 degree flight path angle would be a little less if 1 degree flaps were not deployed until lower altitudes. However, with low level thrust, speed could easily be maintained on the –2.0 degree flight path.

Figure 4 describes a constant -3.0 degree flight path angle CDA. As shown, the speed drops more slowly from 220 knots to 195 knots, and drops more rapidly when 10 degree and additional flaps are deployed. Due to speed loss the autothrottle increases thrust level to maintain minimum speed at a distance of about 12 nautical miles from the threshold. This would limit the effectiveness of noise reduction. An Advanced CDA should avoid thrust increase from Idle until the FAF is reached.

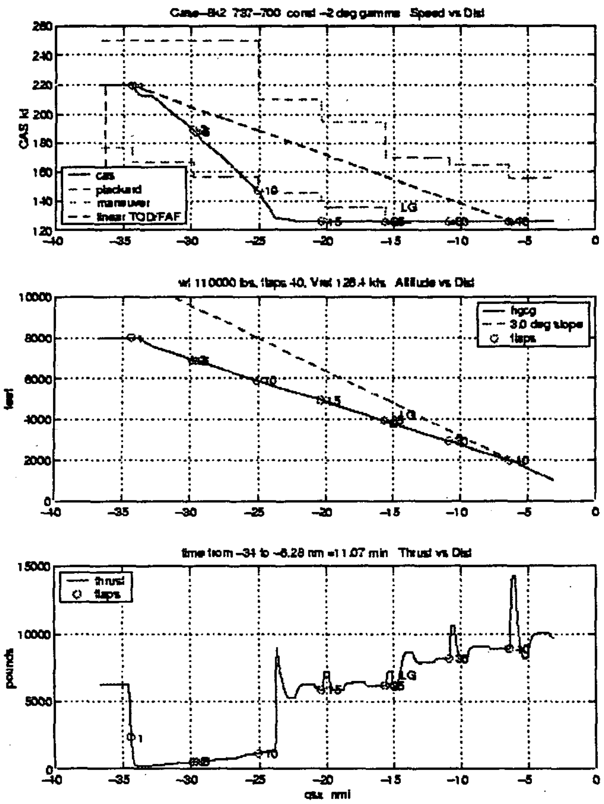

Figure 3. CDA With -2.0 Deg Flight Path Angle

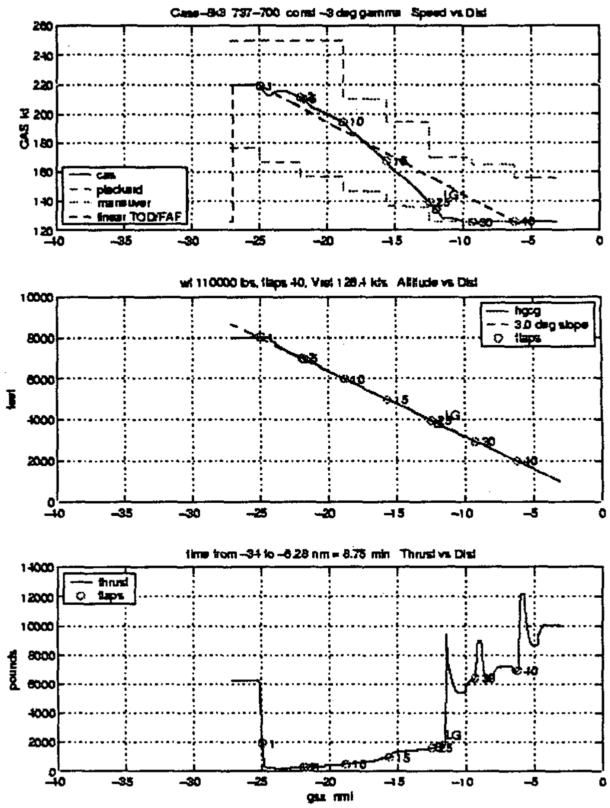

Figure 4. CDA With -3.0 Deg Flight Path Angle

To complete the description of basic Idle-thrust descent characteristics, a –4.0 degree flight path descent is illustrated in Figure 5. In this case the airspeed actually increases after thrust is set to Idle and 1.0 degree flap is deployed. Only after 5 degree flaps does the airspeed start to drop. By the time of landing gear and 40 degree flap deployment, the speed is reduced to landing speed at the FAF. Note that flap placard speeds are exceeded during the descent. Thrust increase for landing does occur just at the FAF. From a noise reduction point of view the Idle thrust is maintained as needed to avoid excess noise over airport communities, but the path is not flyable due to excessive stress on flap surfaces.

In all of these fixed FPA descent examples it is assumed that a vertical autopilot function or FMS VNAV function exists to accurately guide the aircraft. In examples to follow, it is assumed that the FMS VNAV can provide vertical guidance to follow a prescribed altitude versus distance profile. Also, it is assumed that the FMS can indicate to the pilot when flap deployment and landing gear deployment are needed, to achieve the needed drag profile.